
# Directional Force Exciter Gearbox

## As adapted from drawings provided by Hofmann Engineering Pty. Ltd.

The objective of this work was to apply design for 'X' methodologies to generate a concept design to replace an original equipment manufacturer product to maximise the needs of the three major stakeholders in the triple bottom line.

SCAN FOR ASSEMBLY VIDEO

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## MCEN4000 Design for Manufacturing: Group Project Report Cover

## Semester 2 Year 2022

**Date submitted: 14 OCTOBER 2022…………………………….**

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By signing the above table, we declare the following:

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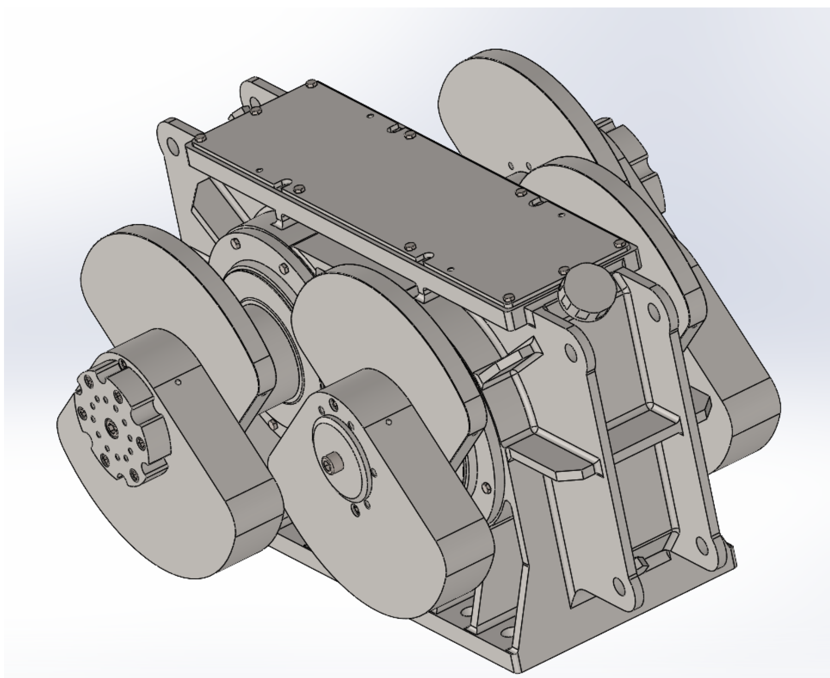
# DFMA of an Exciter Gearbox

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# Contents

# Abstract

The overall purpose of this report is to design a directional force exciter gearbox (DFEG) to replace the Schenck DF704S model for the application of powering linear vibrating screens. This is being done primarily to reduce the reliance of customers upon original equipment manufacturers (OEM) for replacement parts and units, particularly in high stress appliances such as DFEGs. A key focus for the design of the DFEG in this report is to ensure that it can be easily installed in place of the Schenck DF704S i.e., after removing a DF704S DFEG, a non-OEM DFEG can be directly swapped in without requiring any special procedure to ensure its alignment with the drive motor coupling, mounting holes or spatial limitations.

Principles of design for manufacture and assembly (DFMA) provide the framework for the entire design process. By making use of concurrent engineering and design for 'X' (DFX) methodologies, a product that satisfies three major stakeholders (people, planet, profit) is the result. The core steps taken in this report can be visualised in Figure 1 shown below.

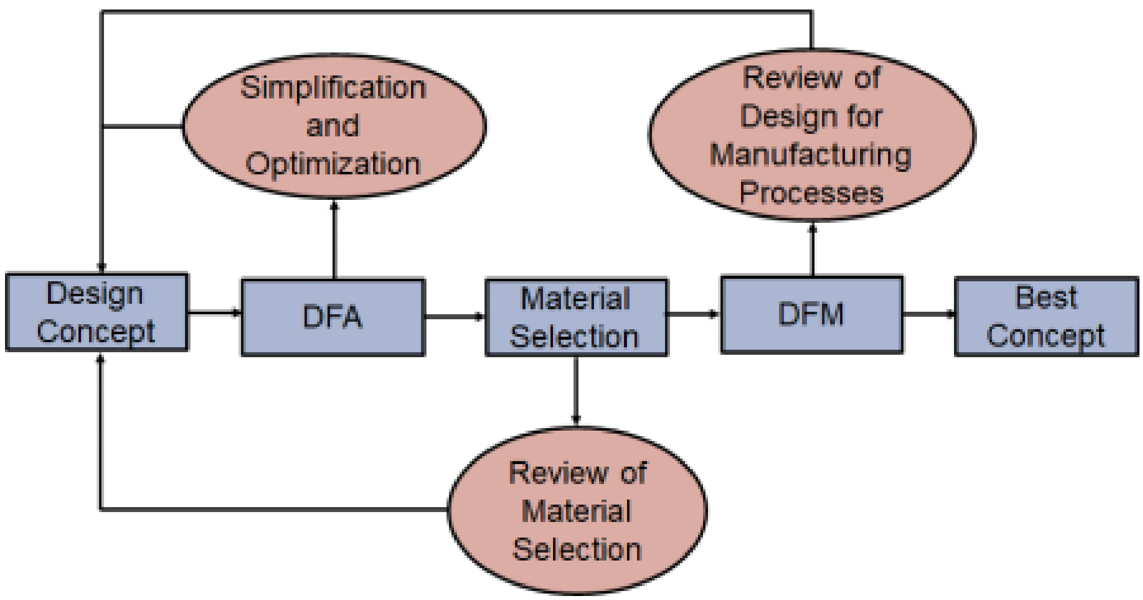


*Figure 1 DFMA Process Loop (Podsiadlo 2022)*

Drawings of a concept design for a DFEG provided by Hofmann Engineering Pty. Ltd. were used as a starting point. Design for assembly (DFA) methodology was employed to simplify the concept design as much as possible by removing parts or by combining parts into subassemblies. Material selection followed, guided by load calculations, lifecycle and dimensional requirements, and a myriad of other factors. Once we were satisfied with the assembly and material selection, the design for manufacture (DFM) analysis was carried out to determine the feasibility of the concept design to be produced to confirm that it was the best concept. The major results and findings were the estimated total concept design unit production manufacture cost of AUD $8,416.27, production time of just over 31 hours, and the total environmental impact of production of 752.6 kg $CO_2$ emissions. Overall, we conclude that by applying DFMA principles paired with concurrent engineering, an affordable, possible, and functional DFEG can be designed without compromising on a realistic cradle to cradle life cycle.

# Introduction

The topic of this report is to design a concept DFEG to directly replace the Schenck DF704S DFEG while employing DFMA principles throughout the entire product design process. In a broader context this report aims to contribute to the body of work highlighting the value of employing techniques such as concurrent engineering and DFX methodologies in product design to meet the needs of three major stakeholders in the triple bottom line: People, planet, and profit. In an industrial context, DFEGs are employed throughout mining industries to facilitate the sorting of varying sized and shaped input bulk materials. Transmission of vibrational energy at a required rotational speed and frequency powers a linear vibrating screen to separate feedstock. The vibration keeps material moving forward along a length; allowing smaller pieces to drop through a screening deck, whilst also maintaining production efficiency by feeding the material onto the next process (Applied Vibration 2022). This is a critical process, the downtime of which causes downstream processes such as conveyors to operate without any utility i.e., a failure at a linear vibrating screening station bottlenecks entire downstream production processes.

The problem being addressed in this work is that customers using the Schenck DF704S DFEG are disadvantaged by their reliance upon OEM parts and products for critical process applications such as in linear vibrating screen sorting stations. The reason this is a problem is because an inherent operational reliability risk arises when only one supplier can provide spare parts or products that are compatible with their products. A customer using these OEM products is forced to hold an expensive ‘just in case’ (JIC) inventory which burns up capital, land space and work hours in maintenance and storage. Alternatively, a customer could rely upon the OEM company to provide parts and replacement units as needed but with only one supplier available there always remains a reliability risk of supply chain or production issues. Further compounding the risk of relying upon OEM companies is that if such a company were to go out of business it becomes exceedingly difficult and, in some instances, impossible to procure replacement parts and products.

The current best way to mitigate this operational reliability risk for customers in situations such as these is to hold inventories of spare parts and products in a JIC inventory model. This results in opportunity costs associated with sunk costs in the inventory itself, the ongoing cost of proper storage and maintenance, and in extra land usage which can be expensive if a significantly large inventory is required, or short transport times are necessary. An additional cost that may arise comes from the risk that not all parts may be acceptably manufactured originally, or that by the time they are being used they may be discovered to be unsuitable. Customers often know that a ‘just in time’ (JIT) inventory model is superior to a JIC model for addressing all of these issues, however they are forced to employ a JIC model nonetheless because of the proprietary nature of OEM parts and products. Being hamstrung in this way is bad for business, procurement and inventory management, and most of all the environment, particularly because of the unnecessary land usage required to store JIC inventory. None of the three major stakeholders in the triple bottom line have their needs met in such a scenario.

The aim henceforth is to address this major issue and attempt to resolve it by providing a concept design for a DFEG that is suitable to replace the Schenck DF704S directly without the need for any special accommodations. The scope of this report is quite specifically defined by the specifications of the Schenck DF704S, namely the spatial envelope, mounting dimensions, force output and rotational speed, which will be discussed in further detail shortly. Additionally, the scope is set to focus primarily on the DFMA side of the product design process with the objective to meet a product volume of 1500 units per year. This limits the theoretical production to manual assembly as the use of automatic or robotic assembly cannot be justified in its cost at this production volume. With this in mind, individual components were not designed for high-speed feeding and orienting. Another limitation of this report is that the materials selected are for one example of a suitable material set given the mechanical requirements of components i.e., although ranges of materials are suitable, only one set has been used in the concept design to follow as a reference point. Additionally, the values for all aspects of the product and its production are theoretical and estimates only i.e., further consideration is required case wise by any prospective manufacturer to make use of this design given their access to suitable stock materials and manufacturing capabilities. This report is also limited to specifically replacing the Schenck DF704S DFEG meaning that it is not directly suitable to replace any other DFEGs. However, what this report does provide is an overview of the mechanical requirements, key components, ranges of materials and types of machines that can be suitable for producing a DFEG.

A table of critical mechanical specifications are shown below in Table 1, and dimensional specifications in Table 2 with an accompanying set of orthographic views with dimensions shown in Figure 2 for ease of visualisation and reading.

**Table 1.** Critical mechanical specifications of the Schenck DF704S DFEG.

| **Speed [min$^{-1}$]** | | **Working Moment [kg·cm]** | | **Static Moment [kg·cm]** | | **Max. Force Output [kN]** | **Motor Power [kW]** | **Mass with Plug Weights [kg]** | **Plug Weight Material** |
|---|---|---|---|---|---|---|---|---|---|
| **Min.** | **Max.** | **Min.** | **Max.** | **Min.** | **Max.** | | | | |
| 650 | 1000 | 14528 | 27302 | 7264 | 13651 | 1000 | 45 | 2650 | Steel |

(Schenck Process n.d.)

**Table 2.** Envelope, mounting and bolt dimensions (all dimensions are in millimeters) and specifications of the Schenck DF704S DFEG.

| A | A1 | B | C | E | F | G | H | J | K | M | N | O | P | R | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 x 130 | - | 940 | 1390 | 763 | n37 | 40 | 432 | 1450 | 460 | 500 | 400 | 1214 | 1064 | 860 | 30 |
| Bolt Size = M36. Metric coarse thread bolt, AS1110 PC 8.8, 830 MPa ultimate tensile strength, minimum; length depends on specific use | | | | | | | | | | | | | | | |

(Schenck Process n.d.)

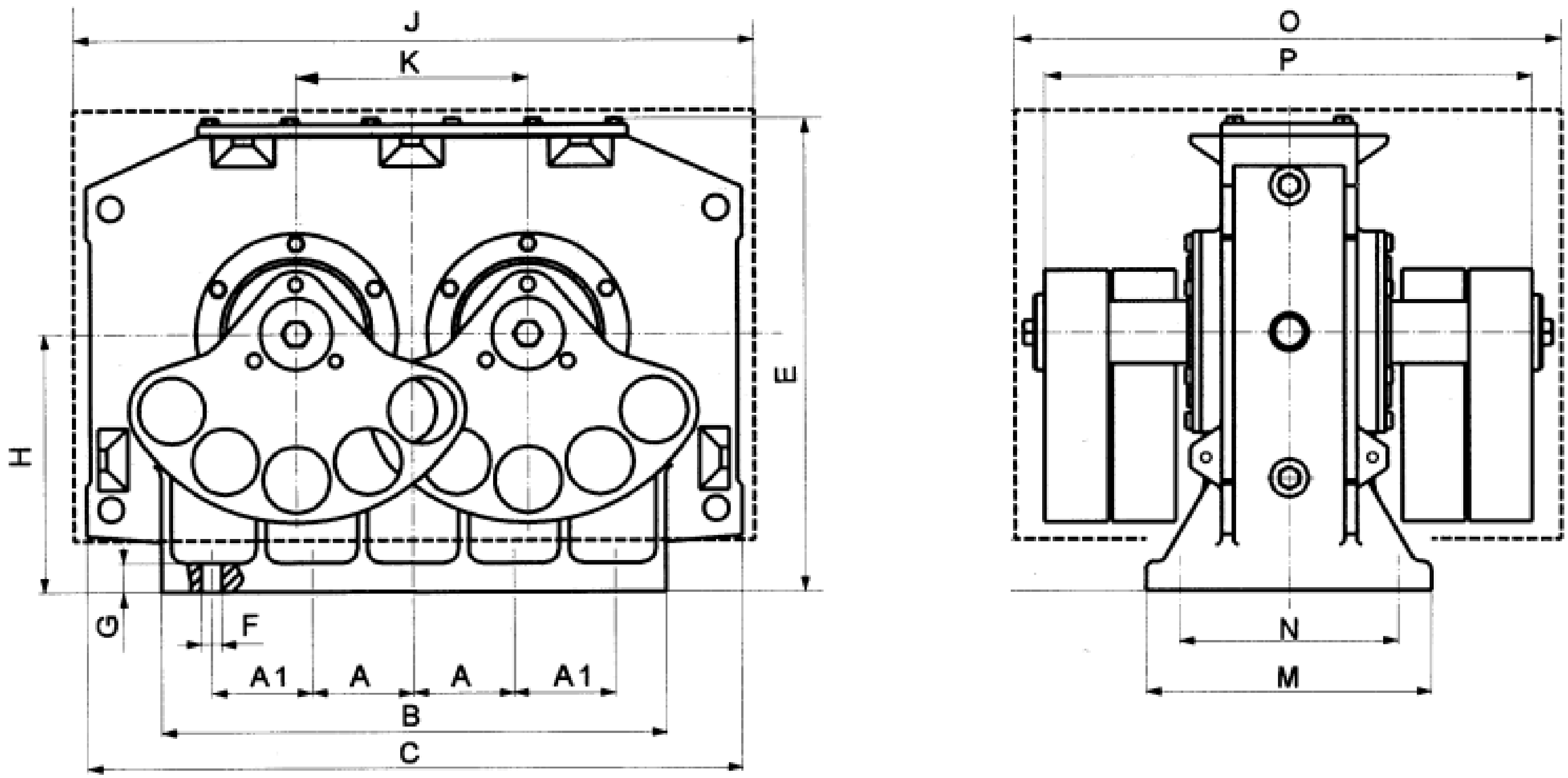


*Figure 2 Schenck DF704S Dimensional Specifications (Schenck Process n.d.)*

Further specific requirements of the Schenck DF704S DFEG and hence the concept design DFEG in this report include a need for both unbalanced masses to be synchronized by a built-in gear drive. This is required to achieve a resultant force acting only in the vertical direction perpendicular to the vibrating screen with non-vertical components of force being cancelled out by being equal and opposite. Additional requirements include minimum maintenance requirements and the ability to be used continuously.

To meet these requirements and the aim of the report, there were a number of steps taken following the structure of the DFMA process shown in Figure 1. Following Boothroyd and Dewhurst DFMA methodology, the first key step was to understand and identify the parts in the original concept design of a DFEG provided in drawings by Hofmann Engineering Pty. Ltd. Once a solid understanding of the key components that comprise a DFEG was reached, the next key step was to determine a feasible assembly sequence to better understand how to improve the assembly. Next, we attempted to optimise the design further by removing or combining parts into sub-assemblies, through additional concept design iterations. Following this, the concept design had to be conformed to the specifications of the Schenck DF704S DFEG. With the specifications of the Schenck DF704S DFEG in mind, calculations were carried out to determine minimum requirements of mechanical components such as the drive and idler shafts. From these calculations, suitable ranges of materials with suitable mechanical properties were determined. These materials were reviewed against their availability, cost, and environmental impact before settling on a baseline set of materials to serve as a reference point in the best concept design. With these materials in mind, a DFM analysis was carried out and approximate manufacture costs were estimated. The result of all of these key steps is a final best concept design that maximises the interests and needs of the three major stakeholders in the triple bottom line.

# Creation of the Design Concept

The best concept design was created by iterating through the DFMA product design process in Figure 1 with major iterations occurring predominantly in the DFA portion of the process. As per the overview in the introduction, the first key step was to gain a foundational understanding of what components go into a DFEG, i.e. identifying the parts of the assembly (Boothroyd, Dewhurst and Knight n.d.). The assembly drawings provided by Hofmann Engineering Pty. Ltd. in Appendix A included a bill of materials (BOM) which provided an insight into what key components are required in a DFEG and also what components would be good targets to try to eliminate from the assembly either by removing them or combining them into subassemblies. After identifying the parts of the assembly, we were able to move forward with the Boothroyd and Dewhurst DFA process and determine a feasible assembly sequence outlined below.

## Feasible Sequence for Assembly of the Hofmann DFEG

1. Start with casing sitting on its base.
2. Rotate the casing 90 degrees and put it up on a hydraulic press.
3. Crane bearings in and press fit them to depth on the upward facing side of the casing.
4. Rotate the casing back 90 degrees and put it back on its base ready to drop the gears in.
5. Drop the gears in one at a time from above and position them and mesh them.
6. Make sure the gears keyways are symmetrically angled with the teeth marked to get the keyways facing straight down towards the base of the casing.
7. Clamp the gears to fix their orientation with either a G or F clamp.
8. Install gear keys into shafts.
9. Position press shims such that they line up with the bearing races.
10. Rotate the casing 90 degrees and put it on the hydraulic press such that the bearings are closest to the table, with the bearings resting on the shims.
11. Remove clamps from step 7.
12. Line up the bearing bores to the gear bores, without disengaging the tooth mesh of the gears.
13. Pick up the shafts and orient them vertically with the gear shoulder closest to the crane (to the top) and align gear/shaft keys with gear keyways.
14. Drop shafts into casing bores and press fit shafts to depth.
15. Crane bearings in and press fit them onto shafts to depth.
16. Pick up the casing, rotate it back 90 degrees onto its base.
17. Operators carry flingers down the lengths of both shafts from both sides and position them to depth in the casing.
18. Put lip seals on each retainer to form a subassembly.
19. Add liquid gasket to the bearing retainer flange face.
20. Crane one bearing retainer in and walk it down the length of the shaft.
21. Put in eight M12 bolts to lock the bearing retainer to the casing
22. Torque the eight M12 bolts to spec.
23. Repeat steps 20 to 22 for the three remaining bearing retainers.

24. Put O-rings into the labyrinth seals.
25. Human operators carry labyrinth subassembly down shaft such that the male side is pointing towards the casing, then press labyrinth seal into retainer via tap fit.
26. Human operators walk spacers onto the drive shaft from both sides.
27. Human operators walk location bushes onto the drive and idle shaft from both ends.
28. Put all four eccentric mass keys into shafts such that the flat side points towards the ends of the shafts.
29. Crane picks up adjustable mass and walks it onto a location bush of the idle shaft.
30. Crane picks up one fixed mass and walks it onto the idle shaft.
31. Thread in hydraulic porta pack to shaft end then press the fixed eccentric mass.
32. Thread in two M16 bolts to lock the adjustable eccentric mass to the fixed eccentric mass.
33. Torque the M16 bolts to spec.
34. Crane picks up adjustable mass and walks it onto drive shaft.
35. While adjustable mass is still on the crane put the locating ring in such that the lip/male side is pointing towards the casing.
36. Put in two M16 bolts to lock the adjustable mass to the fixed mass.
37. Human operator walks tab washer down shaft and aligns locating tab with the slot on the thread of the shaft.
38. A human operator walks lock nut down shaft with tapered side facing towards the gearbox.
39. Fully tighten lock nut onto thread.
40. Bend one tab of the tab washer over the lock nut such that it is fully seated in the slot of the lock nut.
41. Repeat steps 29 to 33 for the remaining eccentric masses with the order being that the other side of the idle shaft is done first followed then by the two sides of the drive shaft.
42. Put magnetic hex plugs in to depth by threading them in.
43. Thread in breather adapter and thread breather into breather adapter.
44. Oil internals.
45. Crane inspection cover over such that all of the bolt holes are aligned i.e., 360-degree angle.
46. Drop all washers and bolts in and tighten them to secure inspection cover.

With an idea of a feasible assembly sequence for the Hofmann DFEG completed, it quickly became apparent that there were some components that could potentially be able to be combined into sub-assemblies and opportunities to improve assembly by modifying parts. The first major iteration attempted to implement both of these improvements.

## First Major Concept Design Iteration

The first major concept design iteration was focused on improving ease of assembly and disassembly by providing better access to the internals of the gearbox and by combining shafts and gears into one component. It also aimed to improve ease of assembly by eliminating components such as vibration and thermal sensors from the assembly. Not many more components could be feasibly removed from the assembly such as fasteners as any substitute such as snap fits, rivets or welds proved to be either not capable of withstanding the mechanical load or greatly reduced the ease of disassembly for inspection or remanufacture.

The thinking was that by having a split casing it would be far easier to drop heavy components in from above i.e., making use of gravity to aid assembly instead of fighting against it. The idea behind combining the gears and shafts into one component was also to aid assembly by having one solid component that could be craned in, instead of multiple components that had to be hydraulically press fit into one another in the casing. Illustration of these two major concept design changes can be seen in Appendix B.1. The key advantages of this first iteration were that heavy components such as the bearings, shafts, and gears, could all be positioned and dropped in from above, with the upper half of the casing to follow.

Upon further consideration however, it became clear that being subject to such intense mechanical loads and vibration, this design change added far more complexity than it resolved. This iteration of the concept design would require so many more fasteners and require very high tolerances of machined surfaces particularly at the interface between the casing halves, that the improvement of ease of assembly could not be justified. Additionally, the idea of combining the shafts with their gears posed major complications for the manufacturing processes required to produce such a part. This initial iteration, although ultimately fruitless, provided an excellent example of the benefits of concurrent engineering that the DFMA process allows. By not following this concept design any further at the advice of experts with manufacturing experience, time was not wasted on a doomed design. Further to this, it forced the ideation of a better solution to improve ease of assembly without compromising on the ease of manufacturability in the final concept design.

## Drive Shaft Calculations

To gain a better understanding of what material properties and dimensions would be required for the entire gearbox we worked out the minimum requirements of the drive shaft as a starting point. The calculations for the loads the shafts would be subject to were carried out for fully reverse cycled bending loading as per Norton and Shigley guidelines (Norton 2011), (Budynas and Nisbett 2011). Through multiple iterations, a minimum diameter of the drive shaft was calculated; please refer to Appendix C.1 through Appendix C.6 for all drive shaft calculations. From these equations we began identifying families of materials that would provide suitable mechanical properties such as yield strength. With the help of Ansys Granta EduPack, we were able to narrow down the Ashby Charts generated to find the most mechanically suitable material for the shafts while keeping in mind the environmental impact and cost per kg of materials as constraints; please see Appendix D for material selection for the drive shaft. Because of the marginal increase in environmental cost but proportionally higher increase in yield strength we selected low alloy steel as a good compromise for the drive shaft material.

## Helical Gear Calculations

Further realisations from calculating the drive shaft minimum requirements and resultant forces were that the axial forces induced by the use of helical gears was sufficiently small so that there was no special requirement for bearings that could specifically handle higher axial loads; please refer to Appendix E for helical gear force calculations.

## Second Major Concept Design Iteration

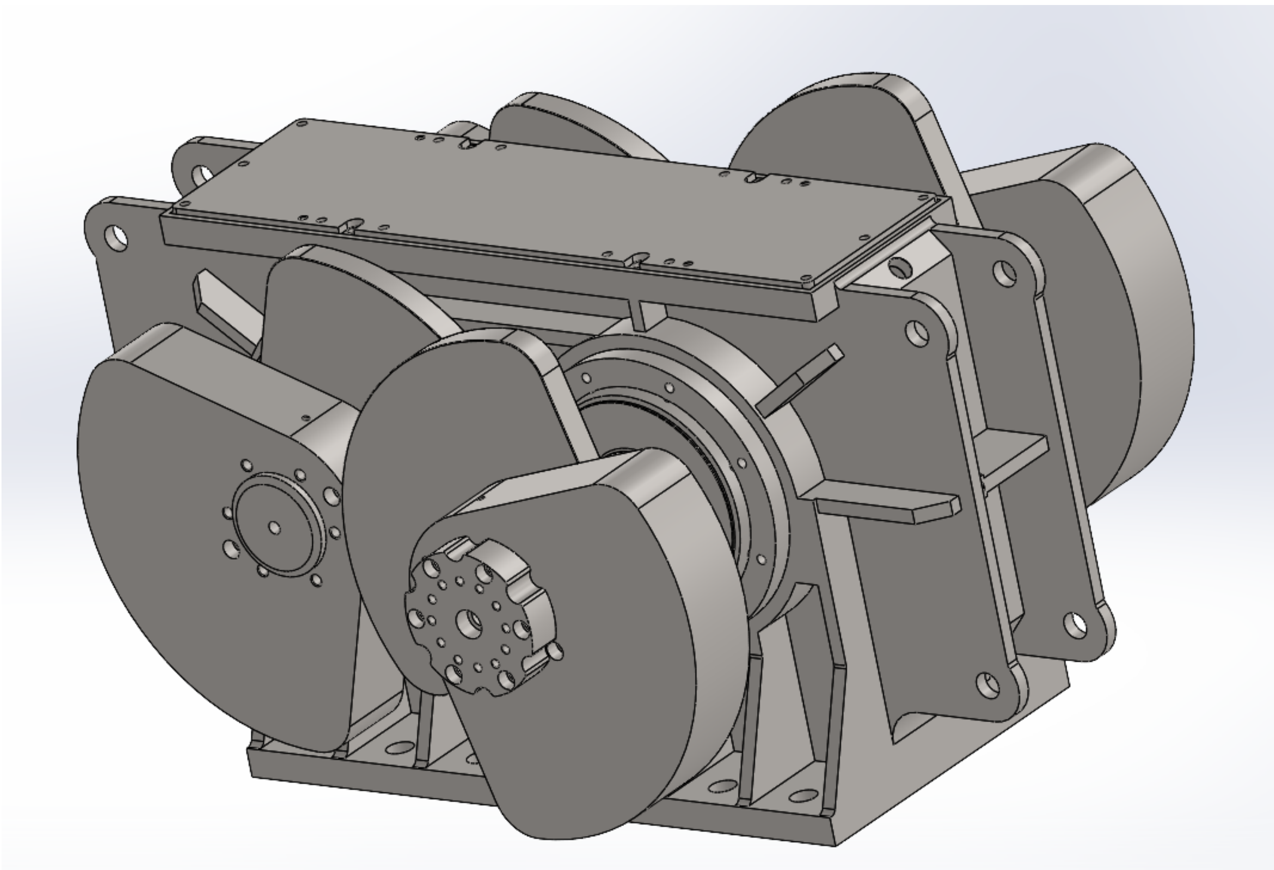

*Figure 3 Second Major Concept Design Iteration*

In the figure shown above, in the second major concept design iteration we decided to keep the shafts and gears as separate components and instead improve ease of assembly by expanding the size of the inspection cover to facilitate putting both gears in simultaneously. The aim was to provide easier access to the gears to minimise the time spent orienting the gears. Broadly speaking this second iteration was very similar to the Hofmann DFEG, however by widening the area for the gears to be positioned and inserted, the ability to fix the rotation of the gears prior to assembly was now possible. From this we were able to make the two gears a sub-assembly by clamping them together. The effect of this design change on the manufacture process was anticipated to be minimal compared to what was already required to manufacture a Hofmann concept DFEG so this second major concept design iteration appeared to be a very strong candidate for a best concept design.

## Third Major Concept Design Iteration

This third major concept design iteration was brought about by a need to address the fact that the bearings that were suitable to fit shafts of minimum diameter were nowhere near mechanically capable of supporting the loads required. From this we found we had to increase the diameters of the shafts and modify the bores of the gears as a result of accommodating a much larger bearing. Two further additional changes were the introduction of a recess into the top of the casing, and to make the inspection cover fully symmetrical to aid in locating and securing it during assembly as shown in the figure below.

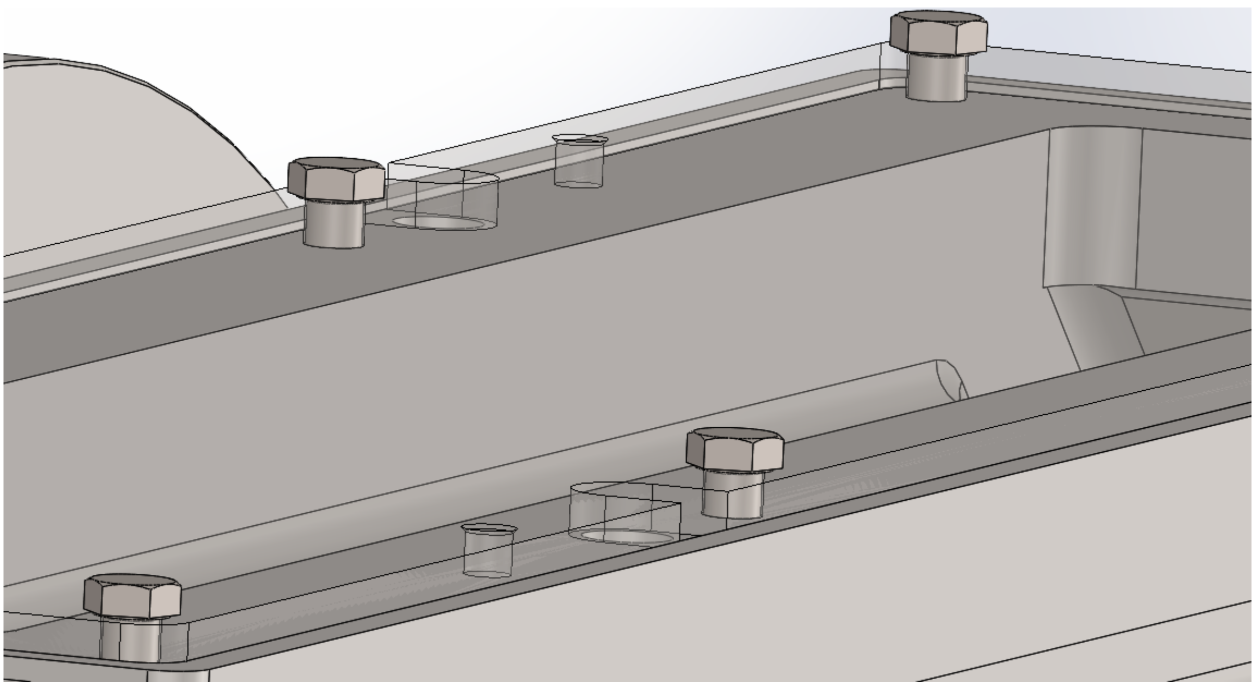

*Figure 4 Third Major Concept Design Iteration*

## Bearing Calculations

The following considerations were made when deciding on how to select bearings, as well as to determine what calculations were relevant to ensure the most suitable bearings were selected:

1. Force output of exciter box must not exceed that of the rolling elements
2. Highest point of wear may be on bearing race when eccentric masses apply max. force
3. Therefore, highest stress will be applied constantly at the same point of the bearing throughout rotation, and this will be most likely point of potential failure

4. Consider instantaneous potential failure from initial start up on inner race of bearings
5. Inadequate lubricant on start up may need to be considered for avoidance of premature failure due to excessive stresses from overload on start-up
6. Could we recommend a soft start motor to improve bearing fatigue life?
7. Condition monitoring sensors for bearing fatigue analysis – heat tracing for indication of excessive loads points
8. Potentially suggest a superior additive-based lubricant – maybe a type of synthetic oil – for bearing "sticking" properties for static coating of bearing. May help to reduce excessively induced bearing stresses on machine start up

From these considerations a criteria for bearing selection was established as follows:

1. Spherical roller bearings
2. Good axial/thrust load capabilities, good radial load
3. Self-aligning - excellent for deflections and misalignment issues

4. Readily Available – SKF

5. Where vibration is not objectionable, static load carrying capacity may be exceeded by up to a factor of 3

Please refer to Appendix F for bearing calculations.

## Final Conceptual Design Considerations

To confirm the suitability of the concept design DFEG, we had to ensure that appropriate fits were employed for parts that were to be in contact such as the bearings to the shafts, shafts to the gear etc. The fits and subsequent tolerances and their calculations for all relevant components are shown in Appendix G following Shigley's guidelines (Budynas and Nisbett 2011).

Additionally, we wanted to confirm that the bolt selection for the drive adapter was suitable to withstand the load it would be under at startup and during operation which we found it was. The calculations for the drive adapter bolt torques are shown in Appendix H.

With these design changes made we now had a slightly modified feasible assembly sequence for this concept design DFEG.

## Feasible Sequence for Assembly of the Concept Design DFEG

1. Get casing sitting on its base.
2. Rotate the casing 90 degrees and put it up on a hydraulic press.
3. Crane bearings in and press fit them to depth on the upward facing side of the casing.
4. Rotate the casing back 90 degrees and put it back on the ground ready to drop the gears in.
5. Drop the gears in one at a time from above and position them and mesh them.
6. Make sure the gears keyways are symmetrically angled with the teeth marked to get the keyways facing straight down towards the base of the casing.

7. Clamp the gears to fix their orientation with either a G or F clamp.
8. Install gear keys into shafts.
9. Position press shims such that they line up with the bearing races.
10. Rotate the casing 90 degrees and put it on the hydraulic table such that the bearings are closest to the table, with the bearings resting on the shims.
11. Remove clamps from step 7.
12. Line up the bearing bores to the gear bores, without disengaging the tooth mesh of the gears.
13. Pick up the shafts and orient them vertically with the gear shoulder closest to the crane (to the top) and align gear/shaft keys with gear keyways.
14. Drop shafts into casing bores and press fit shafts to depth.
15. Crane bearings in and press fit them onto shafts to depth.
16. Pick up the casing, rotate it back 90 degrees such that it sits normally on the ground i.e., the bottom of the casing is on the ground.
17. Operators carry flingers down the lengths of both shafts from both sides and position them to depth in the casing.
18. Put lip seals on each retainer to form a subassembly.
19. Add liquid gasket to the bearing retainer flange face.
20. Crane one bearing retainer in and walk it down the length of the shaft.
21. Put in eight M12 bolts to lock the bearing retainer to the casing.
22. Torque the eight M12 bolts to spec.
23. Repeat steps 20 to 22 for the three remaining bearing retainers.
24. Put O-rings into the labyrinth seals.
25. Human operators carry labyrinth subassembly down shaft such that the male side is pointing towards the casing, then press labyrinth seal into retainer via tap fit.
26. Human operators walk spacers onto the drive shaft from both sides.
27. Human operators walk location bush's onto the drive and idle shaft from both ends
28. Put all four eccentric mass keys into shafts such that the flat side points towards the ends of the shafts.
29. Crane picks up adjustable mass and walks it onto a location bush of the idle shaft.
30. Crane picks up one fixed eccentric mass and walks it onto the shaft that the adjustable mass was just installed on to.
31. Thread in hydraulic porta pack to shaft end then press fit the fixed eccentric mass.
32. Put in two M16 bolts to lock the adjustable eccentric mass to the fixed eccentric mass.
33. Torque the M16 bolts to spec
34. Repeat steps 29 to 33 for the remaining eccentric masses with the order being that the other side of the idle shaft is done first followed then by the two sides of the drive shaft.
35. Place the locking cap on one end of the idle shaft.
36. While holding the locking cap, put the M24 bolt in and hand tighten.
37. Torque the M24 bolt to spec.
38. Repeat stepe 35 to 37 for the other side of the idle shaft.
39. Place the drive adapter on one end of the drive shaft.
40. While holding the drive adapter, put the M24 bolt in and hand tighten.
41. Line up the M16 bolt holes with the holes on the fixed eccentric mass.
42. Put in six  M16 bolts to lock the drive adapter to the fixed eccentric mass.
43. Torque the M16 bolts to spec.

44. Torque the M24 bolt to spec.
45. Repeat steps 39 to 44 for the other side of the drive shaft.
46. Thread in the 1” NPT  magnetic hex plugs.
47. Thread in breather.
48. Thread in the ⅜” NPT plug.
49. Thread in the 1” NPT plug.
50. Oil internals.
51. Add liquid gasket to the inspection cover recess on the top of the casing.
52. Crane the inspection cover onto the top of the casing such that it sits into the recess.
53. Drop all ten M12 and bolts in and tighten them to secure inspection cover.

## Detailed Design and Engineering Drawings of the Best Concept

Please refer to the appendices as directed for engineering drawings as per the following:

- Assembly Drawing: Appendix X.1
- Exploded View of Main Components: Appendix X.2
- Appendix location of relevant drawings in column 6 of Table 3.
- Appendix location of relevant DFM Concurrent Costing reports in column 7 of Table 3.

### Bill of Materials of Best Concept Design

**Table 3.** Bill of materials of best concept design.

| Part No. | Part Name | Qty | Material | Manufacturing Process | Appendix Location of Relevant Drawing | Appendix Location of DFM Costing Report |
|---|---|---|---|---|---|---|
| 1 | GEARBOX CASING | 1 | GENERIC LOW CARBON STEEL | SAND CASTING, AUTOMATIC | Appendix X.3.1 | Appendix Y.1 |
| 2 | INSPECTION COVER | 1 | GENERIC LOW CARBON STEEL | SHEET METAL LASER CUTTING | Appendix X.3.2 | Appendix Y.2 |
| 3 | DRIVE SHAFT | 1 | LOW-ALLOY STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.3 | Appendix Y.3 |
| 4 | IDLER SHAFT | 1 | LOW-ALLOY STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.4 | Appendix Y.4 |
| 5 | DRIVE GEAR – 115 TOOTH, 4 MOD, 20° PA, 20° HELIX | 1 | LOW-ALLOY STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.5 | Appendix Y.5 |
| 6 | IDLER GEAR – 115 TOOTH, 4 MOD, 20° PA, 20° HELIX | 1 | LOW-ALLOY STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.6 | Appendix Y.5 |
| 7 | BEARING-SKF 22334 CC/W33 | 4 | - | PURCHASED | - | - |
| 8 | FLINGER | 4 | GENERIC LOW CARBON STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.7 | Appendix Y.6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 9 | BEARING RETAINER | 4 | GENERIC LOW CARBON STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.8 | Appendix Y.7 |
| 10 | DOUBLE LIP SEAL – SKF CR SEAL – 200 X 230 X 15 VITON | 4 | - | PURCHASED | - | - |
| 11 | SEAL, O-RING, 160 X 174 X 7, ISO 3601, N70 | 4 | - | PURCHASED | - | - |
| 12 | LABYRINTH SEAL | 4 | GENERIC LOW CARBON STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.9 | Appendix Y.8 |
| 13 | SPACER | 2 | GENERIC LOW CARBON STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.10 | Appendix Y.9 |
| 14 | LOCATION BUSH | 4 | GENERIC LOW CARBON STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.11 | Appendix Y.10 |
| 15 | ADJUSTABLE ECCENTRIC MASS | 4 | GENERIC LOW CARBON STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.12 | Appendix Y.11 |
| 16 | FIXED ECCENTRIC MASS | 4 | GENERIC LOW CARBON STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.13 | Appendix Y.12 |
| 17 | LOCKING CAP | 2 | GENERIC LOW CARBON STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.14 | Appendix Y.13 |
| 18 | DRIVE ADAPTER | 2 | GENERIC LOW CARBON STEEL | MACHINED/CUT FROM STOCK | Appendix X.3.15 | Appendix Y.14 |
| 19 | 1” NPT MAGNETIC HEX PLUG | 2 | - | PURCHASED | - | |
| 20 | PLUG, HEX, STEEL, 1” NPT | 1 | - | PURCHASED | - | |
| 21 | PLUG, HEX, STEEL, 3/8” NPT | 1 | - | PURCHASED | - | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 22 | BOLT, HEX HEAD, M12 X 1.75 X 35 LG, AS 1110, PC8.8, STEEL | 10 | - | PURCHASED | - | |
| 23 | BOLT, HEX HEAD, M12 X 1.75 X 50 LG, AS 1110, PC8.8, STEEL | 32 | - | PURCHASED | - | |
| 24 | BOLT, SHCS, M16 X 2.0 X 70 LG, DIN 912, PC12.9, STEEL | 12 | - | PURCHASED | - | |
| 25 | BOLT, SHCS, M16 X 2.0 X 120 LG, DIN 912, PC12.9, STEEL | 8 | - | PURCHASED | - | |
| 26 | BOLT, SHCS, M24 X 3.0 X 70 LG, DIN 912, PC12.9, STEEL | 4 | - | PURCHASED | - | |
| 27 | BREATHER - STAUFF - SES5-10-B16-0-0 | 1 | - | PURCHASED | - | |
| 28 | KEY, 40X22 FORMC X 106 LG | 4 | KEY STEEL | PURCHASED | - | |
| 29 | KEY, 45X25 FORMA X 84 LG | 2 | KEY STEEL | PURCHASED | - | |

Note that the reason for choosing mostly low carbon and low alloy steels was to ensure that the availability of stock for any prospective manufacturers and to help keep the cost of stock material per kg low without causing disproportionately high environmental impact, while stick achieving the mechanical properties necessitated.

# Product Evaluation

## Manufacturing Cost

From the DFM Concurrent Costing reports for each manufactured part, an estimated total cost to manufacture the required number of each component per DFEG at 1500 units per year is shown below.

**Table 4.** Summary of DFM Concurrent Costing Reports for one DFEG unit.

| Product/ Component | Cost |
|---|---|
| **Adjustable Eccentric Mass** | $ 1,101.95 |
| **Bearing Retainer** | $ 264.31 |
| **Drive Shaft** | $ 507.70 |
| **Fixed Eccentric Mass** | $ 2,983.99 |
| **Gearbox Casing** | $ 1,405.22 |
| **Idler and Drive Gear** | $ 748.93 |
| **Idler Shaft** | $ 419.94 |
| **Inspection Cover** | $ 36.16 |
| **Labyrinth Seal** | $ 707.13 |
| **Location Bush** | $ 39.92 |
| **Locking Cap** | - |
| **Spacer** | $ 246.01 |
| | $ 8,461.27 |

## Environmentally Conscious Design

Throughout the concept design process, the methodology of DFX was observed to enable concurrent engineering to be implemented particularly through the combination of DFA and DFM between designers and manufacturers in the team. Alongside this ideation process however we have maintained and observed a design for environment/sustainability methodology in a myriad of aspects. This was done by use of Ansys Granta EduPack to compare suitable materials' mechanical properties against their environmental impact in the form of embodied energy and $CO_2$ production in primary processing. Additionally, the ability to be recycled was also used as a metric to help with materials selection for the purpose of reducing the amount of material ending up in land fill at the end of the concept design DFEG's lifecycle. To better understand the impact of the traditional lifecycle of a product such as the concept design DFEG presented in this work, a life cycle analysis was carried out.

### Goal and Scope

The purpose of this life cycle analysis is to determine the environmental impacts of the designed exciter gearbox and develop strategies to mitigate these impacts. With sustainable manufacturing being a major component of most industrial processes, developing sustainable products will allow the gearbox to comply with environmental regulations more easily as well as potentially cutting costs in areas that would traditionally be neglected.

The analysis on the gearbox will cover all aspects of its life cycle from material extraction through to disposal and recycling with the goal of achieving a circular life cycle with minimal material being disposed of at the end of each cycle. Emissions during each step of the process will also be analysed to determine the overall impact of each cycle on the environment such that processes can be changed and adjusted to reduce the total emissions of the product.

Once weaknesses in the production cycle of the gearbox have been identified, an analysis will be carried out to identify strategies to improve the design or process.

### Inventory

The exciter gearbox will require several inputs in order to be manufactured and these inputs will heavily depend on how the life of the gearbox is planned to be carried out. A more traditional approach to manufacturing the gearboxes involves acquiring the raw material for the product, manufacturing the components, assembling the final product, utilising the product, and finally disposing of the product once it has reached the end of its life. The material flow for the traditional process applied to the exciter gearbox can be seen below.

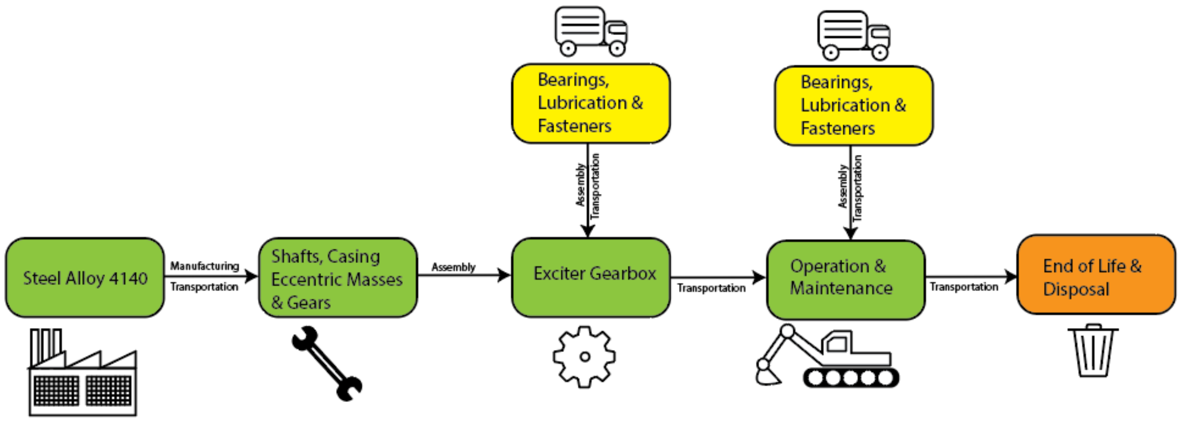


*Figure 5 Traditional Life Cycle*

Using this approach to manufacture the gearbox steel alloy would be purchased from a supplier in the form of stocks of various shapes and sizes. These stocks will need to be refined into individual components that the gearbox will be assembled from. The stocks will have their own associated environmental impact in manufacturing and as such an estimate will be taken based on the total amount of material required for all components of the gearbox. The stocks will also need to be transported to the factory and depending on the mode of transportation this will impact the environmental impact of the product. The most logical mode of transportation will be trucking as the Hofmann Engineering factory is located in an urban environment that is close to major road connections. A study has found that around 57gCO2 per tonne of material per kilometre of travel is emitted when utilising trucks in an urban setting (ICCT, 2022) which will be the estimate used to determine CO2 emissions for truck transportation.

To manufacture the shafts the primary processes that are traditionally used are milling and turning processes to remove material from the cylindrical bar stock eventually shaping it into the desired shaft. Secondary processes can involve heat treatments and stress relaxation if required. Machining can require a large amount of power especially when using high speed tool heads as the cooling and lubrication system can require up to 31% of the total energy used (Zhao, Liu, He, Cao, & Guo, 2017). With an average CO2 emission rate of 0.335kg CO2 per kWh (United States Government, 2022) higher energy consumption will drastically increase the total carbon footprint of the shafts.

Similar processes are used to manufacture eccentric masses with a heavier focus on milling rather than turning due to the non-circular shape of the desired component. However, a similar situation exists with higher machine speeds drastically increasing energy consumption leading to a large CO2 footprint for the component. As the masses are quite thick, they will require extra time to be safely machined without damaging the cutting tools working away on the material. Due to the relatively simple shape of the eccentric masses the time taken to cut the workpiece will be slightly reduced compared to more complicated components. As four eccentric masses are required to assemble one exciter gearbox the amount of time spent machining the masses could be significant if not controlled.

Gears require specialised gear cutting tools in order to be accurately manufactured resulting in specialised machines being used to cut the teeth of the gear. Traditional milling and turning processes are used to shape the stock into the blank gear shape before the teeth are added. Due to the complexity of the process, computer-controlled machines are preferred to carry out the process as these machines are more accurate, faster, and often require less energy than traditional hand machining. For the exciter gearbox two helical gears will be required and due to the high loads present in the machine, hardening and heat treating will be desirable.

Due to the complex but sturdy shape of the casing, casting is the most economical choice however, it is also an extremely energy intensive process requiring upwards of 2.2GJ of energy to melt 1 tonne of steel (Salonitis, Zeng, Mehrabi, & Jolly, 2016). This process is also prone to releasing large quantities of emission with potentially toxic emissions such as sulphides escaping into the atmosphere. The overall completed unit is expected to weigh around 2.4 tonnes with most of the mass coming from the casing. As such the efficiency of the casing process will play a major role in the environmental impact of the gearbox.

Some components for the gearbox will need to be outsourced as the bearings are too complex to design and make in-house and producing fasteners is unnecessary due to standard parts being widely available at competitive prices. As such, the environmental impact of these components will depend mainly on the source of the parts and the transportation method to receive the parts. Lubrication will be essential for the operation of the gearbox and will need to be an outsourced material added to the gearbox due to the complex chemical nature of the material. The choice of lubrication will be essential in determining the environmental impact of the gearbox as the production process of the lubrication will have environmental impacts associated with its production chain and leaks and spills are to be expected requiring the impact on the environment of the lubrication to be analysed.

The assembly processes will require significantly less energy than the manufacturing stage, however a longer assembly time will lead to an increase in energy consumption due to the energy overheads associated with running a factory such as lighting and air conditioning. Due to the large number of heavy components, manual assembly will require machinery to move and transport parts around such as cranes and forklifts. The energy required to lift an object can be determined from the following equation and can give a rough idea of the energy required to hoist components such as the shafts and casing into position.

$$Ep = mgh \qquad \text{Equation 1}$$

As the efficiency of most electric motors varies between 75% to 96% a 0.8 modifier will be added to the equation to give a more accurate estimation of the total energy used hoisting the components giving equation 2.

$$Ep = \frac{mgh}{0.8} \qquad \text{Equation 2}$$

This equation will be used in estimating energy consumption in any hoisting operation to analyse the impact of assembly on the environment.

**Impact Assessment – Material Extraction**

Much of the gearbox will be constructed from alloy steel which will require mostly iron and coal as the raw resources for the product. Iron is a plentiful element in the Earth's crust and so is coal making supply of the two resources plentiful. Both the coal and iron must go through an industrial process to form steel which is then often treated further with alloying elements of heat treatment processes to create the final desired type of steel. There are two main methods of producing steel which are blast furnace production and arc furnace production.

In the blast furnace method of producing steel the iron ore is first sintered in a sintering furnace to create sinter ore which is to be converted into steel. Coal is placed in a coke oven where it is burnt in a low oxygen environment to produce coal coke. Both the sinter ore and the coal coke are poured into a blast furnace through a funnel at the top and hot air blowing from the bottom at 1200oC chemically reacts with the materials as they sink to the bottom. A molten liquid called pig iron is produced at the bottom of the furnace where the temperature can reach levels in excess of 2000oC. Once the coke and iron have reacted with one another the pig iron is poured into a basic oxygen furnace with some amount of recycled steel which is kept at a high temperature to produce molten steel (POSCO Newsroom, 2017). The molten steel then can be cast into stock shapes to be used in manufacturing processes.

Producing steel in an electric arc furnace (EAF) utilises the heat generated by electric arcs from graphite electrodes to produce the heat needed to create the molten steel. The huge amount of power required to operate an arc furnace requires industrial power supplies such as those from the grid. It is assumed that most of the power being supplied by the grid was generated by combustion of non-renewable resources. Arc furnaces mainly recycle scrap steel into new steel stocks and can melt a variety of steel types at once. The steel scrap is placed into the EAF and is melted by the heat generated from the electric arcs and carbon from the electrodes is infused into the mixture to create the molten steel. Once the steel has been created it is usually refined further to adjust the contents of the steel and add any alloying elements (Britannica, 2022). Once this process has been completed the steel can be cast into its stock shapes.

Producing steel in a blast furnace is a much more CO2 intensive process due to the number of heating steps required and the producing and use of coal coke. It is estimated that producing steel in a blast furnace generates 1.987 tonnes of CO2 per tonne of steel created. As the gearbox is expected to weigh around 2.4 tonnes the expected carbon footprint from creation of the raw steel for the gearbox will be around 4.77 tonnes. However, creation of steel in an EAF will emit on average 0.357 tonnes of CO2 per tonne of steel bringing the total carbon footprint of the gearbox materials to 0.86 tonnes if an EAF is used. As much of the gearbox is constructed from steel it will be assumed that the total carbon footprint associated with the raw materials for the gearbox will come from the steel needed for manufacturing.

In terms of costing, steel produced in a blast furnace will cost roughly $1062.5 AUD per tonne to manufacture (Steel on the net , 2022) and steel produced in an EAF will cost roughly $998.3

AUD per tonne to manufacture (Steel on the net , 2022). Steel produced from EAFs offer both a cheaper and more environmentally friendly source of steel compared to traditional blast furnaces. However, this is not without its drawbacks as China is the world's largest steel producer with most of its steel being produced with blast furnaces. Due to its proximity to Australia and relative abundance of blast furnace steel, finding a supplier that provides competitive EAF steel may be difficult and the small price difference may become irrelevant when sourcing a supplier for the steel.

**Impact Assessment – Manufacturing Process**

There are several components that will be manufactured in-house that will be directly accounted for using 0.335kg $CO^2$ per kWh to estimate the carbon footprint of manufacturing enough components for one gearbox. The components that are to be manufactured in house are the casing, inspection cover, drive shaft, idler shaft, gears, flingers, bearing retainers, labyrinth seals, spacers, location bushes, eccentric masses, locking caps, drive adapters and keys. The bearings, seals, fasteners and plugs will be imported as premade components due to the availability of standard parts and the unnecessary complexity of manufacturing these parts in-house. The flingers, retainers, labyrinth seals, spacers, location bushes, locking caps, drive adapters and keys will be excluded from the analysis as they are unlikely to impact the final $CO^2$ footprint of the gearbox to a significant degree.

The drive shaft is to be manufactured from a 210mm diameter circular bar stock 3m of ASI4140 steel which is 3000mm in length. A horizontal band saw will first be used to cut the length of the stock from 3000mm to 1060mm taking roughly 423 seconds to complete the operation for one part. Next a turning machine is used to cut away material from the shaft shaping it into the desired final shape. This is done by first using rough cuts to remove large amounts of material to produce the rough shape of the component before finishing cuts are completed to finetune the shape into the final dimensions. It is expected to take roughly 6753 seconds (~ 2 hours) to manufacture one part excluding loading and unloading times and the tool will consume roughly 2.61 kW of power when active. During this process, keys and metric threads will be cut into the workpiece for the gear, bearings and tapped holes at each end of each of the shafts. As the workpiece is expected to weigh over 834kg, handling the component will require hoisting by crane and significant time to set up beforehand. The part will need to be roughly hoisted up 1-2m onto the machine taking around 240 second of total loading and unloading time. Applying this to equation 2 the energy required in handling comes out as 20.4kW. While the $CO^2$ impact of craning may be overestimated as hoisting will not occur for the entire duration of the part handling it will help account for other factors that are not accounted for such as lighting and ventilation in the workshop.

**Table 5.** $CO^2$ Footprint of the Drive Shaft

| Process | Man Hours (h) | Power Consumption (kW) | kWh | $CO^2$ Footprint (kg) |
|---|---|---|---|---|
| Horizontal bandsaw | 0.118 | 1 | 0.118 | 0.04 |
| TC-300/1000 turning centre | 1.88 | 2.61 | 4.907 | 1.64 |
| Part Handling & Power Overheads | 0.067 | 20.4 | 1.37 | 0.49 |
| | | | Total | 2.17 |

As the idler shaft is almost identical to the drive shaft it will be assumed that the idler shaft has the same carbon footprint.

The helical gears for the gearbox are cut from a 478mm diameter cylindrical bar stock weighing around 4321kg. The stock will first be cut down to size using a horizontal bandsaw before being loaded onto a turning machine. The turning machine will remove material to cut out the shoulder and mill other features such as the keyway into the gear. The refined gear piece is then placed onto a gear hobbing machine where the gear teeth are then cut into the shape. The gear is then induction hardened for a couple of hours to improve the ware characteristics of the teeth. The part handling energy consumption during the process was determined to be 106kW assuming craning is occurring during the entire process.

**Table 6**. $CO^2$ Footprint of the Helical Gears

| Process | Man Hours (h) | Power Consumption (kW) | kWh | $CO^2$ Footprint (kg) |
|---|---|---|---|---|
| Horizontal Bandsaw | 1.28 | 1 | 1.28 | 0.43 |
| TC-300/1000 turning centre | 1.89 | 2.61 | 4.93 | 1.75 |
| Gear Hobbing Machine | 1.41 | 3 | 4.23 | 1.50 |
| Induction Hardening | 2.85 | 100 | 285 | 101.2 |
| Part Handling & Power Overheads | 1.04 | 106 | 110 | 39.1 |
| | | | Total | 144 |

The stock for the eccentric masses is a solid rectangular bar of steel that is 449mm wide, 3048mm long and 573mm high weighing around 6195kg. The bar is cut into the rough size of the eccentric mass using a horizontal bandsaw before it is loaded onto a turning machine to mill the piece into the desired final shape. Drilling and threads are added during this phase as well. The estimated time for part handling is 24 minutes and is expected to consume 152kW assuming the piece is being craned for the entire handling duration.

**Table 7.** $CO^2$ Footprint of the Eccentric Masses

| Process | Man Hours (h) | Power Consumption (kW) | kWh | $CO^2$ Footprint (kg) |
|---|---|---|---|---|
| Horizontal Bandsaw | 0.056 | 1 | 0.056 | 0.02 |
| TC-300/1000 turning centre | 5.17 | 2.61 | 13.49 | 4.79 |
| Part Handling & Power Overheads | 0.4 | 152 | 60.8 | 21.6 |
| | | | Total | 26.41 |

The case for the gearbox is to be sand cast from 852kg of low carbon steel. A mould is made from sand using a pattern to create the desired shape for the casing which molten steel will be poured into. The steel will need to be heated up to over 1550°C to ensure the entirety of the raw material is molten. To melt the 852kg of steel to this temperature 3.2GJ of energy is required based on the standard properties of low carbon steel (Vishwakarma, 2022). The energy used to melt the steel can be converted directly into kWh using a conversion factor of 1/3600000. Once the cast has cooled the casing can be placed on a turning machine and a horizontal milling centre (HMC) to machine the extra features in the casing such as indentures, holes, and threads. The part handling time is expected to take around 1.02 hours to complete having a power consumption of 20.9kWh

**Table 8.** $CO^2$ Footprint of the Casing

| Process | Man Hours (h) | Power Consumption (kW) | kWh | $CO^2$ Footprint (kg) |
|---|---|---|---|---|
| Automatic Sand Casting Process | N.A. | N.A. | 888.9 | 315.6 |
| TC-300/1000 turning centre | 0.39 | 2.61 | 1.02 | 0.36 |
| Haas HMC HS-3 | 2.3 | 15.66 | 26.02 | 9.23 |
| Part Handling & Power Overheads | 1.02 | 20.9 | 21.3 | 7.56 |
| | | | Total | 332.75 |

The inspection cover is cut from cold rolled steel sheet metal that is 280mm wide, 1030mm in length and has a thickness of 10mm having a mass of 23kg. The sheet metal is to be laser cut out into the desired shape. The holes and taps are then added to the inspection cover using a drill press to add the drill holes and tapped holes to the cover. As the piece is sufficiently light that a worker could manually move the piece into a machine without mechanical assistance craning power is not needed, however this will still be determined to estimate some of the overhead energy impacts on the part. If the part was to be constantly craned during handling it would consume

**Table 9**. $CO^2$ Footprint of the Inspection Cover

| Process | Man Hours (h) | Power Consumption (kW) | kWh | $CO^2$ Footprint (kg) |
|---|---|---|---|---|
| Laser Cutting | 0.18 | 2 | 0.36 | 0.128 |
| Drill Press | 0.11 | 0.82 | 0.09 | 0.032 |
| Part Handling & Power Overheads | 0.032 | 0.56 | 0.018 | 0.006 |
| | | | Total | 0.166 |

The imported parts for the gearbox consist of 42 M12 bolts, 20 M16 Bolts, 4 M24 bolts and 4 22334 CCK/W33 spherical roller bearings. Each of the bearings is estimated to weigh around 58 kg (SKF, 2022). The averages size of the bolts are M14 bolts so assuming the bolts are 100mm in length the 66 bolts will weigh 0.1kg. As it will be difficult to estimate the $CO^2$ footprint of manufacturing these components it will be assumed that the energy required to machine the parts is 4.72 $Jmm^{-3}$ with a material removal rate of 500 $mm^3s^{-1}$ (Zhao, Liu, He, Cao, & Guo, Energy consumption in machining: Classification, prediction, and, 2017). Firstly the volume of the bolts and bearings need to be found which is 840000$mm^3$ and 49000000$mm^3$ respectively. The energy expended in removing the material to make the parts can be determined from equation 3 where V is the volume of material and ε is the machining energy.

$$\text{Energy Expended} = \mathrm{V}\varepsilon \qquad \text{Equation 3}$$

The time taken to machine the components can be determined from equation 4 where ϵ is the rate of material removal.

$$\text{Machining Time} = \frac{\mathrm{V}}{\epsilon} \qquad \text{Equation 4}$$

The power of the machines can be estimated from the machining time and energy expenditure so that the kWh used to produce the components can be determined. From this the $CO^2$ footprint can be calculated. The table below shows a breakdown of the $CO^2$ footprint estimation.

**Table 10.** Imported Part $CO^2$ Footprint

| Component | Part Volume to be removed ($mm^3$) | Energy Expended (kJ) | Estimated kW | Time Taken (h) | kWh | $CO^2$ Footprint (kg) |
|---|---|---|---|---|---|---|
| Metric bolts | 840000 | 3965 | 2.4 | 0.47 | 1.128 | 0.40 |
| 22334 CCK/W33 bearings | 49000000 | 231280 | 2.4 | 27 | 64.8 | 21.7 |

The total $CO^2$ footprint from manufacturing can be determined from summing the individual $CO^2$ footprint of each component which is done in the table below.

**Table 11.** $CO^2$ Footprint of Manufacturing

| Component | $CO^2$ Footprint (kg) |
|---|---|
| Drive Shaft | 1.772 |
| Idler Shaft | 1.772 |
| Gears x2 | 288 |
| Eccentric Masses x4 | 106 |
| Casing | 332.75 |
| Inspection Cover | 0.166 |
| Metric Bolts | 0.40 |
| 22334 CCK/W33 bearings x4 | 21.7 |
| Total | 752.6 |

**Impact Assessment - Transportation**

Transportation of heavy mining equipment is mostly carried out using trucks, trains, and boats to deliver machines from factories to the worksite. Each method has its own strengths and weaknesses that will be more suitable for different applications. The planned exciter gearbox will weigh around 2.4 tonnes and will be over a meter in length on its shortest face. To transport the gearbox all three methods can be utilised as the gearbox is not so large that specialised transportation equipment is required to move it.

Moving goods via trucks will produce around 100 gCO2t-1km-1 (ICCT, 2022) and is the least environmentally friendly transportation method as transporting goods via ships produces 25 gCO2t-1km-1 and transporting via trains produces 75 gCO2t-1km-1 (Time for Change, 2022). Some degree of truck travel is essential as trucks have access to almost any location via roads while trains and boats are restricted to rail and waterways respectively. For the purpose of this analysis, it will be assumed that the ultimate destination for the gearbox will be telfer as this is a mine site up in the north of Western Australia where much mining is conducted. Telfer is located 1678 km north of Perth and would take roughly 17 hours of continuous driving at 100 kmh-1 to reach if the gearbox was to be transported via truck. During this time an estimated 402.7 kg of CO2 will be emitted. An alternative route would be to deliver the gearbox to Fremantle port where it can be loaded onto a ship to travel to Port Hedland to then be trucked to Telfer. The table below gives a breakdown of the CO2 emission associated with this travel route.

**Table 12**. CO2 Footprint of Transporting the Gearbox by Sea

| Transportation Step | $gCO^2t^{-1}km^{-1}$ | Distance (km) | $CO^2$ Footprint (kg) |
|---|---|---|---|
| Factory to Fremantle | 100 | 15 | 1.5 |
| Fremantle to Port Headland | 25 | 1335 | 33.4 |
| Port Headland to Telfer | 100 | 476 | 47.6 |
| | | Total | 82.5 |

A significant reduction in CO2 emissions can be achieved by transporting the gearbox via cargo ships amounting to an estimated 320.2 kg of CO2. This option may also be a more commercially viable option as sea travel is often the most economical choice for freighting goods long distances.

**Impact Assessment – Utilisation**

The gearbox is designed to have an operational lifetime of 4 years of constant operation. To run the gearbox a 45 kW motor is required to be connected to the drive shaft to provide the input torque. Over its lifetime the gearbox will consume approximately 1,576,800 kWh of energy, amounting to a CO2 footprint during operation of 52.9 Tonnes of CO2. Maintenance will need to be carried out on the gearbox from time to time, however the downtime intervals for the gearbox will be incredibly small as downtime will result in lost profits encouraging companies using the gearbox to keep it up and running as much as possible.

**Impact Assessment – Disposal and Recycling**

Under a traditional product lifecycle once the gearbox has reached the end of its life it would either be disposed of to landfill or in most cases be sold on as scrap metal to be recycled into other things. The bearings will need to be completely disposed of as they are the first critical component to fail and the shaft will need to be completely melted down and recast due to the fatigue it would have experienced during its operation. At this point a brand-new gearbox will be ordered to replace the used one ending the life of one gearbox and starting the life of the next.

It will be assumed that the steel in the gearbox will be taken to an EAF to be scrapped and recycled. Excluding any transportation emissions, recycling the 2.4 tonnes of steel in the gearbox will emit around 0.86 tonnes of $CO^2$. At this point the gearbox has reached the end of its life and the material will then be used to construct new products.

Following a traditional approach to manufacture and use the gearbox the total $CO^2$ footprint is estimated to be 59,365kg cover the course of its life assuming only cost-effective strategies are employed. These strategies are taking advantage of more readily available blast furnace steel mills and utilising sea transport. A breakdown of all factors contributing to the $CO^2$ footprint of the gearbox is shown below.

**Table 13.** Life Cycle Stage $CO^2$ Breakdown

| Life Cycle Stage | Total $CO^2$ Footprint (kg) |
|---|---|
| Material Extraction | 4,770 |
| Manufacturing | 752.6 |
| Transportation | 82.5 |
| Utilisation | 52,900 |
| Disposal and Recycling | 860 |
| Total | 59,365 |

### Improvement Assessment

To better improve the sustainability of the product a less traditional product life cycle will need to be looked at. Rather than following the traditional linear cradle to grave process the goal should be to achieve a circular cradle to cradle process. Due to the recyclable nature of steel the gearbox does follow a roughly circular process under the current life cycle, however it would be more desirable to use the same gearbox components in new gearboxes rather than melting the steel back into raw stock to be used in other products. A proposed modification to the lifecycle is shown below.

Observing Table 13, the most significant contributor to the products environmental impact is utilisation stage as almost 53 tonnes of CO2 is emitted during this stage. However not much can be done to address the product in this stage of the life cycle as it is up to the customer on how they use it and where they get the energy from. If a customer chooses to power the gearbox using green technologies, then the impact from utilisation could be reduced significantly, however for this assessment it will be assumed that 52.9 tonnes of CO2 is unavoidable during utilisation.

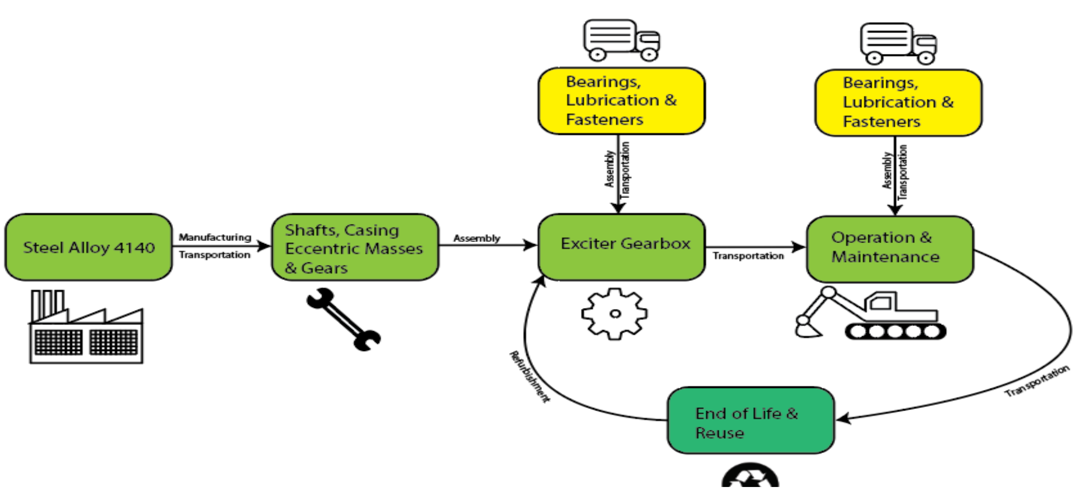


*Figure 6 Improved Cradle-Cradle Life Cycle*

The next biggest area for improvement would be to address the source of the steel for the product. Currently new steel is being purchased from blast furnace suppliers for every new gearbox, however the casing that makes up much of the material needed for the gearbox could be refurbished and reused in subsequent gearboxes once the product has reached the end of its life. Deformation is likely to occur at the bearing bores which is likely to occur due to the high loads on these areas. Much of the casing should remain intact only requiring minor refurbishments if the relevant maintenance has been carried out over the course of its operational life.

The shafts are much larger than the required 140mm to achieve a safe fatigue life on the gearbox, however due to the unpredictable nature of fatigue, testing would need to be done on the shafts to determine if they are suitable for reuse. As a result of this it will be assumed that the shafts are not suitable for reuse and need to be recycled. The eccentric masses and keyways should be suitable for reuse as they experience only moderate loads and are generally quite robust components. Reuse of the components may be possible after an inspection and refurbishment. The gears are likely to wear down over the course of the product's life, however it is not unimaginable that the gears can return in a state where they would be suitable to be reused in a new gearbox after a refurbishment process. On return, perform non-destructive testing (NDT) to check for any micro cracks, then measure tooth wear with a coordinate measuring machine (CMM).

Reusing the casing, gears, keys, and eccentric masses of the gearbox can potentially cut down on the CO2 footprint of manufacturing the product as the raw material does not need to be purchased with the accompanying CO2 emissions and the energy expended in refurbishing a component is much less than producing a component from a stock as less cutting needs to be done and in some cases only minor grinding may be required. It is impossible to accurately estimate the refurbishment process for each part as the process will need to be tailored as components will be returned in different states. It will be assumed that the CO2 footprint of refurbishing a part is only 20% as the manufacturing process contributes only 13.6% of the total CO2 to manufacture a gearbox. 6.4% extra is added to account for any unknown processes that could contribute to the CO2 footprint during refurbishment. Accounting for the new raw material that needs to be ordered to replace the shafts, the new CO2 footprint of material extraction and manufacturing is as follows.

**Table 14.** CO2 Footprint of Refurbishing a Gearbox

| Component | $CO^2$ Footprint (kg) |
|---|---|
| New Steel | 120 |
| Drive Shaft | 1.772 |
| Idler Shaft | 1.772 |
| Gears | 57.6 |
| Eccentric Masses | 22.1 |
| Casing | 66.55 |
| Inspection Cover | 0.033 |
| Metric Bolts | 0.4 |
| 22334 CCK/W33 bearings | 21.7 |
| Total | 292 |

Implementing a reuse scheme alongside the manufacture of the gearboxes can potentially reduce the $CO_2$ footprint of subsequent gearboxes being sold by 5231kg. The $CO_2$ footprint of new steel for a refurbished gearbox is only 120kg compared to 4,770kg for a new gearbox and the manufacturing footprint has reduced by 581kg. This can potentially save the manufacturer money as a result of less material needing to be purchased and fewer man hours required to sell a new product; however, a cost analysis of this process will need to be conducted to determined the extent of the cost savings. The $CO_2$ footprint of transportation is expected to double to 165kg to account for a back-and-forth trip, but this increase in overall $CO_2$ due to this is negligible compared to the potential savings. Reusing gearbox components is a valid option for this project as there are potential cost savings that can be made as well as making the product more competitive compared to others both economically and environmentally.

**Quality Control and Management**

The quality of the redesigned gearbox is paramount to ensure that all components and therefore the combined unit itself may satisfactorily be interchanged with the Schenk DF 704S exciter gearbox without compromising quality and reliability. Consideration towards the interrelationship between process capabilities and tolerance selection for critical components was of utmost significance when ensuring the quality management of the final design concept. A considerable factor in the selection of integrating multiple material removal processes within the same machine was seen to result in the innate reduction of potential defects within critical components. Further to this, redesign allowed for re-evaluation of not only the existing model for means of easier assembly but improving the quality of the product. It is widely accepted that product quality is greatly influenced by the design both mechanically and aesthetically, therefore a large emphasis was placed on simplifying the overall product as well as manufacturing capabilities and techniques.

Quality control stages when manufacturing the components pertained to ensuring that quality was managed and controlled at critical points of material removal stages. It was especially important to include such steps into stages of the machining processes to ensure that tolerances are to be acceptably met before further manufacture of components. These steps allow for the inclusion of visual inspection of machined parts and cutting tools, permitting that any unforeseen errors that may occur during these stages of manufacture may be addressed and corrected as soon as possible before continuing on to the assembly line.

# Discussion

## Function

The final design of the exciter gearbox has achieved a significant predicted lifetime before any expected equipment failures are likely. Due to the considerably large forces present within the exciter unit, the shaft was designed to withstand the maximum load capable of being produced by the exciter gearbox of 1000kN, over an infinite number of cycles. Furthermore, the shaft material selection of 4140 alloy steel, which is strong yet relatively inexpensive, permitted the minimum required diameter of the shaft to be greatly reduced, mostly due to the favourable yield strength of 4140 alloy compared to ordinary 1040 plain carbon steel. This presented benefits not only recognisable by advantageous mechanical properties, but also by improved manufacturing turnaround capabilities, as a reduction in shaft diameter greatly reduces machined component turnaround.

The conceptual design phase of the drive shaft indicated the most likely point of component failure would be due to the spherical roller bearings. As such, sizing and selection of the bearings was done so in accordance with maintaining a minimum reliability factor at full output load of 90% over a four-year period. The likelihood of prolonged exposure at maximum output force requirements may be considered improbable, and as such permits a valid assumption that the bearings themselves will remain in service for a significantly longer time period than the predetermined design criteria stipulated.

Opting for a helical gear design presented a more time-consuming processing turnaround for manufacturing the component as opposed to spur gears, however, functional benefits by means of helical gear selection far outweigh the alternative. Smoother torque transfer between the mating teeth is achieved by multiple teeth in contact simultaneously, providing a significantly favourable selection when compared to a spur gear arrangement.

Adjustable eccentric masses have been implemented into the updated design, providing relative ease of manoeuvrability for the desired output loads. The Schenk design incorporates removable plugs in the body of the eccentric masses to achieve the required output forces for varying process load requirements. However, by implementing the adjustable masses in the iterative design, this improves the design significantly for two main factors. Firstly, it was observed that ergonomically, removal and installation of the eccentric mass plugs on the Schenck model makes for a considerably difficult practical task for maintenance personnel. Further to this, the time required to remove and install the components was seen to potentially exacerbate production downtime due to additional time required for the task. Secondly, the addition of plugs for each eccentric mass introduces more components to be manufactured and assembled. The reduction in components by eliminating the plugs from the eccentric masses proves more efficient for DFM and DFA processes as well as potentially proving more economically beneficial. By implementing the adjustable eccentric masses, maximum production may be achieved without compromising the required output load specifications regarding the Schenk unit.

## Manufacturability

Consideration to the most effective manufacturing techniques were paramount to ensure efficient production could be achieved. Main features relating to critical components such as the drive and idler shafts were selected such that all surface features including roughing and finishing, as well as cutting of keyways were able to be completed within the same CNC machine. This allows for maximum component accuracy through avoidance of unnecessary removal and reloading of critical parts, which may potentially compromise the accuracy and overall quality of the component when in service. This philosophy was implemented towards the manufacture of other critical components such as the drive and driven gears, eccentric masses - both fixed and adjustable - and the inspection cover. The ability to conduct the majority of material removal within the same machine for each of the manufactured components meant that, with the exception of occasional worker intervention for rotating and setting of the component, little additional material removal or finishing processes were required.

The main weakness concerning the manufacturability of the exciter gearbox mainly pertains to the casting process of the gearbox casing. Dimensions and subsequent weight of the unit would require additional logistics after the casting process including secondary processing techniques such as milling of the bottom flange face, flats of the bolt holes and the inspection cover recess. Setup and alignment of these secondary processes would invariably require additional lifting mechanisms, such as overhead gantry cranes or other mechanical aids proving timely in their method.

## Ease of Assembly

The inherent size and overall weight of the majority of components would entail a relatively slow assembly process. Additionally, tolerances pertaining to the fixed eccentric masses, drive and idler gears require a force fit due to the nature of load output, yielding a hindrance in the physical assembly of mating parts. Once more, the use of lifting aids - mainly overhead gantry cranes - would be necessary to rotate and orientate components such as the gearbox housing to allow for the insertion of gears through the inspection cover opening. Furthermore, the drive and idler shafts would also require to be craned in, precisely aligning with their respectively mating gear, whilst employing a hydraulically operated press to obtain the interference fit. Due to the nature of force fitting the gears and fixed eccentric masses to the shafts, increased temperature of bores and decreased temperatures of shafts must be allowed for the efficient assembly of the force fit mating components, which would require skilled mechanical maintenance personnel to ensure this critical process is carried out as speedily as possible. It is important to note that large scale assembly processes inherently result in increased assembly times purely due to the size of components that are to be assembled. It is therefore not exclusive nor through oversight of the redesign of this exciter gearbox that challenges are present throughout the assembly.

## Cost

Effective production costs were observed through a multitude of critical components for the gearbox assembly. The drive and idler shafts along with their subsequent gears display promising quantities pertaining to the cost vs life volume of manufacturing the components. Essentially, this analysis provides a fundamental overview relating to the expected timeframe to which manufacturing the components begins to yield profitable returns for the number of components to meet the required production volume. The figure below illustrates the generated cost vs life volume plot of the eccentric masses to be produced internally. Initially, it can be observed that total cost vs life volume remains constant during initial production, yet after a relatively short period the effective cost of the components plateaus well in advance of the required output quantity volume. Equivalently, this was also observed for other critical components, and may be observed in the respective appendices as aforementioned the benefit of such results has been attributed to logical selection of material removal processes, in that maintaining the majority of material removal processes within the same machine yields less initial tooling expenses as well as unnecessary additional investment in capital equipment for individual material removal processes.


*Figure 7 Total Cost v Life Volume*

Alternatively, cost drawbacks were observed to relate to the gearbox casing. Initial tooling expenses were deemed in excess of $60,000, with this mainly attributed to the casting process involving initial tooling setup requirements. In terms of physical manufacture, production expenses were largely ascribed to material costs of which contributed to the bulk of the total cost of the gearbox casing. Although this is to be expected with casting process and given an initial outlay of tooling setup invariably contributes to longer cost against life volume benefits, a reasonable assumption of internally producing the gearbox costing would indeed be the most viable option economically, rather than incurring additional labour and transportation costs, which consequently would further increase the cost return per volume of gearbox casings produced.

It has been generally noted that a direct relationship of maximizing feedstock material for machining is a key constituent in effectively producing components enabling the optimization of manufacturing cost per component. An example of this relates to material removal of components such as the drive and idler shafts, where the majority of the cost is related to the stock material, rather than the processing of component features. By maximizing the amount of manufacturable components per raw feedstock material, processing and hence manufacturing capabilities may be greatly enhanced for more economic production.

## Overall Quality

Quality control for component manufacture was selected to ensure the most efficient means of feature measurement met dimensional characteristics according to the design. An example of this relates to manufacturing of the drive shaft components. Once lathe and milling operations are complete, a human operator will ensure that the dimensional specifications are met by taking necessary measurements via either outside micrometres for shaft diameters or vernier callipers to measure inside dimensions of the keyways. As well as dimensional integrity, this also allows time within the manufacturing scope for the human operator to visually inspect the component aesthetically to ensure the components are free from deficiency. Additionally, a similar process would be carried out for both drive and driven gears to ensure compatibility of both the bore and keyways, as well as the outside diameter of gear geometry before hobbing, to ensure that sufficient material remains for the accurate cutting of the helical gear teeth. Furthermore, the gearbox housing requires inspection after primary manufacturing processes pertaining to being cast and subsequently sand-blasted to remove excess slag, to ensure that excess material has been removed before secondary milling and finishing (painting) may be carried out.

It may be reasonable to expect that with a relatively large and systematic scale of production that variations in manufacturing processes are to be controlled. Tolerances were selected due to the requirements of the exciter gearbox; however, the machines were also selected to ensure that sufficient process capability was incorporated to fulfil the required tolerances. A weakness in this instance may be related to the force fit nature of critical mating components related to the eccentric mass-to-shaft fits. The requirement to produce such critical tolerances would highlight the need for better process capabilities in that more precise machining equipment would become essential to ensure tolerances are compatible with processing capability.

# Conclusion

The key findings of this work were the benefits of concurrent engineering when designing concept products to replace OEM products to reduce customers' reliance and need for trust in one supplier. Concurrent engineering served to be instrumental to implement DFX methodology to avoid wasting time on doomed concept designs at the advice of experts in manufacture. By using DFX methodology it became easier to keep track of environmental and economic impacts of material and manufacturing process selections to ensure that no one major stakeholder in the triple bottom line ended up being ignored and disproportionately affected. A stark benefit of this approach was to not have a sudden realisation after weeks of work that a concept design was unsuitable because of its environmental impact, or obscenely high material cost or requirement of exotic and complex manufacturing processes, for example. From carrying out this work, some recommendations for future work have emerged. These include a further analysis of vibrational response of the entire concept design DFEG, possible material reduction in large parts such as the shafts and casing to reduce and further focus on material selection and manufacture processes to further reduce cost and environmental impact. The purpose of these recommendations is to better optimise the needs of two of the three major stakeholders in the triple bottom line: profit and planet.

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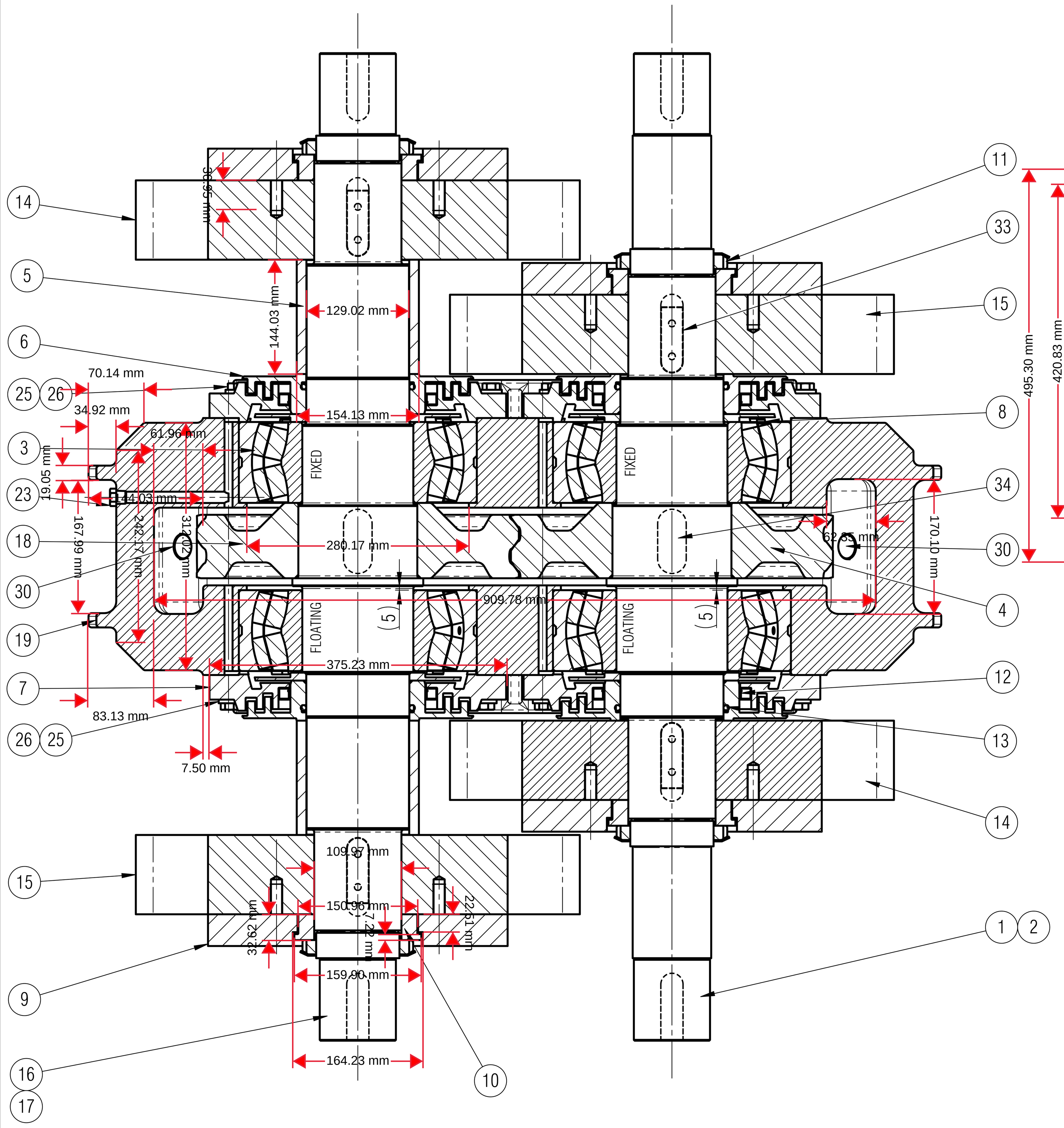
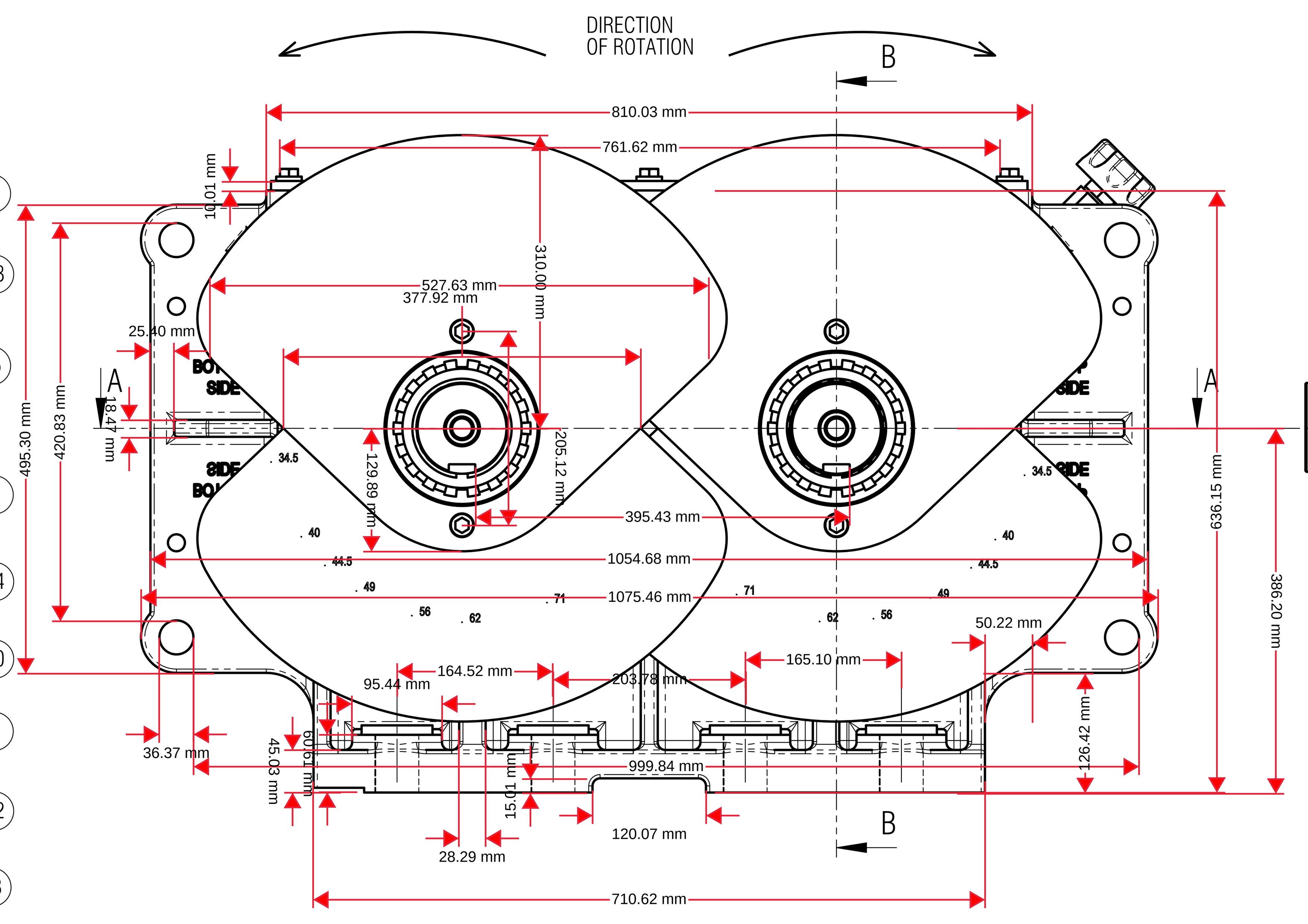
# Appendix A

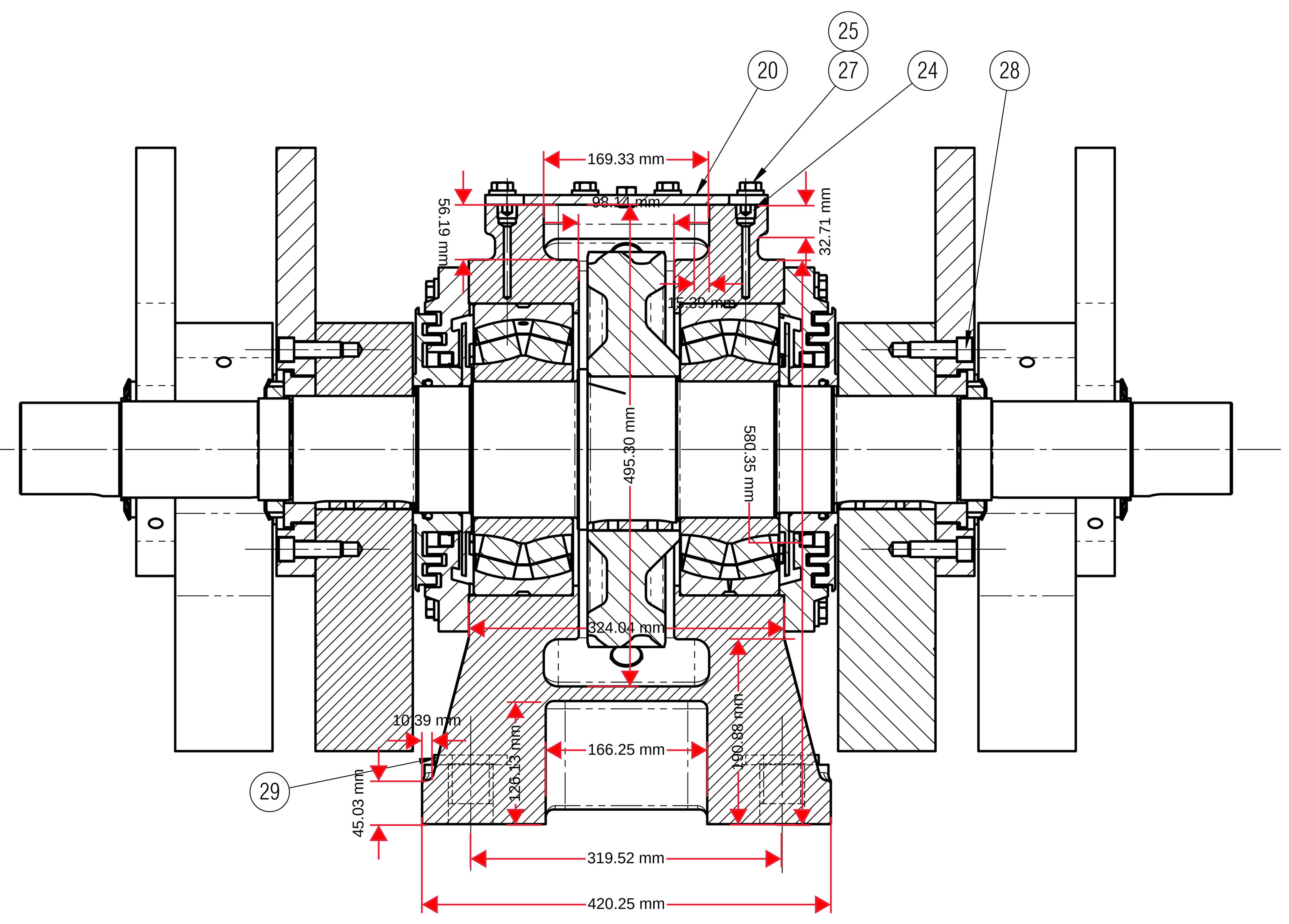
**Hofmann Engineering Pty. Ltd. Assembly Drawing**

*INSERT "AARON'S DIMENSIONAL NOTES V2"*



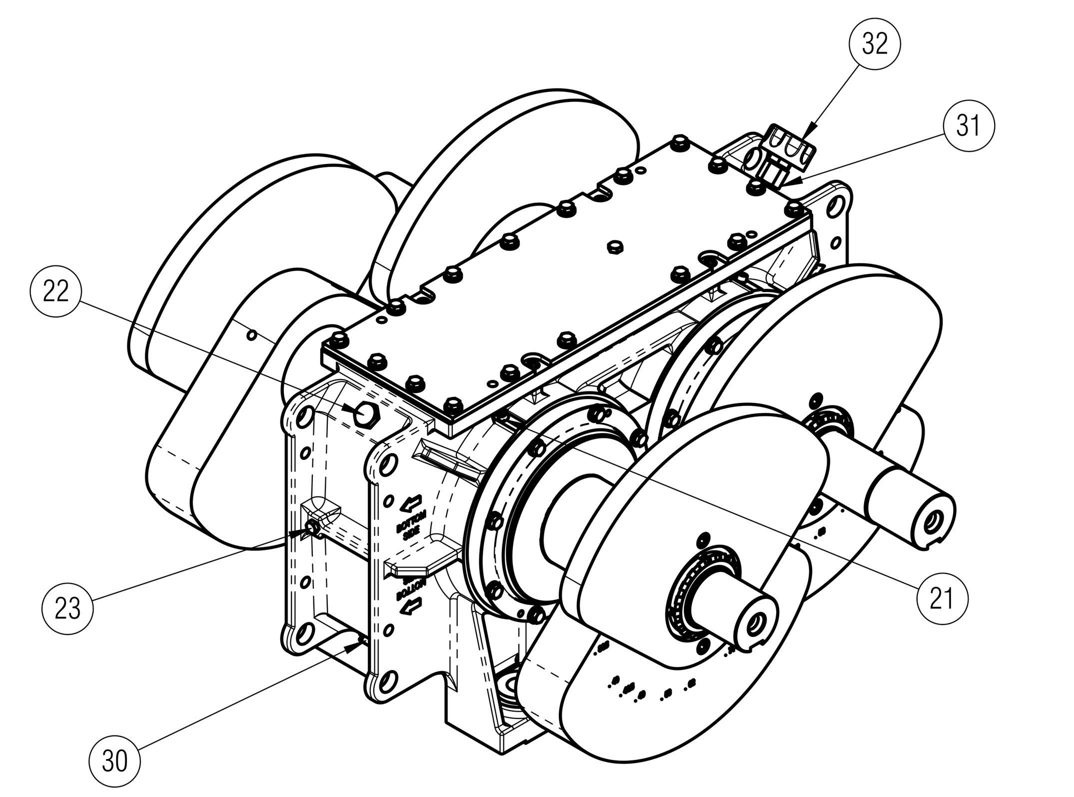

SECTION A-A
(ROTATED 90° CCW )




SECTION B-B

| ITEM | DESCRIPTION | QTY |
|---|---|---|
| 1 | DRIVE SHAFT | 1 |
| 2 | | 1 |
| 3 | BEARING-SKF 22328 CCJA/W33VA406 | 4 |
| 4 | GEAR, LEFT HAND | 1 |
| 5 | SPACER | 2 |
| 6 | LABYRINTH SEAL | 4 |
| 7 | BEARING RETAINER | 4 |
| 8 | FLINGER | 4 |
| 9 | OUTER ECCENTRIC MASS | 4 |
| 10 | LOCATION BUSH | 4 |
| 11 | LOCKNUT, SKF KM 21, & TAB WASHER | 4 |
| 12 | DOUBLE LIP SEAL - SKF CR SEAL - 170x200x15, VITON | 4 |
| 13 | SEAL, O-RING, 130 x 144 x 7, ISO 3601, N70 | 4 |
| 14 | ECCENTRIC MASS ITEM 2 | 2 |
| 15 | ECCENTRIC MASS ITEM 1 | 2 |
| 16 | IDLER SHAFT | 1 |
| 17 | | 1 |
| 18 | GEAR, RIGHT HAND | 1 |
| 19 | GEARBOX CASING | 1 |
| 20 | INSPECTION COVER | 1 |
| 21 | BOLT, SHCS, M10 x 1.5 x 10 LG ,DIN 912, PC12.9, STEEL | 4 |
| 22 | PLUG, HEX, STEEL, 1" NPT | 1 |
| 23 | PLUG, HEX, STEEL, 3/8" NPT | 2 |
| 24 | 1/2" N.P.T. PRESSURE PLUG | 4 |
| 25 | WASHER, HARDENED, M12, ASTM F436M, TYPE 1, STEEL | 49 |
| 26 | BOLT, HEX HEAD, M12 x 1.75 x 50 LG ,AS 1110, PC8.8, STEEL | 32 |
| 27 | BOLT, HEX HEAD, M12 x 1.75 x 35 LG ,AS 1110, PC8.8, STEEL | 17 |
| 28 | BOLT, SHCS, M16 x 2.0 x 50 LG, DIN 912, PC12.9, STEEL | 8 |
| 29 | BASE PLATE PACKER | 8 |
| 30 | 1"NPT MAGNETIC HEX PLUG | 2 |
| 31 | BREATHER ADAPTER | 1 |
| 32 | BREATHER - STAUFF - SES5-10-B16-0-0 | 1 |
| 33 | KEY, 28x16 FormC x 83 lg | 4 |
| 34 | KEY, 36x20 FormA x 81 lg | 2 |



ISOMETRIC VIEW
NTS

BOLT TORQUE VALUES

| BOLT SIZE | PROPERTY CLASS | Nm | lb ft |
|---|---|---|---|
| M10x1.5P SHCS | 12.9 | 72 | 53 |
| M12x1.75P HEX | 8.8 | 73 | 54 |
| M16x2.0P SHCS | 12.9 | 306 | 226 |

NOTES:
1. ALL EXTERNAL BOLTS TO BE ASSEMBLED WITH LOCTITE ANTI-SEIZE
2. ALL INTERNAL BOLTS TO BE ASSEMBLED WITH LOCTITE 262

GENERAL NOTES
1. ALL DIMENSIONS IN mm U.O.N. DO NOT SCALE
2. REMOVE SHARP EDGES 0.5 x 45° U.O.N.
3. ALL JOINT FACES TO BE SEALED USING PERMATEX No.3 LIQUID GASKET
4. ALL INTERNAL BOLTS TO BE LOCKWIRED

MASS

REFERENCE DRAWINGS

| REV. | DATE | DESCRIPTION | DRN.BY | CHK.BY | APP.BY |
|---|---|---|---|---|---|

MACHINING PERMISSABLE DEVIATIONS TO AS1100.201
LINEAR & ANGULAR DIMENSIONS TO ACCURACY GRADE "M" (MEDIUM)
ALL GEOMETRY TOLERANCES TO ACCURACY GRADE "K"

AS1100.201 MEDIUM SERIES

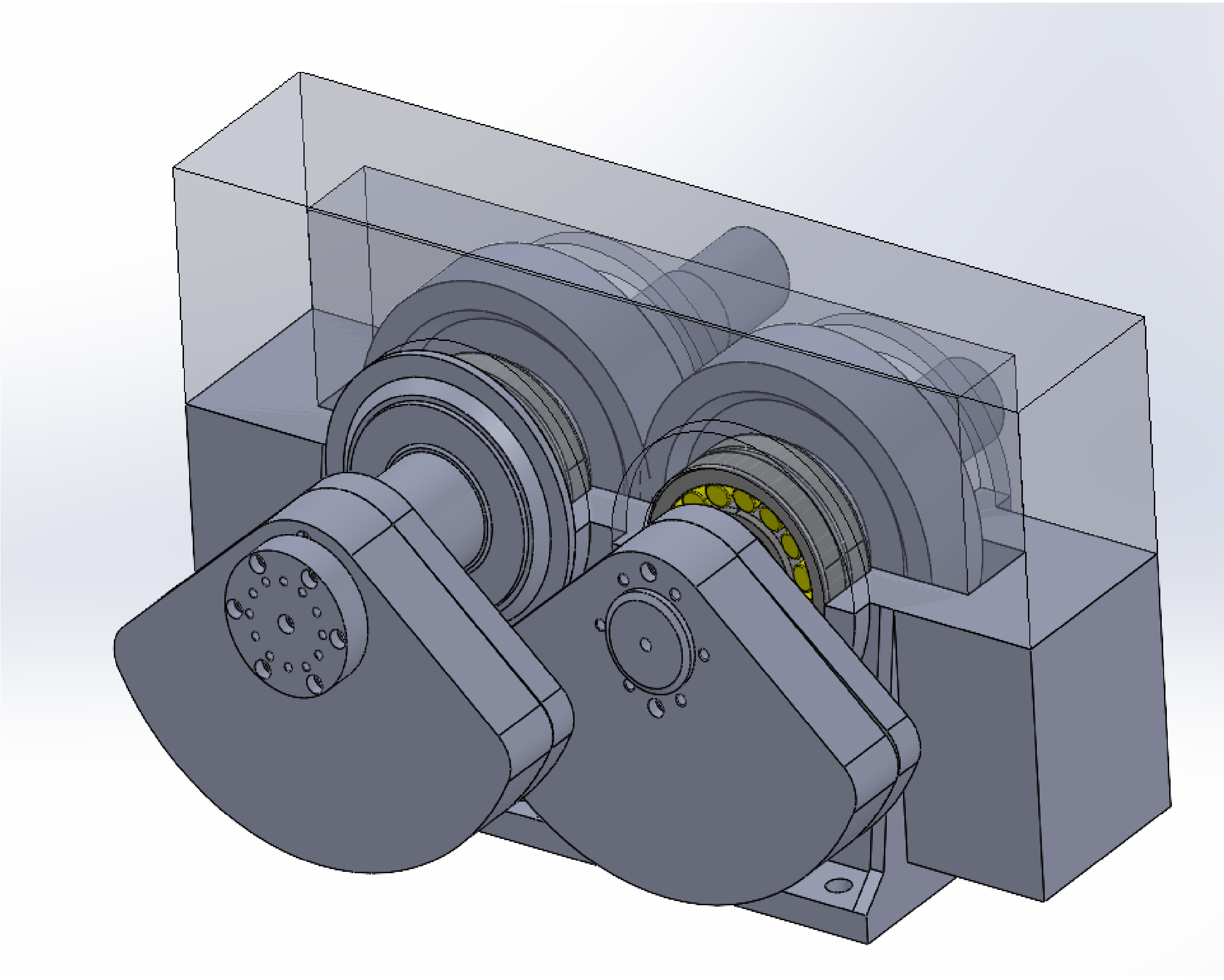
| NOMINAL DIM | TOLERANCE |
|---|---|
| 0.5 - 6 | ±0.1 |
| >6 - 30 | ±0.2 |
| >30 - 120 | ±0.3 |
| >120 - 315 | ±0.5 |
| >315 - 1000 | ±0.8 |
| >1000 - 2000 | ±1.2 |
| >2000 - 4000 | ±2.0 |

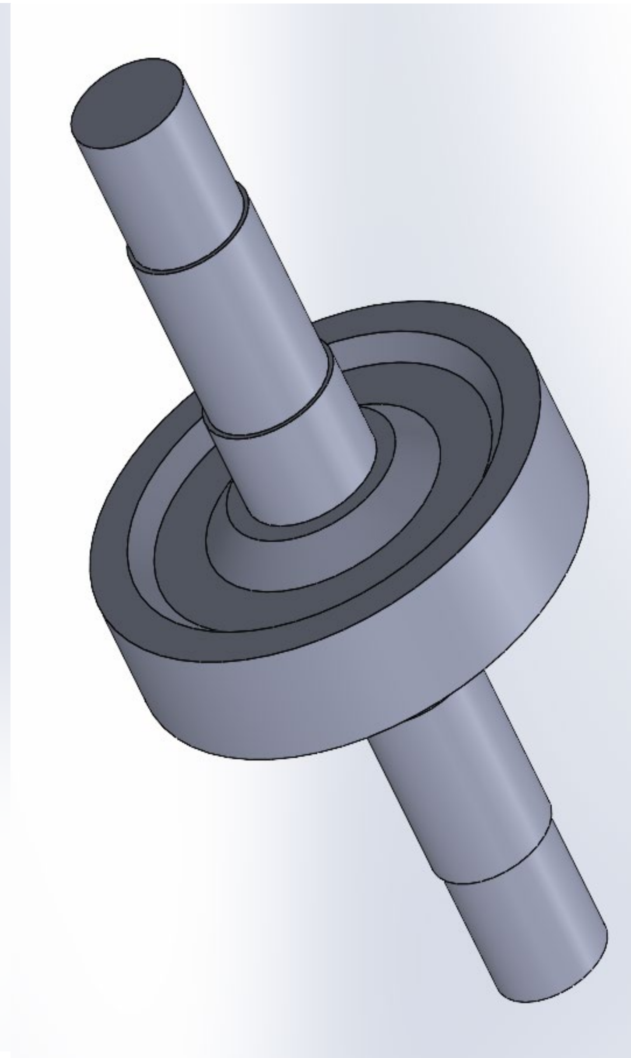
HOFMANN Engineering ®

SCALE 1:5
DATE
DRAWN
CHECKED
APPROVED
O.E.M.
MODEL
DESC
-
ASSEMBLY
CLIENT
O.E.M. PART No –
HOFMANN ITEM No –
DESIGN FOLIO No
SHEET SIZE A1
DRAWING No
REV

# Appendix B.1

**First Major Concept Design Iteration**





# Appendix C.1

**Initial Drive Shaft Load Calculations**

Shaft Bending/Shear Force Calculations.

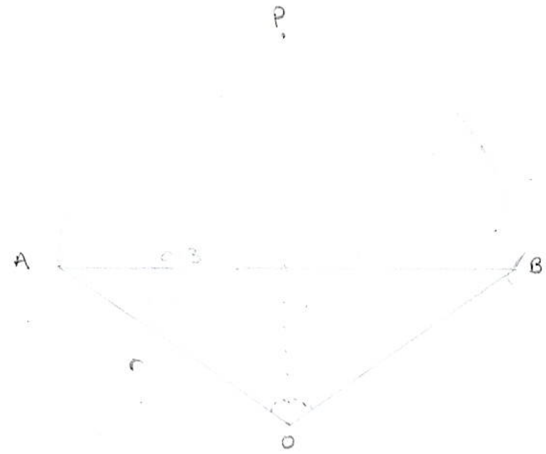
considerations: • upper and lower eccentric masses
(upper: larger; lower: smaller)

• gear to be positioned in middle of shaft(s).

• bearing support reactions.

• calculate hypothetical loads induced by net eccentric masses.

• calculate load induced by gear.




Area of sector $= \pi r^2 \times \frac{\theta}{360}$

Geometry approximations of eccentric masses:

$r \approx 250mm$

$\theta \approx 120°$

Area of sector APB $= \pi(0.25)^2 \times \frac{120}{360} = A_1$

$\therefore A_1 = 0.065m^2$

Area of Triangular Section, $A_2$:

$0.5bh$

$b = 2(0.25\sin 60) = 0.433m$

$h = 0.25\cos(60) = 0.125m$

$A_2 = 0.5 \times 0.433 \times 0.125$

$\therefore A_2 = 0.027m^2$

Total Area of Segment:

$A_1 + A_2 = 0.065 + 0.027$

$\therefore A_T = 0.092m^2$

mass of larger eccentric mass.

$m_{e_1} = \rho V_1$

• Assumption of material density as $\rho = 7800kg/m^3$ (steel)

• Assumed thickness of larger mass = 30mm (0.3m) - est. from drawing

$m_{e_1} = 7800kgm^{-3} \times (0.092m^2 \times 0.03m)$

$\therefore m_{e_1} = 21.53\ kg$

Smaller eccentric mass

Same basic geometry, but different thickness.

$t_{e_2} = 0.01m$ (10mm)

$m_{e_2} = 7800\ kgm^{-3} \times (0.092m^2 \times 0.01m)$

$\therefore m_{e_2} = 7.176\ kg$

## Forces exerted by eccentric masses:

Total force in each direction = Net force from masses.

$F = m\omega^2 r$

Base $\omega$ on max rating = 1000 kN force bearing.

$$\omega = \text{rpm} \times \frac{2\pi}{60}$$

$$= 1000 \times \frac{2\pi}{60}$$

$$\therefore \omega = 104.7 \ \frac{\text{rad}}{\text{s}}$$

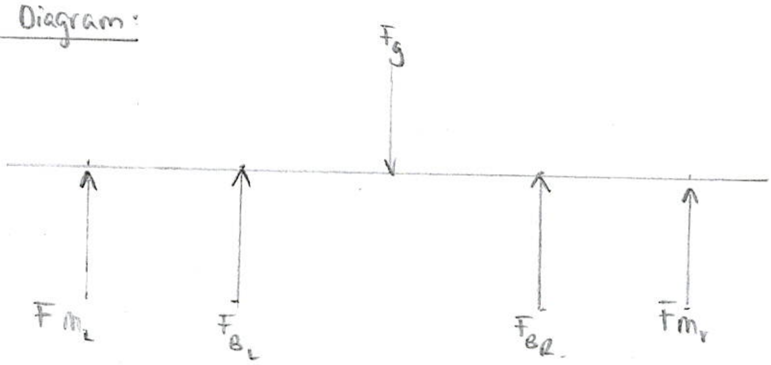
$$F = m_{net}\,\omega^2 r$$

$$= (21.53 - 7.176) \times (104.7)^2 \times 0.25$$

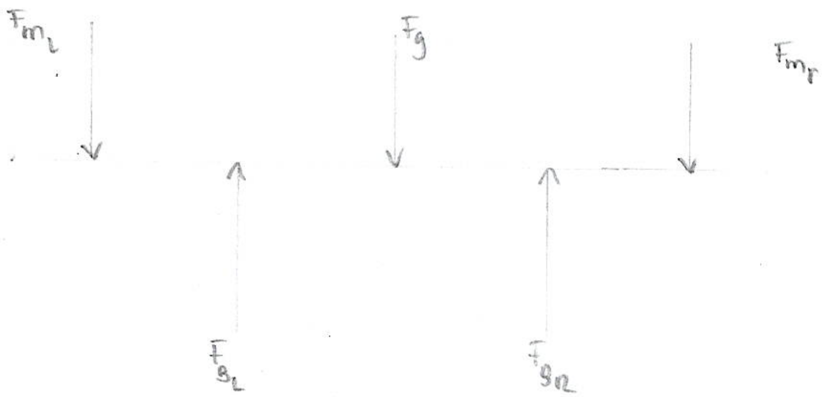
$$\therefore F = 39.34 \text{ kN}$$ = force exerted by eccentric masses.

## Load Diagram:

Top:

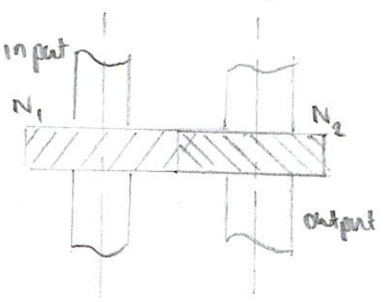



Bottom:




## Gear force calculations:

Considerations:
- Both gears equal in size
- Helical gears; axial/thrust loads considered.




$N_1 = N_2$

Gear exerts shear force on shaft.

force exerted on $G_2$, from $G_1$ must reciprocate.
torque applied by drive motor must be equal to
torque applied by gear. on same axis of rotation.

Note : Power supplied, $P$ = 45 kW = 45000 W.

$P = T\omega$

So: $T = \dfrac{45{,}000}{1000 \times \frac{2\pi}{60}} = 429.7\ \text{Nm}$

Force applied Tangentially $= \dfrac{T}{r}$ → of shaft : Assumption = 0.03 m (30mm radius).

$F_t = 28.646\ \text{kN}$

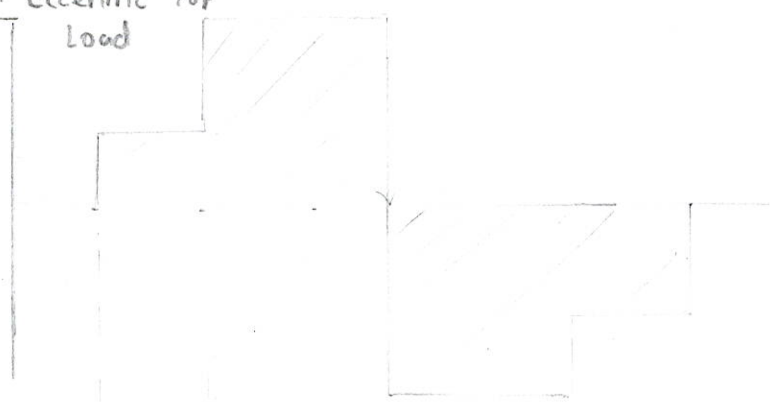
Forces Radially $= F_t \tan(\phi)$
$= 28.8 \tan(20)$

∴ $F_r = 10.41\ \text{kN}$

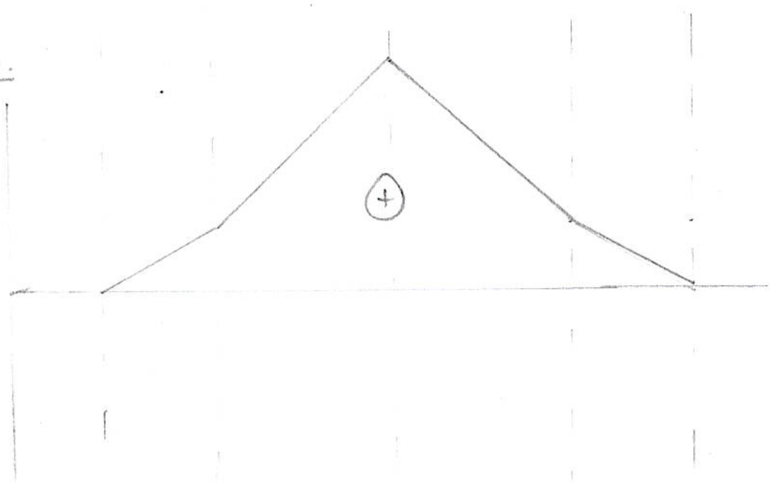
$F_{g_{total}} = \sqrt{(10.41)^2 + (28.46)^2}$

$F_{g_{total}} = 30.34\ \text{kN}$

S.F. Diagram : Eccentric Top Load



BM - Diagram.



# Appendix C.2

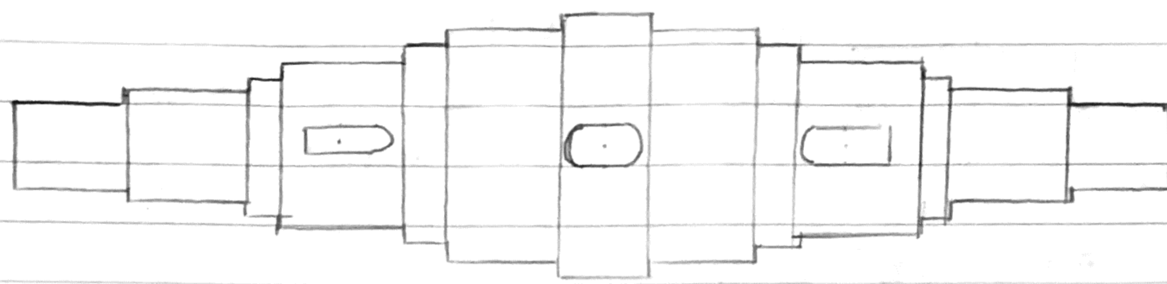
**Secondary Drive Shaft Load Calculations**

# DFM Assignment

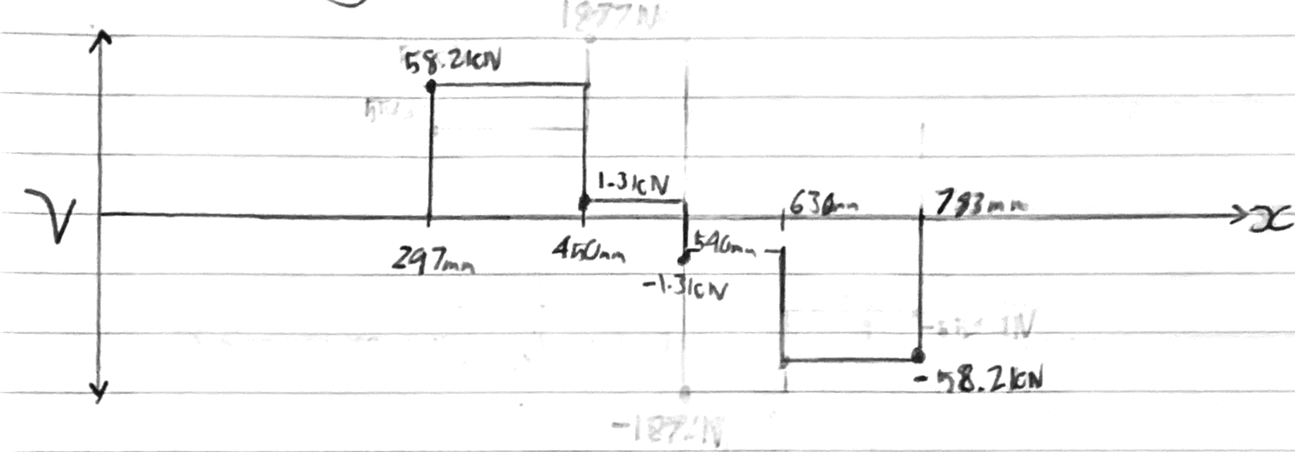
4/8/2022

## Drive Shaft

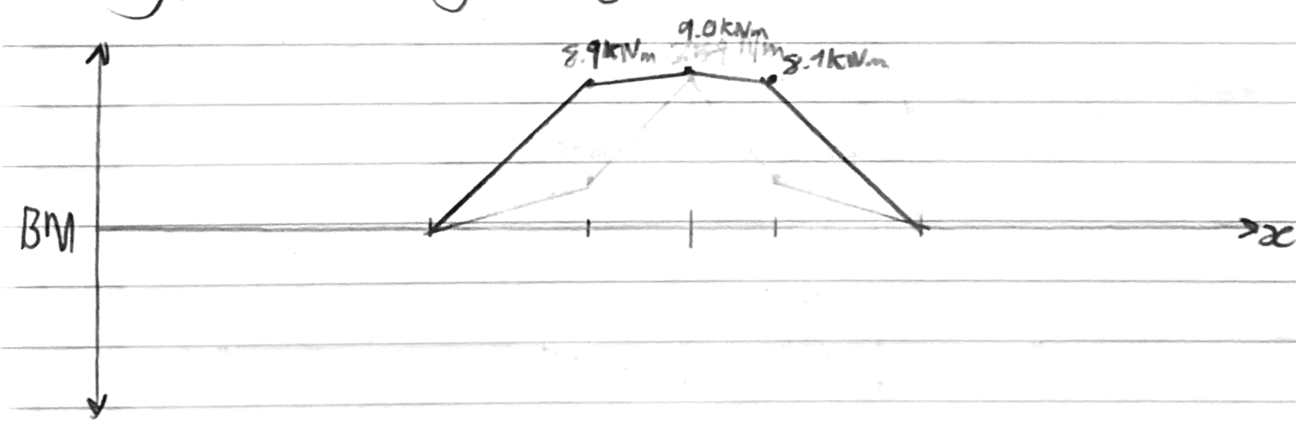
1cm = 69.09mm



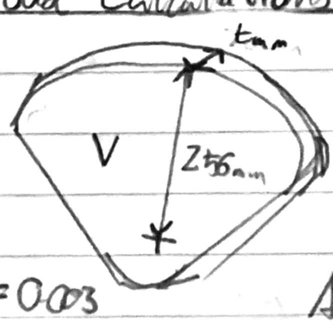
## Shear Force Diagram (weights top)

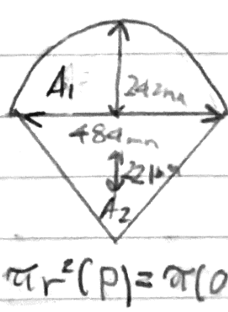



## Bending Moment Diagram (weights top)




## Load Calculations




Large Mass $= V_L(\rho) = (0.0097)(7900) = 76.6$ kg

Small Mass $= V_s(\rho) = (0.003)(7900) = 23.8$ kg

$\therefore$ Total Contributing mass $= 52.8$ kg @ $r = 100$mm

$F_c = m\omega^2 r = 52.8(105)^2(0.1) = \underline{58,212N}$

$V_s = 0.003$

$V_L = (A_1 + A_2)t$

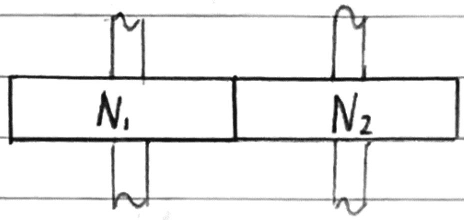
$V_L = 0.0097m^2$

$A_1 = \pi r^2(\rho) = \pi(0.242)^2(0.4) = 0.074$

$A_2 = \frac{BH}{2} = \frac{0.484(0.221)}{2} = 0.053m^2$

4/8/2022

## Gear Loads




$N_1 = N_2 \therefore GR = 1$

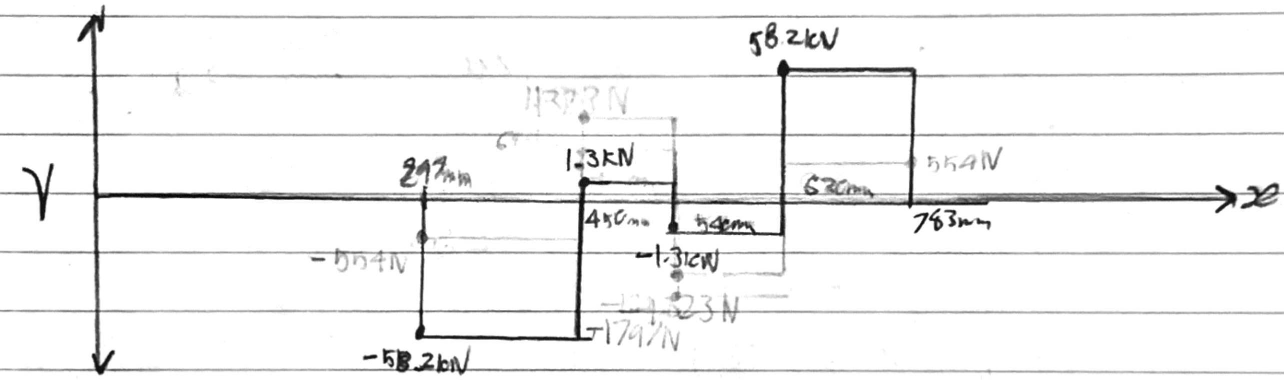
Input torque $= \frac{P}{\omega} = \frac{45 \times 10^3}{1000(\frac{2\pi}{60})} = 430\,Nm$

$F_{gT} = \tau / r = 430/(0.173) = 2486\,N$

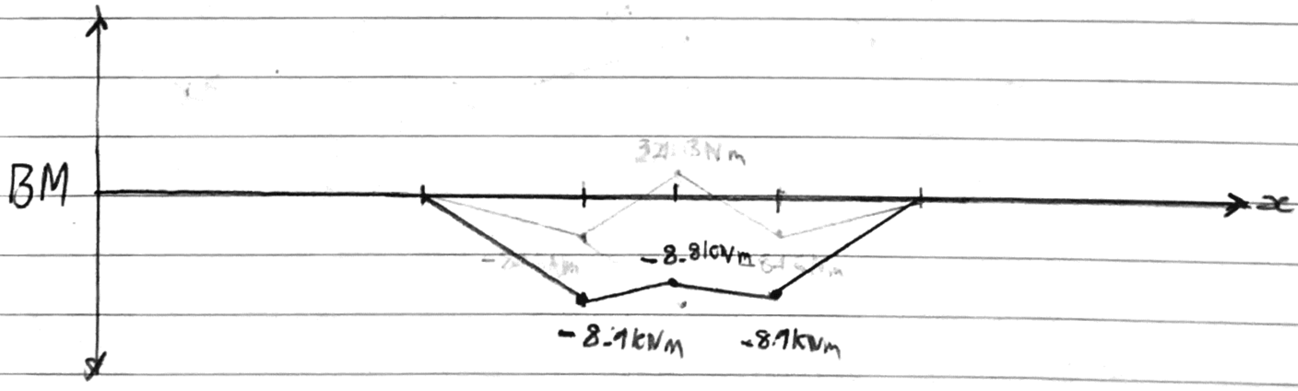
$F_{gR} = F_{gT} \tan(\phi) = 2486 \tan(20) = 905\,N$ where $\phi$ = Pressure angle (assuming $20^\circ$)

$F_{gTotal} = \sqrt{F_{gT}^2 + F_{gR}^2} = 2646\,N$

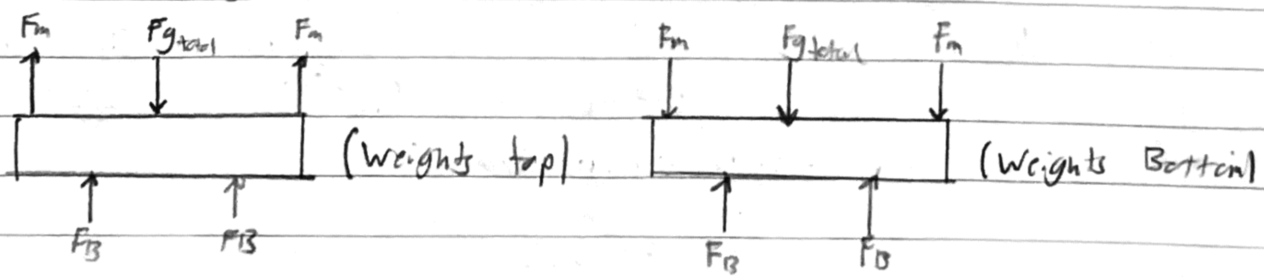
## Shear Force Diagram (weights Bottom)




## Bending Moment Diagram (weights Bottom




## Force Positions



# Appendix C.3

**Initial Drive Shaft Minimum Diameter Calculations**

# DFM Assignment

8/8/2022

## Minimum Shaft diameter

Shear Stress: $D = \sqrt{2.94 K_t (V)\left(\frac{FOS}{S_n}\right)}$

Bending Moment: $D = \left(\frac{32(FOS)}{\pi}\sqrt{\left(\frac{K_t M}{S_n}\right)^2 + \frac{3}{4}\left(\frac{T}{S_y}\right)^2}\right)^{1/3}$

$S_n = S_n'(C_L)(C_D)(C_S)$

$S_n' = 0.5(S_u)$

Assuming Steel Alloy 4140

$S_y = 655 MPa$

$S_u = 1020 MPa$

$FOS = 2$

Point of interest: Gear Saddles

$D = \sim 133mm$ $D/d = 1.08$

$d = \sim 123mm$ $r/d = 0.02$

$r = 3mm$ Assumption $\therefore K_{ts} = 2.4$

Min diameter for Bending moment:

$D_M = \left(\frac{32(2)}{\pi}\sqrt{\left(\frac{1.6(9\times10^3)}{321.3\times10^6}\right)^2 + \frac{3}{4}\left(\frac{430}{655\times10^6}\right)^2}\right)^{1/3}$

$S_n = \frac{1020}{2}(1)(0.9)(0.7) = 321.3 MPa$

$M = 9kNm$

$= 111.2mm$

Min diameter for Shear Stress:

$D_V = \sqrt{2.94(1.9)(58.2\times10^3)\left(\frac{2}{321.3}\right)}$

$= 44mm$

Point of interest: Ecentric mass shoulders

$D = \sim 85.5mm$ $D/d = 1.125$

$d = \sim 76mm$ $r/d = 0.04$

$r = 3mm$ Assumption $K_t = 1.9$

$S_n = 321.3 MPa$

$V = 58.2kN$

# Appendix C.4

**Revised Factor of Safety of Drive Shaft Minimum Diameter Calculations**

# Revised Factor of Safety - Alloy Steel shaft.

Original FoS = 2.

Revised FoS = 1.5.

## Shear stress

$$D = \sqrt{2.94\, k_t\, V \cdot \left(\frac{FoS}{S_n}\right)}$$

$$= \left[2.94 \times 1.9 \times (58.2 \times 10^3) \times \left[\frac{1.5}{321.3 \times 10^6}\right]\right]^{1/2}.$$

$\therefore D = 38.9\ mm \sim 39\ mm.$

## Bending stress:

$$D = \left[\frac{32\,(FoS)}{\pi} \sqrt{\left(\frac{k_t \cdot M_{cr}}{S_n}\right)^2 + \frac{3}{4}\left(\frac{T}{S_y}\right)^2}\,\right]^{1/3}$$

$$= \left[\frac{32\,(1.5)}{\pi} \sqrt{\left(\frac{1.9 \times 9 \times 10^3}{321.3 \times 10^6}\right)^2 + \frac{3}{4}\left(\frac{430}{655 \times 10^6}\right)^2}\,\right]^{1/3}$$

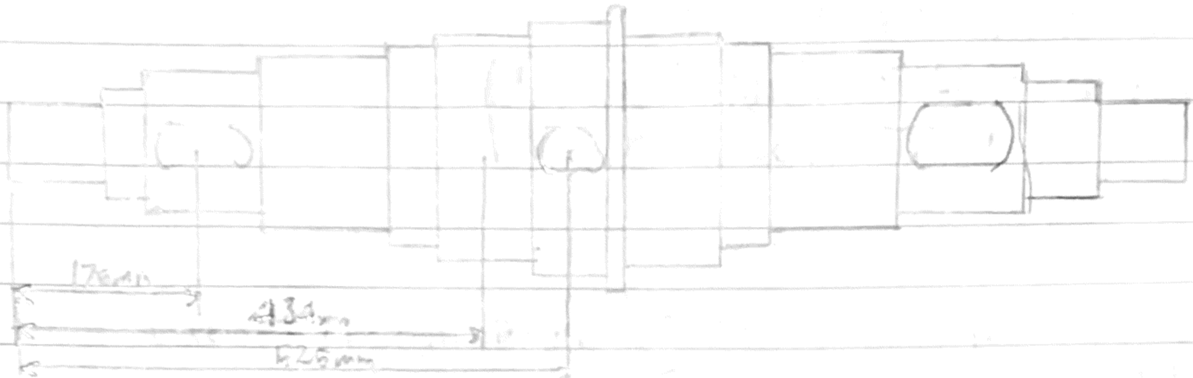
$\therefore D_{BM} = 93.3\ mm.$

# Appendix C.5

**Worst Case Drive Shaft Minimum Diameter Calculations**

19/8/2022

## Counter Shaft




## Shaft Forces

Eccentric Mass: $m\omega^2 r$

$m = M_L + m_s = \sim 100$ kg (Previous Calcs)

$\omega = 1000$ rpm $= 105$ rads$^{-1}$ (Based on Scheme Max speed)

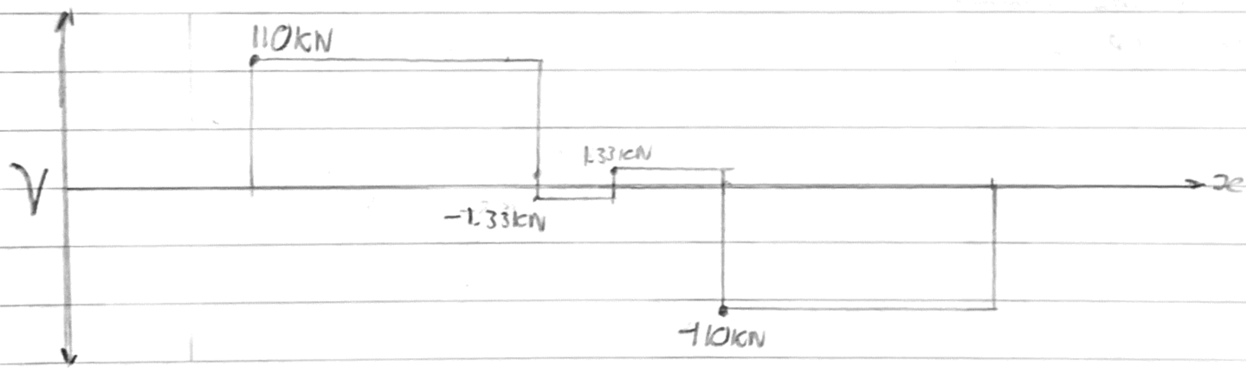
$r = 100$mm (Estimation)

$F_E = 100(105)^2(0.1) = \underline{110.3\text{ kN}}$

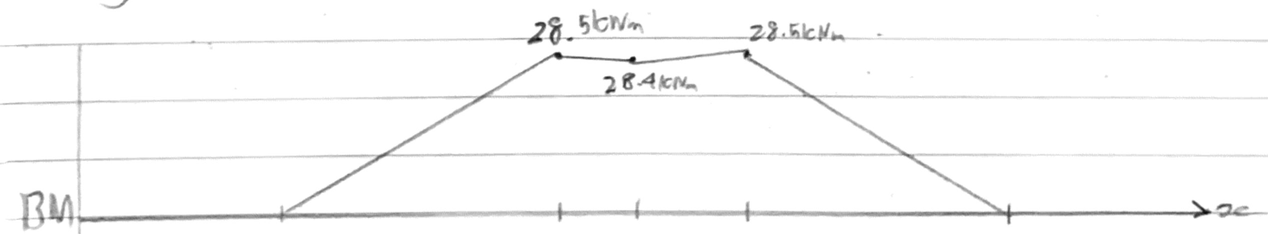
Gear Force:

$F_G = \underline{2.65\text{ kN}}$ (Previous Calcs)

## Shear Force




## Bending Moment



## Shaft Min diameter

Shear Stress: $D_{min} = \sqrt{2.94 K_t (V) \left(\frac{FOS}{S_n}\right)}$

Bending Moment: $D_{min} = \left( \frac{32(FOS)}{\pi} \sqrt{\left(\frac{K_t M}{S_n}\right)^2 + \frac{3}{4}\left(\frac{T}{S_y}\right)^2} \right)^{1/3}$

Shear Stress:

$K_t = 1.9$ (Previous Calcs)

$V = 110\ kN$ (Force diagram)

$FOS = 1.5$ (Chosen)

$S_n = 321.3\ MPa$ (Previous Calcs)

$D_{min} = \sqrt{2.94(1.9)(110 \times 10^3)\left(\frac{1.5}{321.3 \times 10^6}\right)}$

$= 53.6\ mm$

Bending Moment:

$FOS = 1.5$ (Chosen)

$K_t = 1.9$ (Previous Calcs)

$M = 28.5\ kNm$ (Force diagram)

$S_n = 321.3\ MPa$ (Previous Calcs)

$T = 430\ Nm$ (Motor Power)

$S_y = 655\ MPa$ (Previous Calcs)

$D_{min} = \left( \frac{32(1.5)}{\pi} \sqrt{\left(\frac{(1.9)(28.5 \times 10^3)}{321.3 \times 10^6}\right)^2 + \frac{3}{4}\left(\frac{430}{655 \times 10^6}\right)^2} \right)^{1/3}$

$= 137\ mm$

# Appendix C.6

**Initial Drive Shaft Minimum Diameter Iterative Fillet Radius Calculations**

## Varying Fillet Radius for Reducing Kt

| Shear Stress | | | | | | |
|---|---|---|---|---|---|---|
| Radius (mm) | FOS | $K_t$ | V (N) | Constant | $S_n$ (Pa) | Minimum Diameter (mm) |
| 3 | 1.5 | 1.91 | 110000 | 2.94 | 321300000 | 53.70 |
| 5 | 1.5 | 1.35 | 110000 | 2.94 | 321300000 | 45.15 |
| 7 | 1.5 | 1.28 | 110000 | 2.94 | 321300000 | 43.96 |
| 9 | 1.5 | 1.2 | 110000 | 2.94 | 321300000 | 42.56 |

| Bending Stress | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Radius (mm) | FOS | Pi | $K_t$ | M (Nm) | $S_n$ (Pa) | T (Nm) | $S_y$ (Pa) | Minimum Diameter (mm) |
| 3 | 2 | 3.142 | 1.91 | 28500 | 321300000 | 430 | 655000000 | 151.12 |
| 5 | 1.5 | 3.142 | 1.79 | 28500 | 321300000 | 430 | 655000000 | 134.37 |
| 7 | 1.5 | 3.142 | 1.65 | 28500 | 321300000 | 430 | 655000000 | 130.77 |
| 9 | 1.5 | 3.142 | 1.58 | 28500 | 321300000 | 430 | 655000000 | 128.89 |

## Safety Factor of 1.3 with Varying Fillet Radius

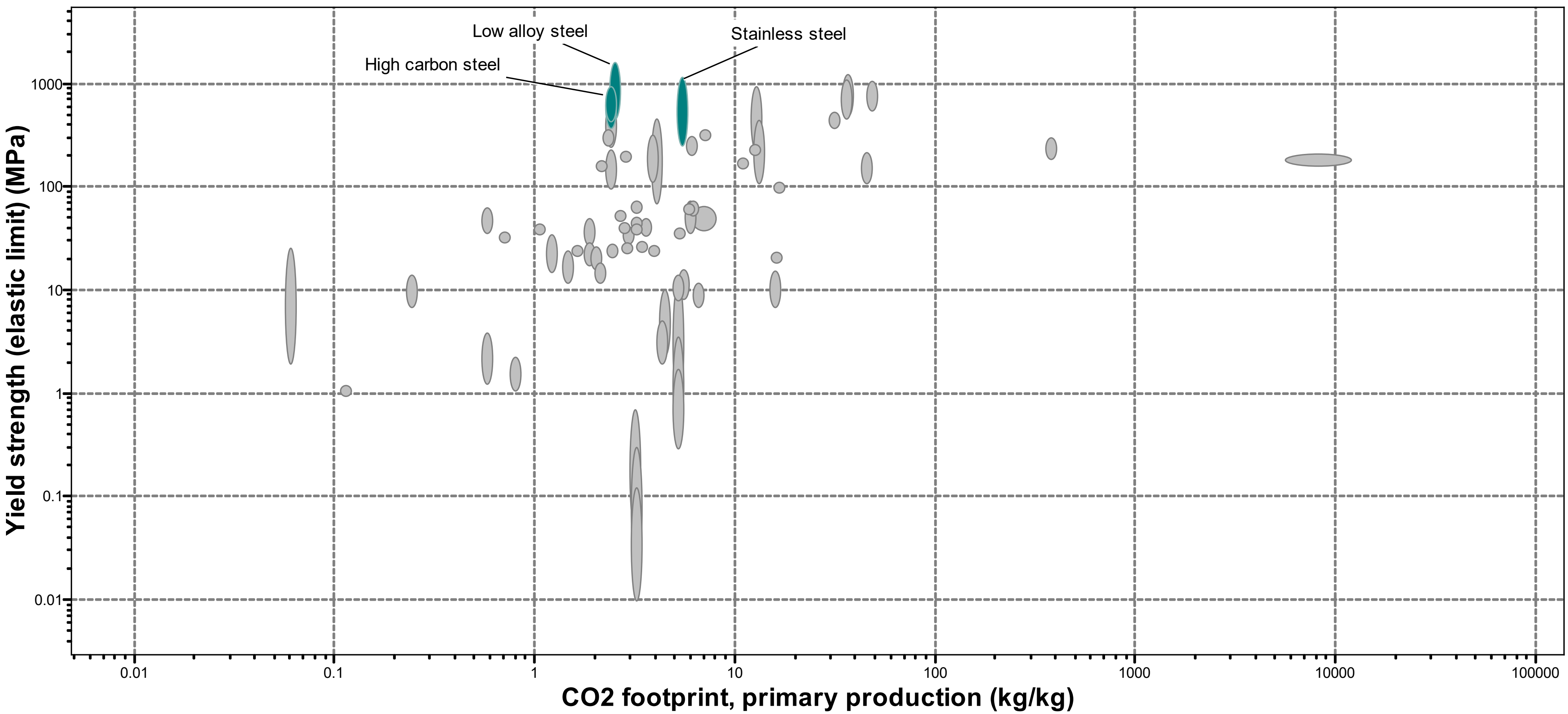
| Shear Stress | | | | | | |
|---|---|---|---|---|---|---|
| Radius (mm) | FOS | $K_t$ | V (N) | Constant | $S_n$ (Pa) | Minimum Diameter (mm) |
| 3 | 1.3 | 1.91 | 110000 | 2.94 | 321300000 | 49.99 |
| 5 | 1.3 | 1.35 | 110000 | 2.94 | 321300000 | 42.03 |
| 7 | 1.3 | 1.28 | 110000 | 2.94 | 321300000 | 40.93 |
| 9 | 1.3 | 1.2 | 110000 | 2.94 | 321300000 | 39.63 |

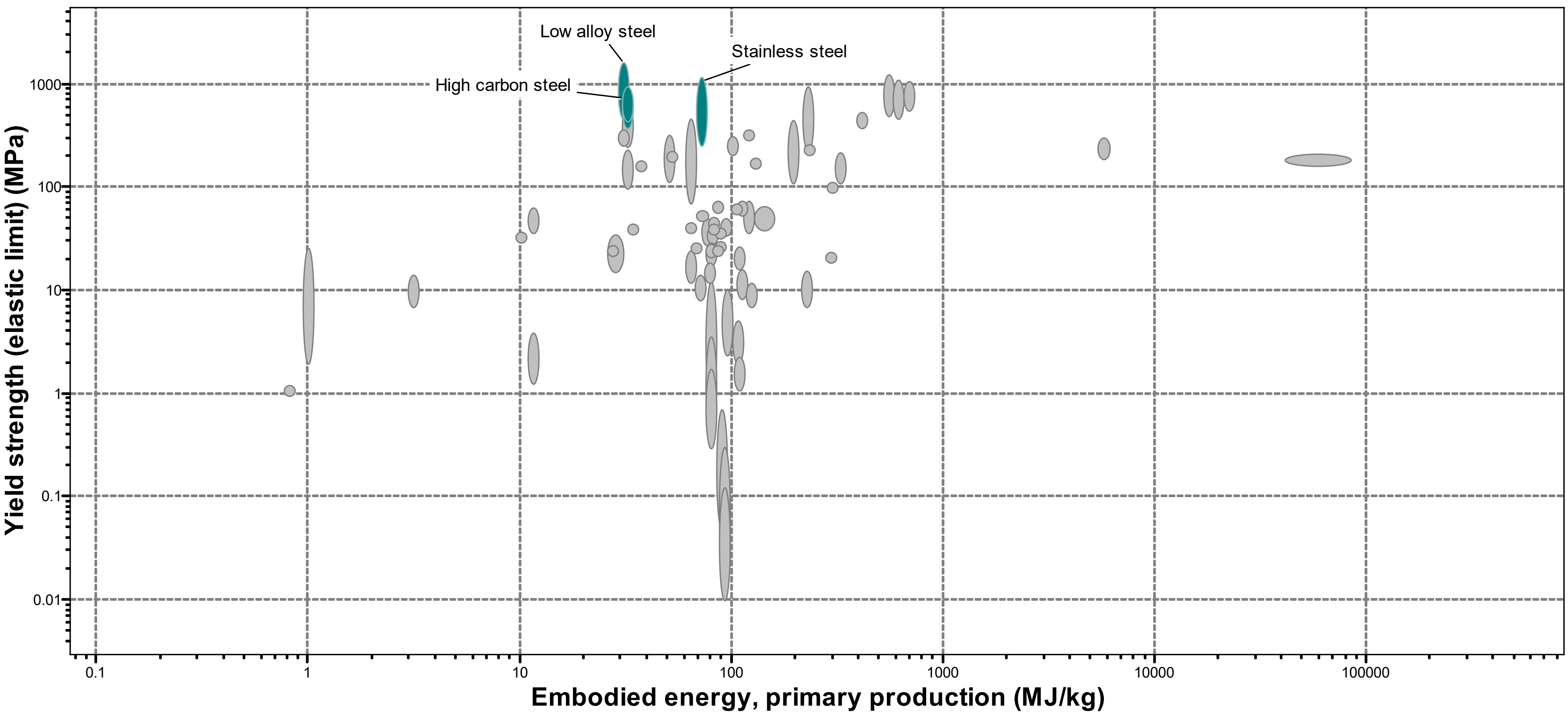
| Bending Stress |
|---|

| Radius (mm) | FOS | Pi | $K_t$ | M (Nm) | $S_n$ (Pa) | T (Nm) | $S_y$ (Pa) | Minimum Diameter (mm) |
|---|---|---|---|---|---|---|---|---|
| 3 | 1.3 | 3.142 | 1.91 | 28500 | 321300000 | 430 | 655000000 | 130.91 |
| 5 | 1.3 | 3.142 | 1.79 | 28500 | 321300000 | 430 | 655000000 | 128.11 |
| 7 | 1.3 | 3.142 | 1.65 | 28500 | 321300000 | 430 | 655000000 | 124.68 |
| 9 | 1.3 | 3.142 | 1.58 | 28500 | 321300000 | 430 | 655000000 | 122.89 |

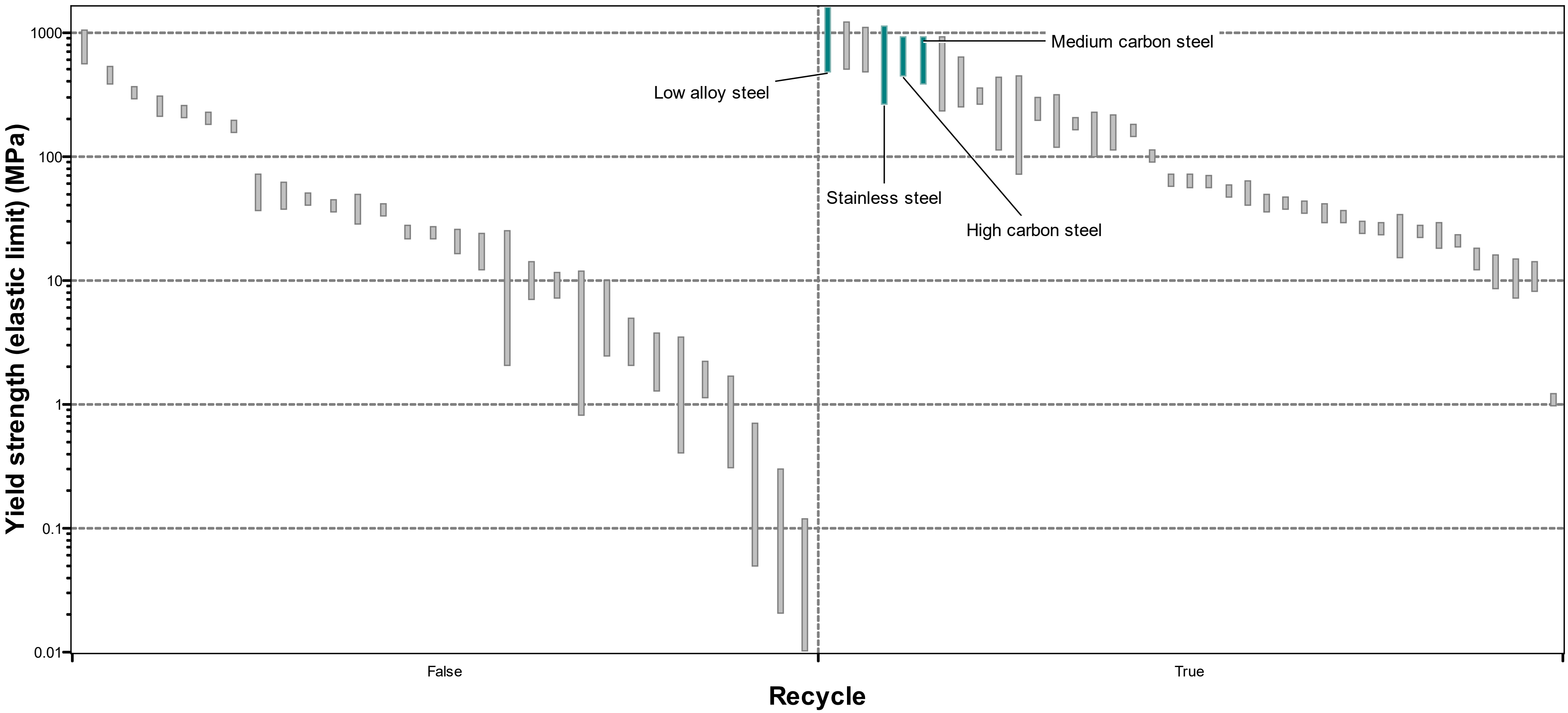
# Appendix D

## Ashby Charts for Selecting Drive Shaft Material

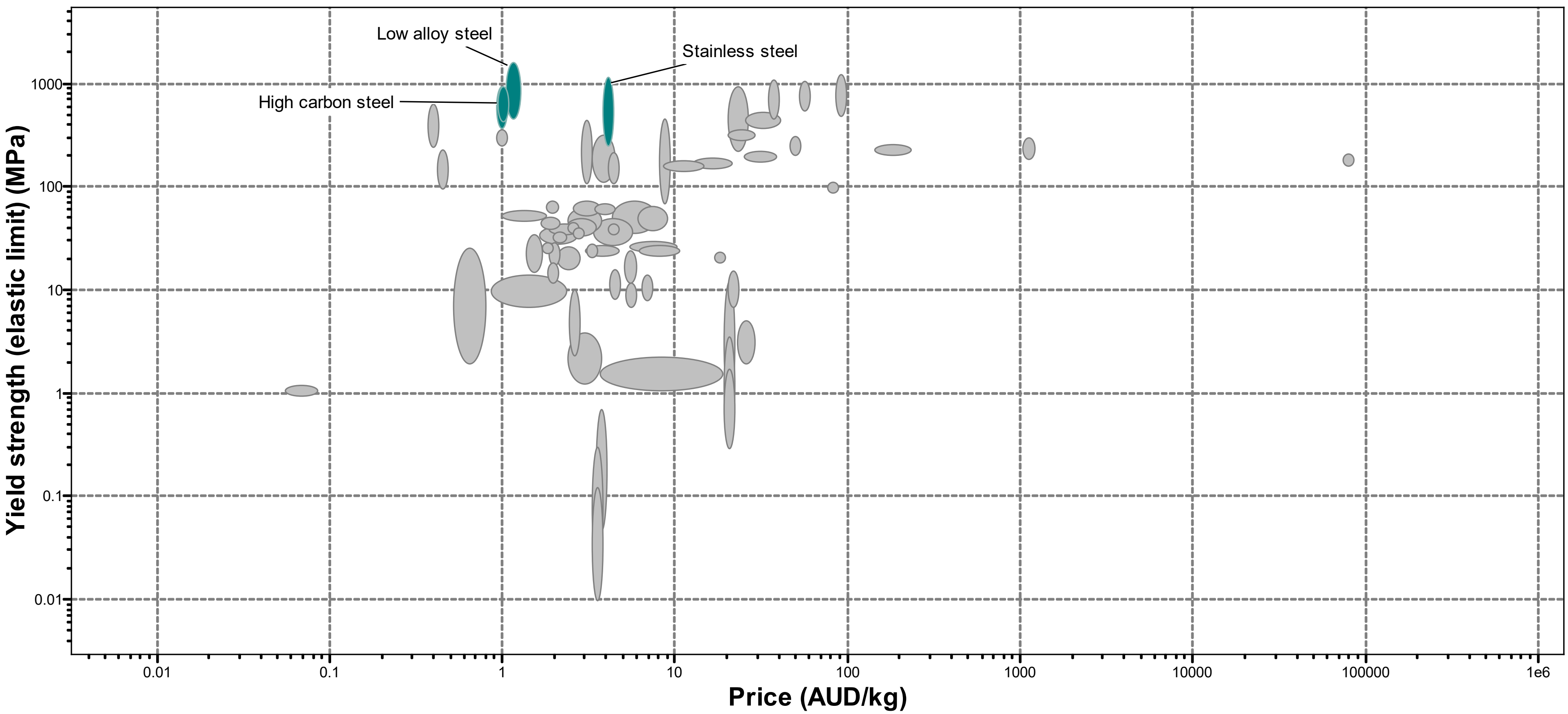




Low alloy steel
Stainless steel
High carbon steel
1000
100
10
1
0.1
0.01
Yield strength (elastic limit) (MPa)
0.1
1
10
100
1000
10000
100000
Embodied energy, primary production (MJ/kg)



Yield strength (elastic limit) (MPa)
1000
100
10
1
0.1
0.01
Medium carbon steel
Low alloy steel
Stainless steel
High carbon steel
False
True
Recycle



Low alloy steel
Stainless steel
High carbon steel
1000
100
10
1
0.1
0.01
0.01
0.1
1
10
100
1000
10000
100000
1e6
Yield strength (elastic limit) (MPa)
Price (AUD/kg)

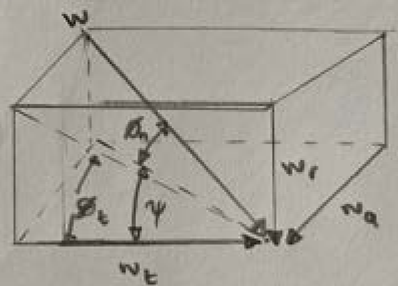
# Appendix E
## Helical Gear Force Calculations

Radial Load:

$$W_r = W_t \tan \phi_t$$

$$= 351.91 \times \tan(21.17)$$

$$\therefore W_r = 136.28 \text{ N}$$




Axial Load.

$$W_a = W_t \cdot \tan \psi$$

$$= 351.91 \tan(20)$$

$$\therefore W_a = 128.08 \text{ N}$$

Total Normal force on tooth:

$$W = \frac{W_t}{\cos\phi \cdot \cos\psi}$$

$$= \frac{351.91}{\cos(20)\cos(20)}$$

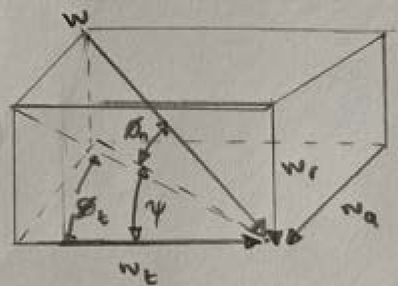
$$\therefore W = 398.53 \text{ N}.$$

Radial Load:

$$W_r = W_t \tan \phi_t$$

$$= 351.91 \times \tan(21.17)$$

$$\therefore W_r = 136.28\ N$$




Axial Load.

$$W_a = W_t \cdot \tan \psi$$

$$= 351.91 \tan(20)$$

$$\therefore W_a = 128.08\ N$$

Total Normal force on tooth:

$$W = \frac{W_t}{\cos\phi \cdot \cos\psi}$$

$$= \frac{351.91}{\cos(20)\cos(20)}$$

$$\therefore W = 398.53\ N.$$

# Appendix F

**Bearing Calculations and Life Analysis**

# Bearing Selection Analysis

$L = 1000(60)(24)(365) = 5.26\times10^8$ revolutions per year

$L_4 = 21.04\times10^8$ revolutions

$F_R = 260\ kN = F_e$ due to small thrust loads

| $F_e$ | $k_a$ | $k_r$ | $L_R$ | |
|---|---|---|---|---|
| 260kN | 2 | 0.3 | $90\times10^6$ | (Estimated from Catalogue and previous cases) |

$$C_1 = 260\times10^3(2)\left(\frac{5.26\times10^8}{0.3(90\times10^6)}\right)^{0.3} = 1,267\ kN \quad 90\% \text{ reliability for 1 year}$$

$$C_4 = 260\times10^3(2)\left(\frac{21.04\times10^8}{0.3(90\times10^6)}\right)^{0.3} = 1,921\ kN \quad 90\% \text{ reliability for 4 years}$$

## Bearing Load Calcs (Draft)

Notes:

Dynamic Load Rating from SKF 22328 CC/W33. $= 1357 \times 10^3$ N.

Radial Load acting on bearings = 110kN (from eccentric mass, max).

Considerations:

- Heavy impact
  - Application factor → 1.5 - 2.0 (either one).
    (2.0 → for spherical roller.)
- Equivalent radial load: $F_e = F_r$.
- 98% reliability

Basic Dynamic Load Required:

$$C_{req} = F_e k_A \left(\frac{L}{k_e L_e}\right)^{0.3}$$ → $F_e = F_r$; $k_A$ = application factor;

L = Bearing Life corresponding to $F_r$ or required life.

Assumptions: Bearings required for machine service of 1 year, i.e., 8760 hrs

$$C_{req} = 110 \times 10^3 \times 2 \left[\frac{8760 \times 1000 \times 60}{0.21 \times (90 \times 10^6)}\right]^{0.3}.$$

∴ $C_{req}$ = 596.6 kN (for 1 year straight).

For 6 months: $C_{req}$ = 484.6 kN.

Note: vibration can cause factor of 3 increase in required static/dynamic load values.

SKF: d = 140 mm; model/part # = 29428 E

C = 1630 kN; $C_0$ = 4300 kN.

# Appendix G
**Fits and Tolerance Calculations**

| | |
|---|---|
| **Tolerances**<br><br>For additional information<br>→ Tolerances | Normal<br>P5 run-out on request (designation suffix C08)<br><br>Except for:<br>• **Bearings with d ≤ 300 mm:**<br>  ○ width tolerance at least 50% tighter than ISO standard (table 1)<br>  ○ P5 run-out<br>• **Bearings for vibratory applications:**<br>  ○ P5 bore diameter<br>  ○ P6 outside diameter<br>• **Bearings for continuous caster applications:**<br>  ○ Normal |

## Adj. Eccentric Masses - updated.

OD Bush = 180mm ; ID ecc. mass = 182.2mm.

H7 / k6 → transitional fit.

**hole:** $\Delta D = 0.040mm$.

$D_{min} = 180mm$;

$D_{max} = D + \Delta D$

$\therefore D_{max} = 180.040mm$.

**Shaft:**

$\Delta d = 0.025mm$.

$\delta_F = +0.003mm$.

$d_{min} = d + \delta_F$

$= 180.0 + 0.003mm$

$\therefore d_{min} = 180.003mm$

$d_{max} = d + \Delta d + \delta_F$.

$= 180.03 + 0.025$

$\therefore d_{max} = 180.055mm$.

## Bearing Tolerances

OD of Shaft = 170 mm.

SKF fit recommendation: H7 / p6, for bore < 300 mm.

Thus, interference → local interference fit.

**Hole:**

$D_{min} = 170\,mm$

$\Delta D = 0.040\,mm$

$\therefore D_{max} = \underline{\underline{170.040\,mm}}$.

**Shaft:**

$\Delta d = 0.025\,mm$.

$\delta_F = +0.043\,mm$.

$d_{max} = d + \delta_F + \Delta d$

$= 170 + 0.025 + 0.043$

$\therefore d_{max} = \underline{\underline{170.068\,mm}}$.

| Type of fit | Description | Symbol |
|---|---|---|
| Clearance | *Loose running fit:* for wide commercial tolerances or allowances on external members | H11 / c11 |
| | *Free running fit:* not for use where accuracy is essential, but good for large temperature variations, high running speeds, or heavy journal pressures | H9 / d9 |
| | *Close running fit:* for running an accurate machines and for accurate location at moderate speeds and journal pressures | H8 / f7 |
| | *Sliding fit:* where parts are not intended to run freely, but must move and turn freely and locate accurately | H7 / g6 |
| | *Locational clearance fit:* provides snug fit for location of stationary parts, but can be freely assembled and disassembled. | H7 / h6 |
| Transition | *Locational transition fit* for accurate location, a compromise between clearance and interference | H7 / k6 |
| | *Locational transition fit* for more accurate location where greater interference is permissible | H7 / n6 |
| Interference | *Locational interference fit:* for parts requiring rigidity and alignment with prime accuracy of location but without special bore pressure requirements | H7 / p6 |
| | *Medium drive fit:* for ordinary steel parts or shrink fits on light sections, the tightest fit usable with cast iron | H7 / s6 |
| | *Force fit:* suitable for parts that can be highly stressed or for shrink fits where the heavy pressure forces required are impractical. | H7 / u6 |

***Source:***
*Shigley's Mechanical Engineering Design by Richard G. Budynas and J. Keith Nisbett (2008), McGraw Hill.*

| Basic Sizes | Upper-Deviation Letter | | | | Lower-Deviation Letter | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | c | D | f | g | h | k | n | p | s | u |
| 0 – 3 | -0.060 | -0.020 | -0.006 | -0.002 | 0 | 0 | +0.004 | +0.006 | +0.014 | +0.018 |
| 3 – 6 | -0.070 | -0.030 | -0.010 | -0.004 | 0 | +0.001 | +0.008 | +0.012 | +0.019 | +0.023 |
| 6 – 10 | -0.080 | -0.040 | -0.013 | -0.005 | 0 | +0.001 | +0.010 | +0.015 | +0.023 | +0.028 |
| 10 – 14 | -0.095 | -0.050 | -0.016 | -0.006 | 0 | +0.001 | +0.012 | +0.018 | +0.028 | +0.033 |
| 14 – 18 | -0.095 | -0.050 | -0.016 | -0.006 | 0 | +0.001 | +0.012 | +0.018 | +0.028 | +0.033 |
| 18 – 24 | -0.110 | -0.065 | -0.020 | -0.007 | 0 | +0.002 | +0.015 | +0.022 | +0.035 | +0.041 |
| 24 – 30 | -0.110 | -0.065 | -0.020 | -0.007 | 0 | +0.002 | +0.015 | +0.022 | +0.035 | +0.048 |
| 30 – 40 | -0.120 | -0.080 | -0.025 | -0.009 | 0 | +0.002 | +0.017 | +0.026 | +0.043 | +0.060 |
| 40 – 50 | -0.130 | -0.080 | -0.025 | -0.009 | 0 | +0.002 | +0.017 | +0.026 | +0.043 | +0.070 |
| 50 – 65 | -0.140 | -0.100 | -0.030 | -0.010 | 0 | +0.002 | +0.020 | +0.032 | +0.053 | +0.087 |
| 65 – 80 | -0.150 | -0.100 | -0.030 | -0.010 | 0 | +0.002 | +0.020 | +0.032 | +0.059 | +0.102 |
| 80 – 100 | -0.170 | -0.120 | -0.036 | -0.012 | 0 | +0.003 | +0.023 | +0.037 | +0.071 | +0.124 |
| 100 – 120 | -0.180 | -0.120 | -0.036 | -0.012 | 0 | +0.003 | +0.023 | +0.037 | +0.079 | +0.144 |
| 120 – 140 | -0.200 | -0.145 | -0.043 | -0.014 | 0 | +0.003 | +0.027 | +0.043 | +0.092 | +0.170 |
| 140 – 160 | -0.210 | -0.145 | -0.043 | -0.014 | 0 | +0.003 | +0.027 | +0.043 | +0.100 | +0.190 |
| 160 – 180 | -0.230 | -0.145 | -0.043 | -0.014 | 0 | +0.003 | +0.027 | +0.043 | +0.108 | +0.210 |
| 180 – 200 | -0.240 | -0.170 | -0.050 | -0.015 | 0 | +0.004 | +0.031 | +0.050 | +0.122 | +0.236 |
| 200 – 225 | -0.260 | -0.170 | -0.050 | -0.015 | 0 | +0.004 | +0.031 | +0.050 | +0.130 | +0.258 |
| 225 – 250 | -0.280 | -0.170 | -0.050 | -0.015 | 0 | +0.004 | +0.031 | +0.050 | +0.140 | +0.284 |
| 250 – 280 | -0.300 | -0.190 | -0.056 | -0.017 | 0 | +0.004 | +0.034 | +0.056 | +0.158 | +0.315 |
| 280 – 315 | -0.330 | -0.190 | -0.056 | -0.017 | 0 | +0.004 | +0.034 | +0.056 | +0.170 | +0.350 |
| 315 – 355 | -0.360 | -0.210 | -0.062 | -0.018 | 0 | +0.004 | +0.037 | +0.062 | +0.190 | +0.390 |
| 355 – 400 | -0.400 | -0.210 | -0.062 | -0.018 | 0 | +0.004 | +0.037 | +0.062 | +0.208 | +0.435 |

*NOTE: Size ranges are over the lower limit and including the upper limit.*

***Source:***
*Shigley's Mechanical Engineering Design by Richard G. Budynas and J. Keith Nisbett (2008), McGraw Hill.*

| Basic Sizes | Tolerance Grades | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | IT6 | IT7 | IT8 | IT9 | IT10 | IT11 |
| 0 – 3 | 0.006 | 0.010 | 0.014 | 0.025 | 0.040 | 0.060 |
| 3 – 6 | 0.008 | 0.012 | 0.018 | 0.030 | 0.048 | 0.075 |
| 6 – 10 | 0.009 | 0.015 | 0.022 | 0.036 | 0.058 | 0.090 |
| 10 – 18 | 0.011 | 0.018 | 0.027 | 0.043 | 0.070 | 0.110 |
| 18 – 30 | 0.013 | 0.021 | 0.033 | 0.052 | 0.084 | 0.130 |
| 30 – 50 | 0.016 | 0.025 | 0.039 | 0.062 | 0.100 | 0.160 |
| 50 – 80 | 0.019 | 0.030 | 0.046 | 0.074 | 0.120 | 0.190 |
| 80 – 120 | 0.022 | 0.035 | 0.054 | 0.087 | 0.140 | 0.220 |
| 120 – 180 | 0.025 | 0.040 | 0.063 | 0.100 | 0.160 | 0.250 |
| 180 – 250 | 0.029 | 0.046 | 0.072 | 0.115 | 0.185 | 0.290 |
| 250 – 315 | 0.032 | 0.052 | 0.081 | 0.130 | 0.210 | 0.320 |
| 315 – 400 | 0.036 | 0.057 | 0.089 | 0.140 | 0.230 | 0.360 |

*NOTE: Size ranges are over the lower limit and including the upper limit.*

***Source:***
*Shigley's Mechanical Engineering Design by Richard G. Budynas and J. Keith Nisbett (2008), McGraw Hill.*

## mechanical tolerances:

**Drive shaft:**

OD = 150mm

**Fixed Eccentric Mass:**

OD = 150mm.

{ both from Solidworks drawings }

**Recommended fit:** Tightest possible (Marcin)

H7 / u6 = force fit.

150 H7 / 150 u6

**For hole fitting:**

$\Delta D = 0.040mm$

$D_{max} = D + \Delta D$

$= 150.040mm.$

**Shaft:**

$\Delta d = 0.025mm$

$d_{min} = \Delta d + \delta_F$

$\delta_F = 0.19mm.$

$\therefore d_{min} = 150.19mm.$

$d_{max} = d + \Delta d + \delta_F.$

$\Delta d = 0.085mm.$

$\therefore d_{max} = 150.215mm.$

## Adj. Ecc. Mass:

- fitted to bush

OD Bush = 180mm ; ID E·mass = ~~180mm~~ 182·2mm. (drawings)

H7/p6 chosen for lesser force fit for adjustment of output load.

**hole:**

~~$D_{min}$~~

$D_{max} = D + \Delta D$

$\Delta D = 0.040$ mm

$\therefore D_{max} = 180.040$ mm.

**Shaft (bush)**

$\Delta d = 0.025$ mm

$\delta_F = 0.043$ mm

$d_{min} = d + \delta_F = 180.043$ mm.

$d_{max} = d + \delta_F + \Delta d$

$\therefore d_{max} = 180.068$ mm.

## Gears to Shaft (s):

- force fit → H7/u6.

Gear ID = 180mm; Shaft OD = 180mm (drawings)

180H7/180u6.

**Hole:** $\Delta D = 0.040$ mm

$D_{max} = D + \Delta D$

$\therefore D_{max} = 180.040$ mm.

**Shaft:** $\Delta d = 0.025$ mm.

$d_{min} = d + \delta_F$

$\delta_F = 0.210$ mm.

$d_{min} = 180.210$ mm.

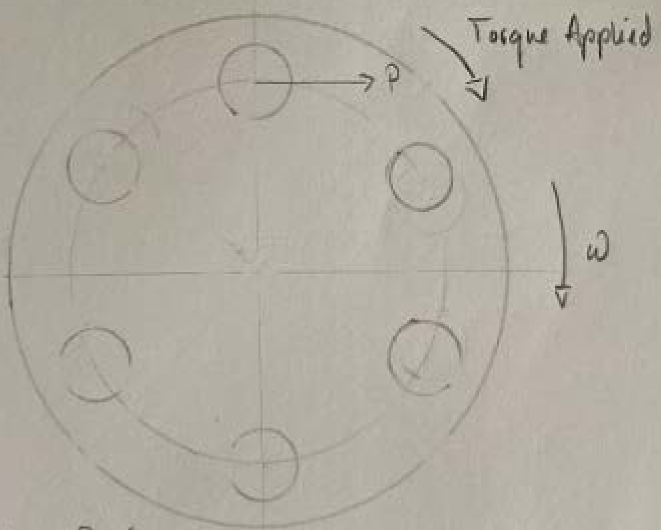
$d_{max} = 180 + 0.210 + 0.025$

$\therefore d_{max} = 180.235$ mm.

# Appendix H

**Drive Adapter Bolt Calculations**

| SAE Class | Diameter $d$ (mm) | Proof Load (Strength)[a] $S_p$ (MPa) | Yield Strength[b] $S_y$ (MPa) | Tensile Strength $S_u$ (MPa) | Elongation, Minimum (%) | Reduction of Area, Minimum (%) | Core Hardness, Rockwell Min | Core Hardness, Rockwell Max |
|---|---|---|---|---|---|---|---|---|
| 4.6 | 5 thru 36 | 225 | 240 | 400 | 22 | 35 | B67 | B87 |
| 4.8 | 1.6 thru 16 | 310 | — | 420 | — | — | B71 | B87 |
| 5.8 | 5 thru 24 | 380 | — | 520 | — | — | B82 | B95 |
| 8.8 | 17 thru 36 | 600 | 660 | 830 | 12 | 35 | C23 | C34 |
| 9.8 | 1.6 thru 16 | 650 | — | 900 | — | — | C27 | C36 |
| 10.9 | 6 thru 36 | 830 | 940 | 1040 | 9 | 35 | C33 | C39 |
| 12.9 | 1.6 thru 36 | 970 | 1100 | 1220 | 8 | 35 | C38 | C44 |




Assumptions: · Shear force P is uniformly distributed by all bolts

· Torque capacity of bolts: $T = P \cdot R \cdot n$ — (1)

· PCD = 190mm; ∴ R = 80mm.

· No. of bolts = 6

· Diameter of bolts = 16mm.

· UTS of 16mm ⌀ ⇒ $S_u$ = 830 mPa. (8.8)

· $P_{shear} \approx$ 60% of UTS, 830 × 0.6 = 498 mPa.

From eq. (1), $P = \tau A_s$ → A = cross-sectional area of bolt.

$\tau$ = 498 mPa.

∴ $P = 498 \times 10^6 \times \frac{\pi}{4}(0.016)^2$ = 100.13 kN

Torque Capacity: $T = (100.13 \times 10^3)(0.08)(6)$

∴ T = 48.1 kNm. → torque capacity of coupling.

motor torque: $P_m = T_m \omega_m$

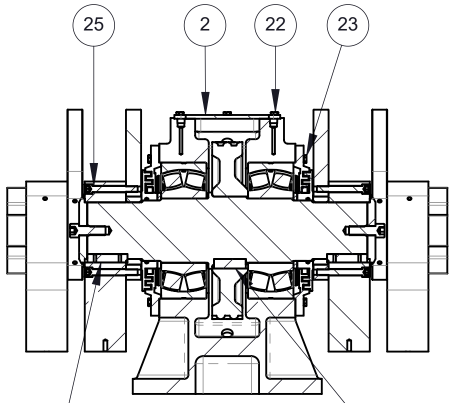
$\omega_m$ = 1000 rpm = $\frac{1000 \times 2\pi}{180}$ = 105 $\frac{rad}{s}$.

Power = 45 kw = 45,000 w.

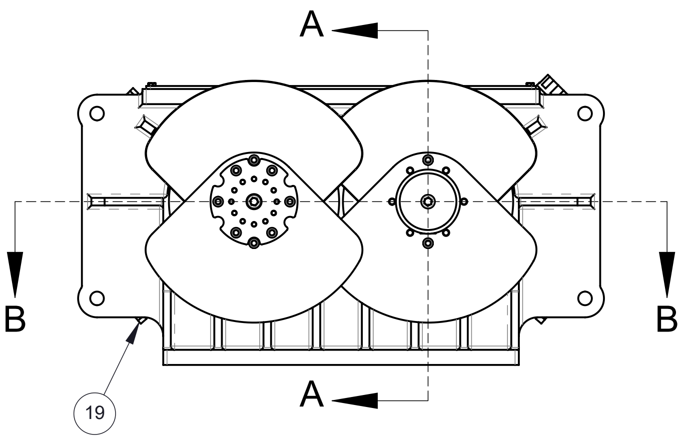
$T_m = \frac{45 \times 10^3}{105}$ = 430 Nm

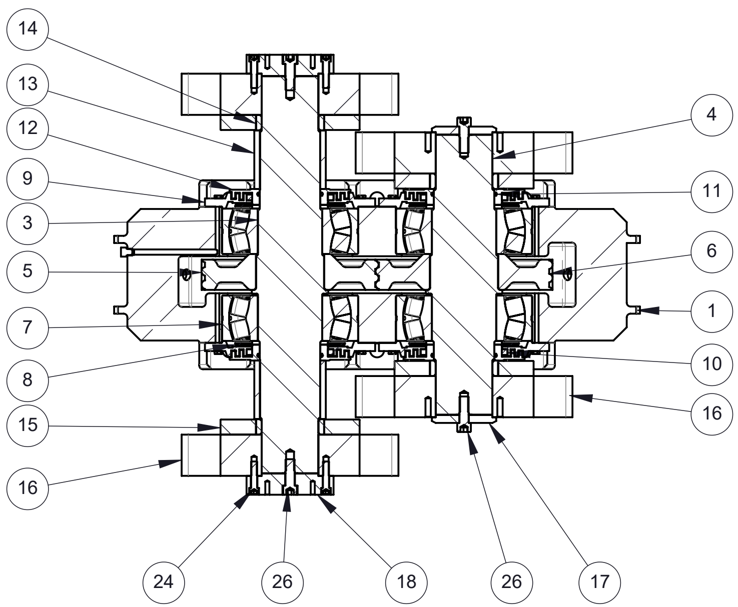
# Appendix X.1

**Assembly Drawing of Best Concept Design**

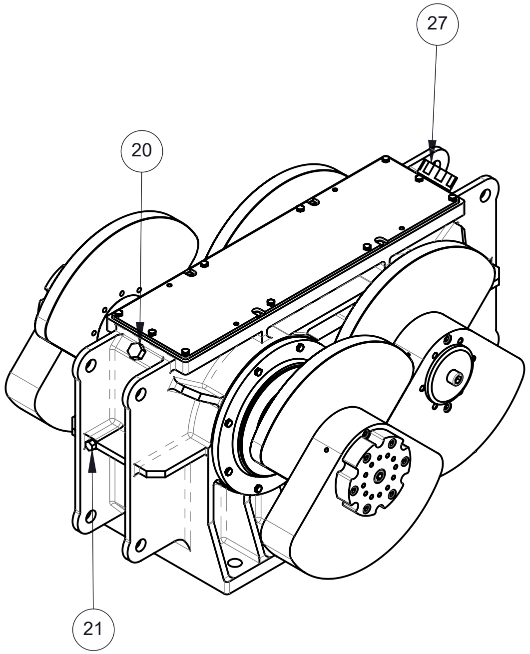



SECTION A-A




SECTION B-B




| ITEM NO. | DESCRIPTION | QTY. |
|---|---|---|
| 1 | GEARBOX CASING | 1 |
| 2 | INSPECTION COVER | 1 |
| 3 | DRIVE SHAFT | 1 |
| 4 | IDLER SHAFT | 1 |
| 5 | DRIVE GEAR - 115 TOOTH, 4 MOD, 20° PA, 20° HELIX | 1 |
| 6 | IDLER GEAR - 115 TOOTH, 4 MOD, 20° PA, 20° HELIX | 1 |
| 7 | BEARING-SKF 22334 CC/W33 | 4 |
| 8 | FLINGER | 4 |
| 9 | BEARING RETAINER | 4 |
| 10 | DOUBLE LIP SEAL - SKF CR SEAL - 200X230X15 VITON | 4 |
| 11 | SEAL, O-RING, 160 X 174 X 7, ISO 3601, N70 | 4 |
| 12 | LABYRINTH SEAL | 4 |
| 13 | SPACER | 2 |
| 14 | LOCATION BUSH | 4 |
| 15 | ADJUSTABLE ECCENTRIC MASS | 4 |
| 16 | FIXED ECCENTRIC MASS | 4 |
| 17 | LOCKING CAP | 2 |
| 18 | DRIVE ADAPTER | 2 |
| 19 | 1" NPT MAGNETIC HEX PLUG | 2 |
| 20 | PLUG, HEX, STEEL, 1" NPT | 1 |
| 21 | PLUG, HEX, STEEL, 3/8" NPT | 1 |
| 22 | BOLT, HEX HEAD, M12 X 1.75 X 35 LG, AS 1110, PC8.8, STEEL | 10 |
| 23 | BOLT, HEX HEAD, M12 X 1.75 X 50 LG, AS 1110, PC8.8, STEEL | 32 |
| 24 | BOLT, SHCS, M16 X 2.0 X 70 LG, DIN 912, PC12.9, STEEL | 12 |
| 25 | BOLT, SHCS, M16 X 2.0 X 120 LG, DIN 912, PC12.9, STEEL | 8 |
| 26 | BOLT, SHCS, M24 X 3.0 X 70 LG, DIN 912, PC12.9, STEEL | 4 |
| 27 | BREATHER - STAUFF - SES5-10-B16-0-0 | 1 |
| 28 | KEY, 40X22 FORMC X 106 LG | 4 |
| 29 | KEY, 45X25 FORMA X 84 LG | 2 |

FINISH UON: DEBUR
ALL DIMENSIONS IN mm UON
GENERAL TOLERANCE UON: ±0.1mm
1.6
SHEET: 1 of 2
THIRD ANGLE PROJECTION
DO NOT SCALE
SCALE: 1:20
SIZE: A4
DRAWN BY AARON STURK

MCEN4000 ASSIGNMENT

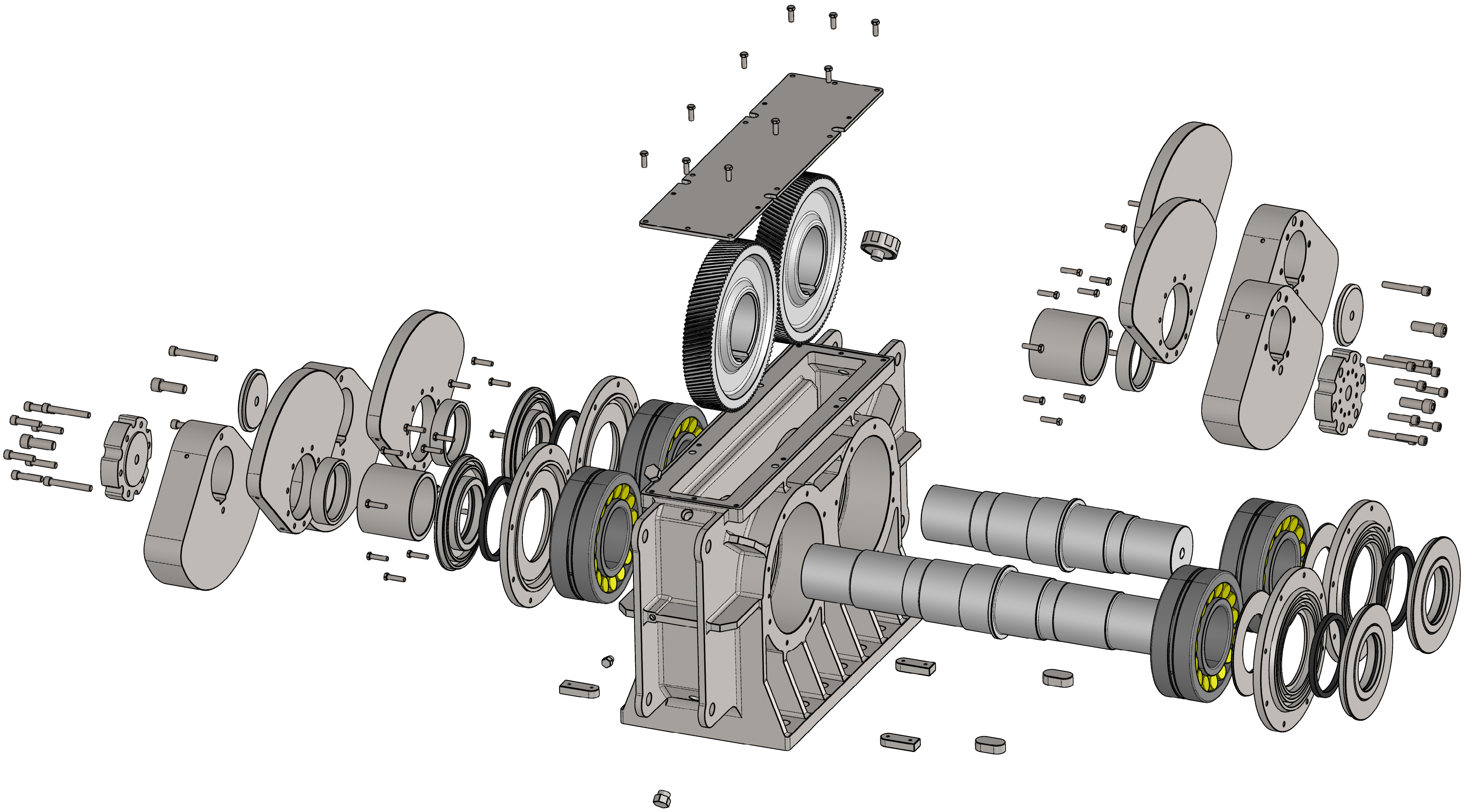
DESCRIPTION:

MATERIAL

| PART: | AUTHOR: | DRAWN DATE: | DWG REV.: | MODEL REV.: |
|---|---|---|---|---|
| Assembly | | | A | A |

# Appendix X.2

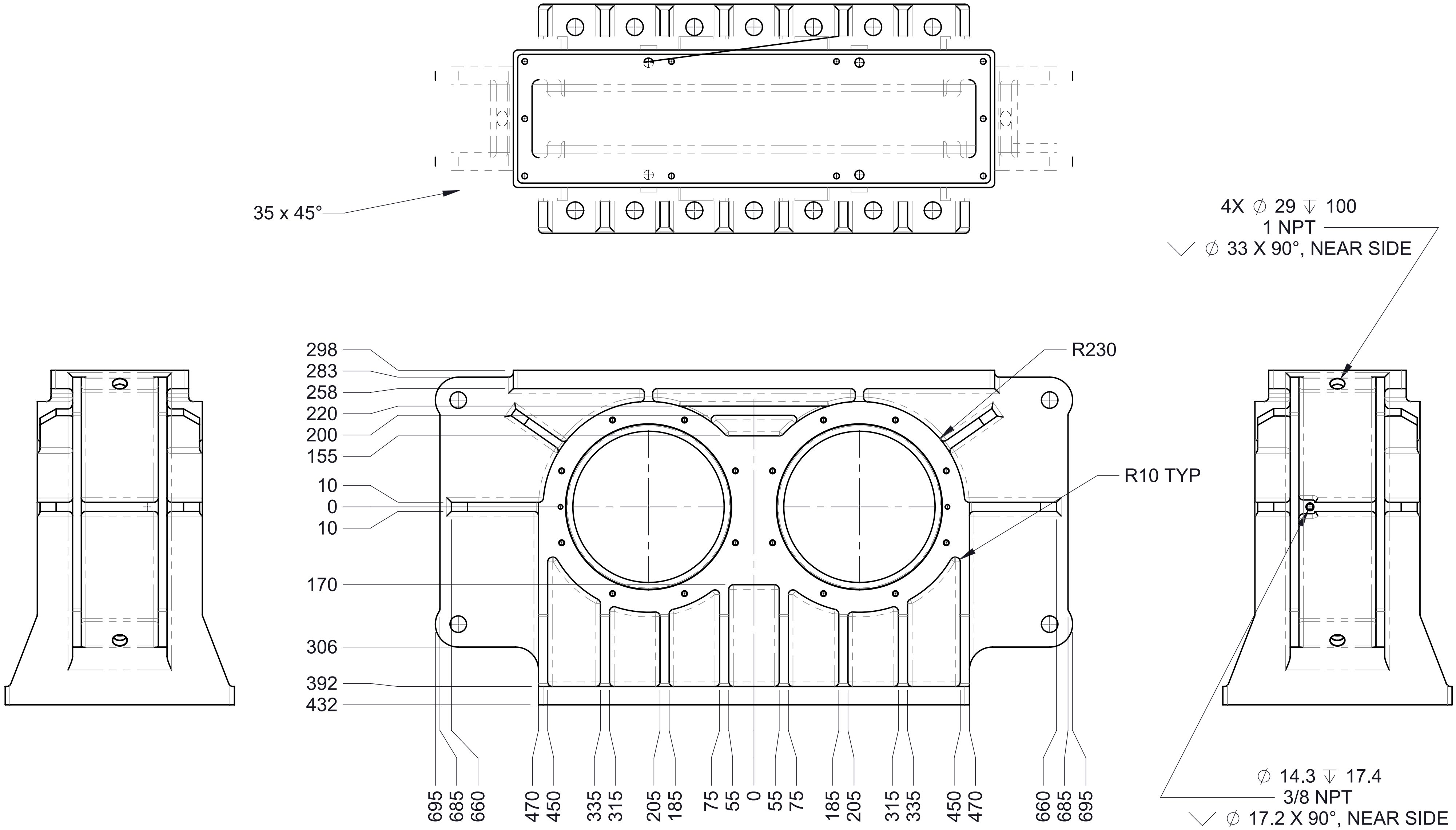
**Exploded View of Main Components of Best Concept Design**



| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: |
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 2 of 2 | DO NOT SCALE | | MATERIAL |
| DRAWN BY AARON STURK | | SCALE: 1:15 SIZE: A4 | | PART: Assembly AUTHOR: DRAWN DATE: DWG REV.: A MODEL REV.: A |

# Appendix X.3.1

**Detailed Drawing of Part No. 1 Gearbox Casing of Best Concept Design**




FINISH UON: DEBUR
GENERAL TOLERANCE
UON: ±0.1mm 1.6

ALL DIMENSIONS IN mm UON
SHEET: 1 of 4

THIRD ANGLE PROJECTION
DO NOT SCALE
SCALE: 1:12
SIZE: A4

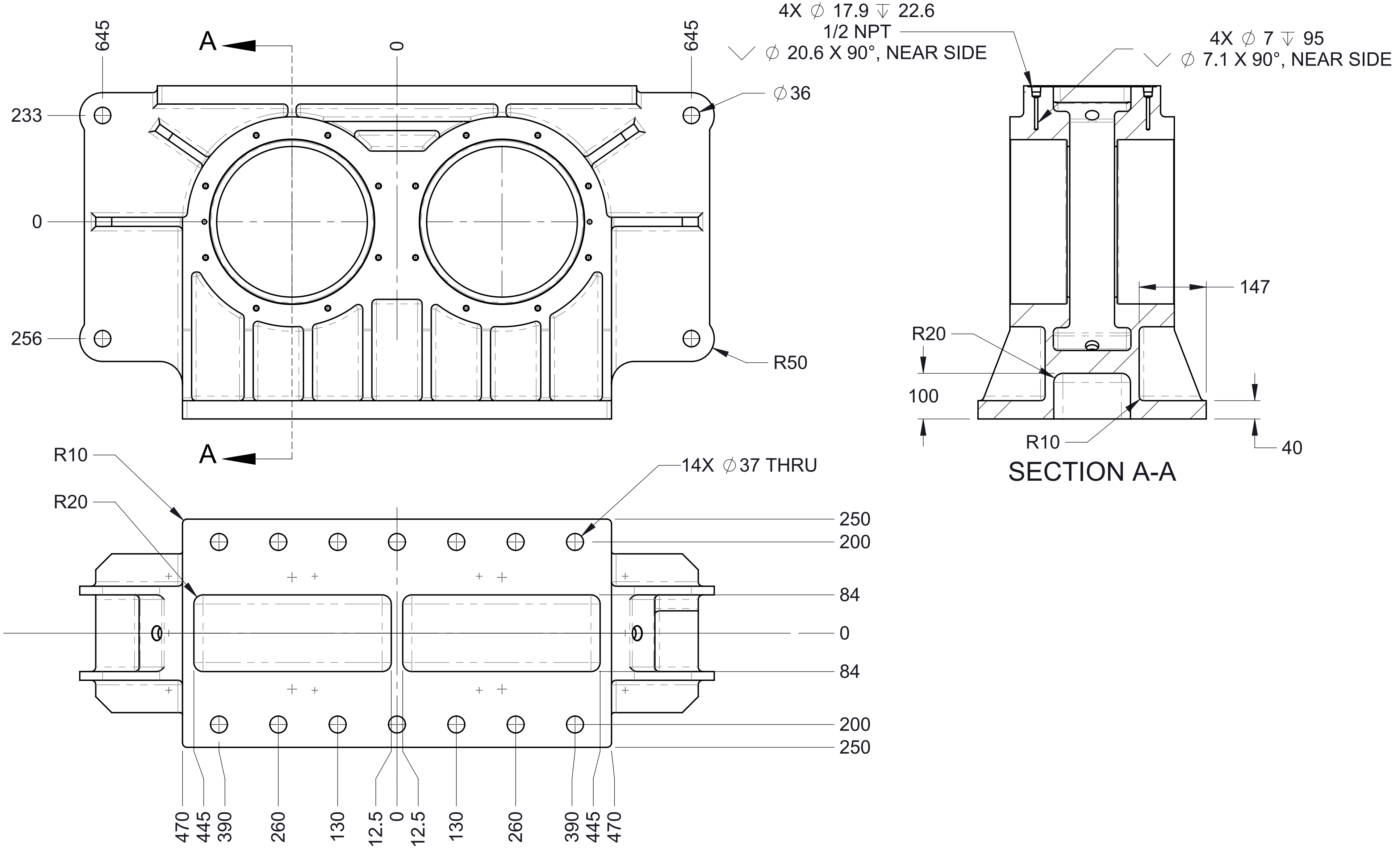
DRAWN BY AARON STURK

MCEN4000 ASSIGNMENT

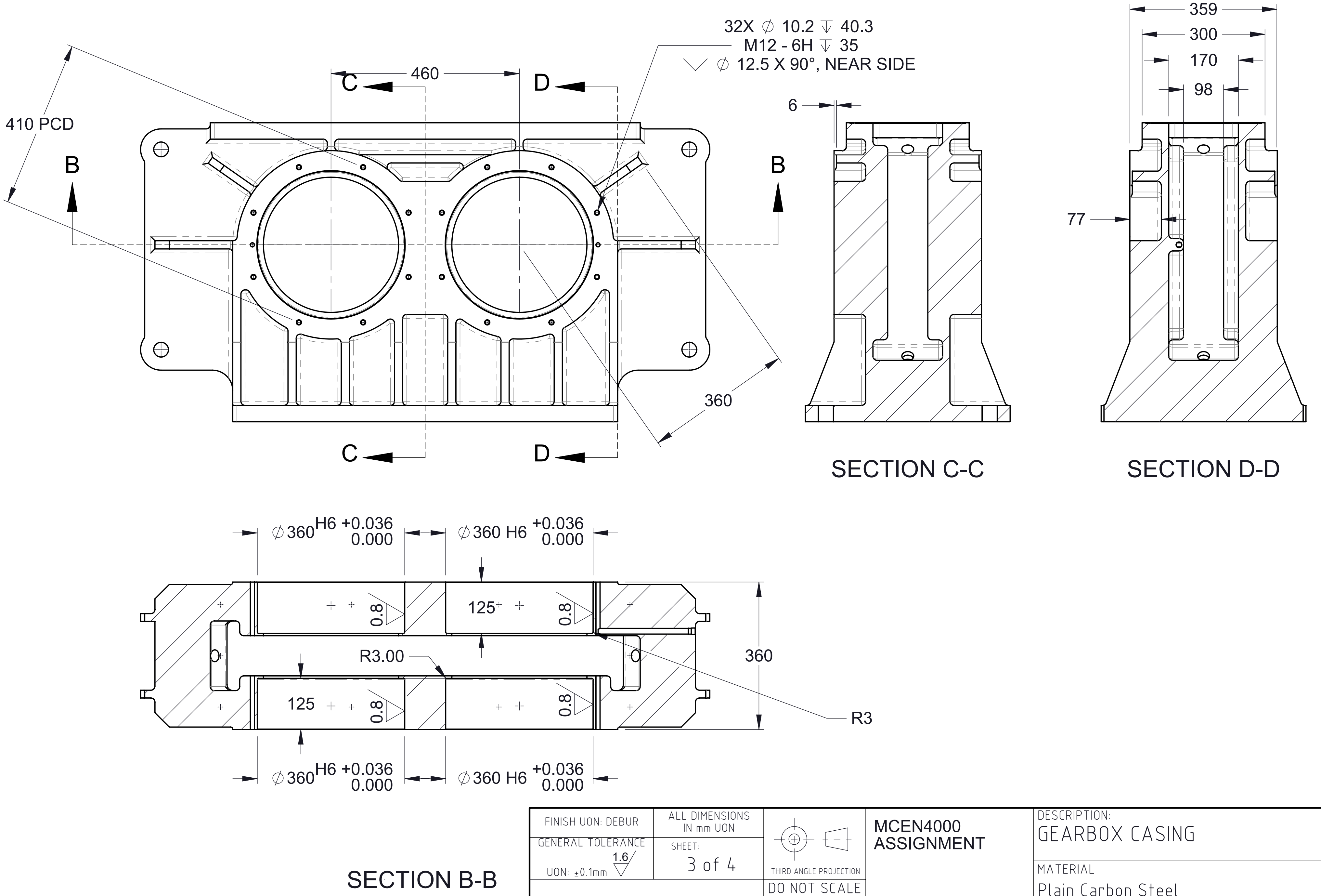
DESCRIPTION:
GEARBOX CASING

MATERIAL
Plain Carbon Steel

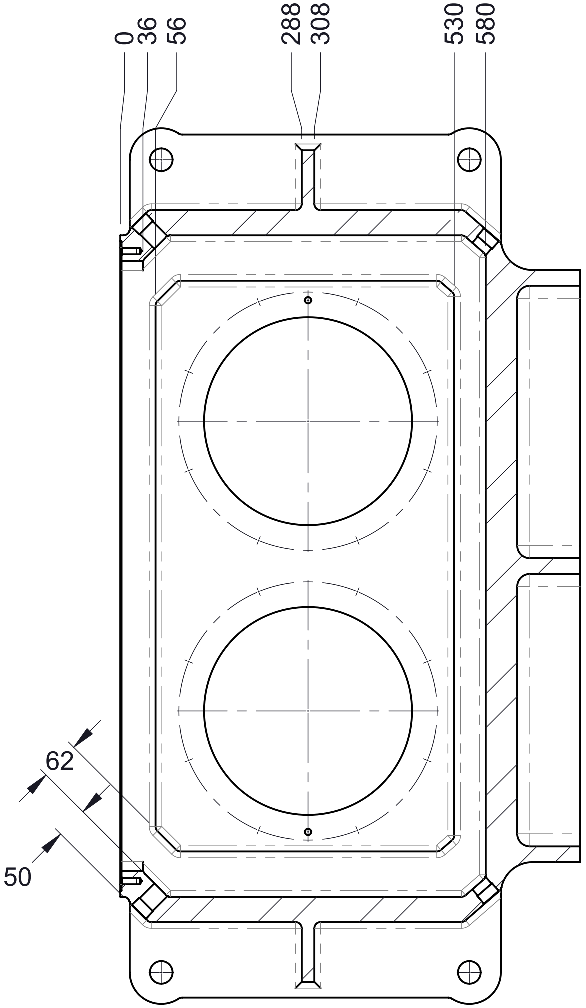
| PART: | AUTHOR: | DRAWN DATE: | DWG REV.: | MODEL REV.: |
| --- | --- | --- | --- | --- |
| 1 GEARBOX CASING | ATS | | A | A |



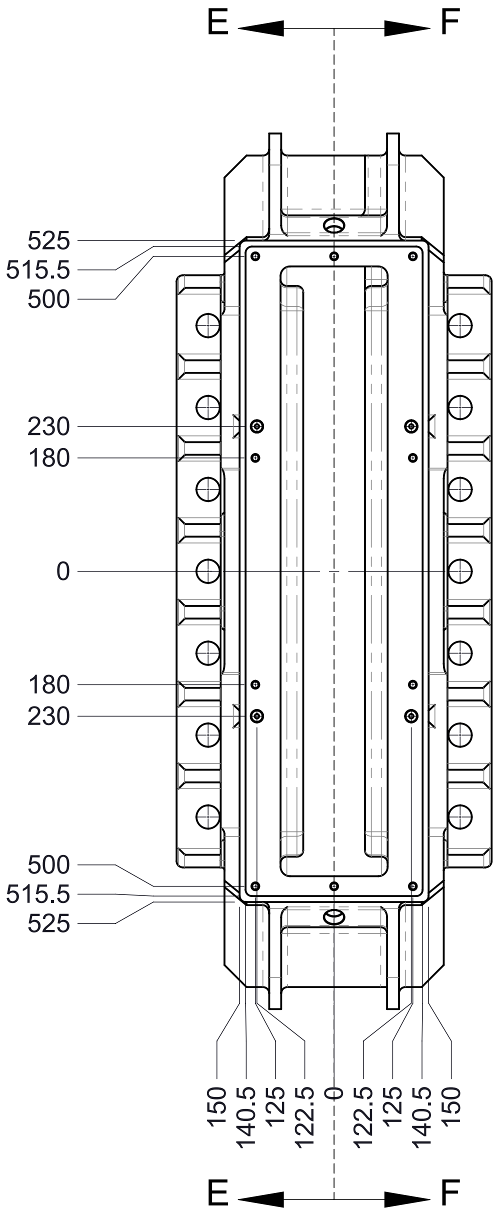

| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: GEARBOX CASING |
|---|---|---|---|---|
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 2 of 4 | DO NOT SCALE | | MATERIAL: Plain Carbon Steel |
| DRAWN BY AARON STURK | | SCALE: 1:12 / SIZE: A4 | | PART: 1 GEARBOX CASING / AUTHOR: ATS / DRAWN DATE: / DWG REV.: A / MODEL REV.: A |

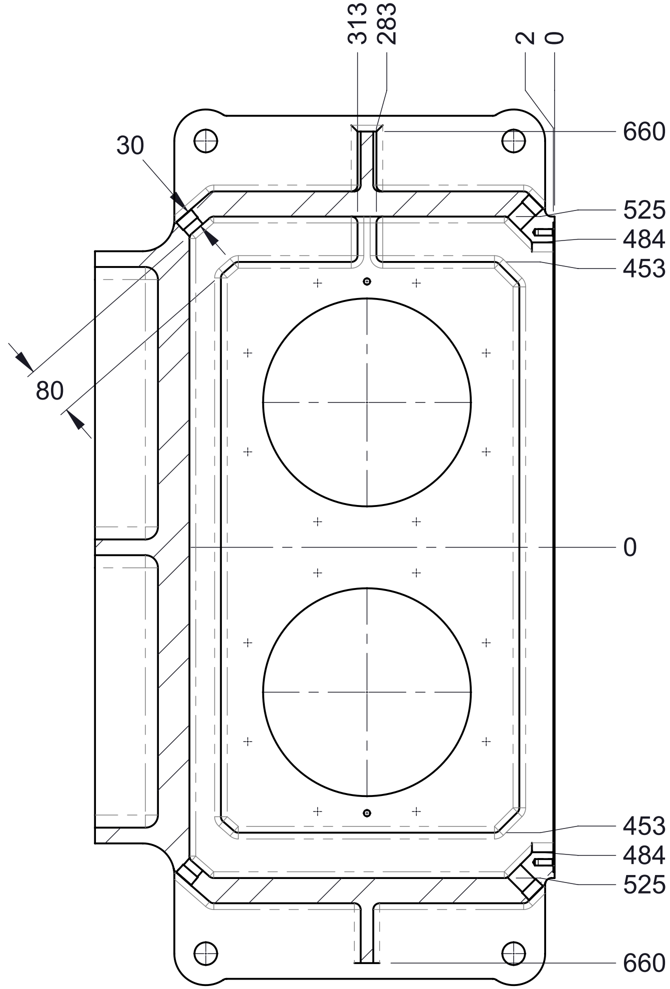



| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | | MCEN4000 ASSIGNMENT | DESCRIPTION: GEARBOX CASING |
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 3 of 4 | THIRD ANGLE PROJECTION | | MATERIAL Plain Carbon Steel |
| DRAWN BY AARON STURK | | DO NOT SCALE | | |
| | | SCALE: 1:12 | SIZE: A4 | PART: 1 GEARBOX CASING / AUTHOR: ATS / DRAWN DATE: / DWG REV.: A / MODEL REV.: A |




SECTION E-E




SECTION F-F

FINISH UON: DEBUR

GENERAL TOLERANCE UON: ±0.1mm 1.6

ALL DIMENSIONS IN mm UON

SHEET: 4 of 4

THIRD ANGLE PROJECTION

DO NOT SCALE

SCALE: 1:12

SIZE: A4

DRAWN BY AARON STURK

MCEN4000 ASSIGNMENT

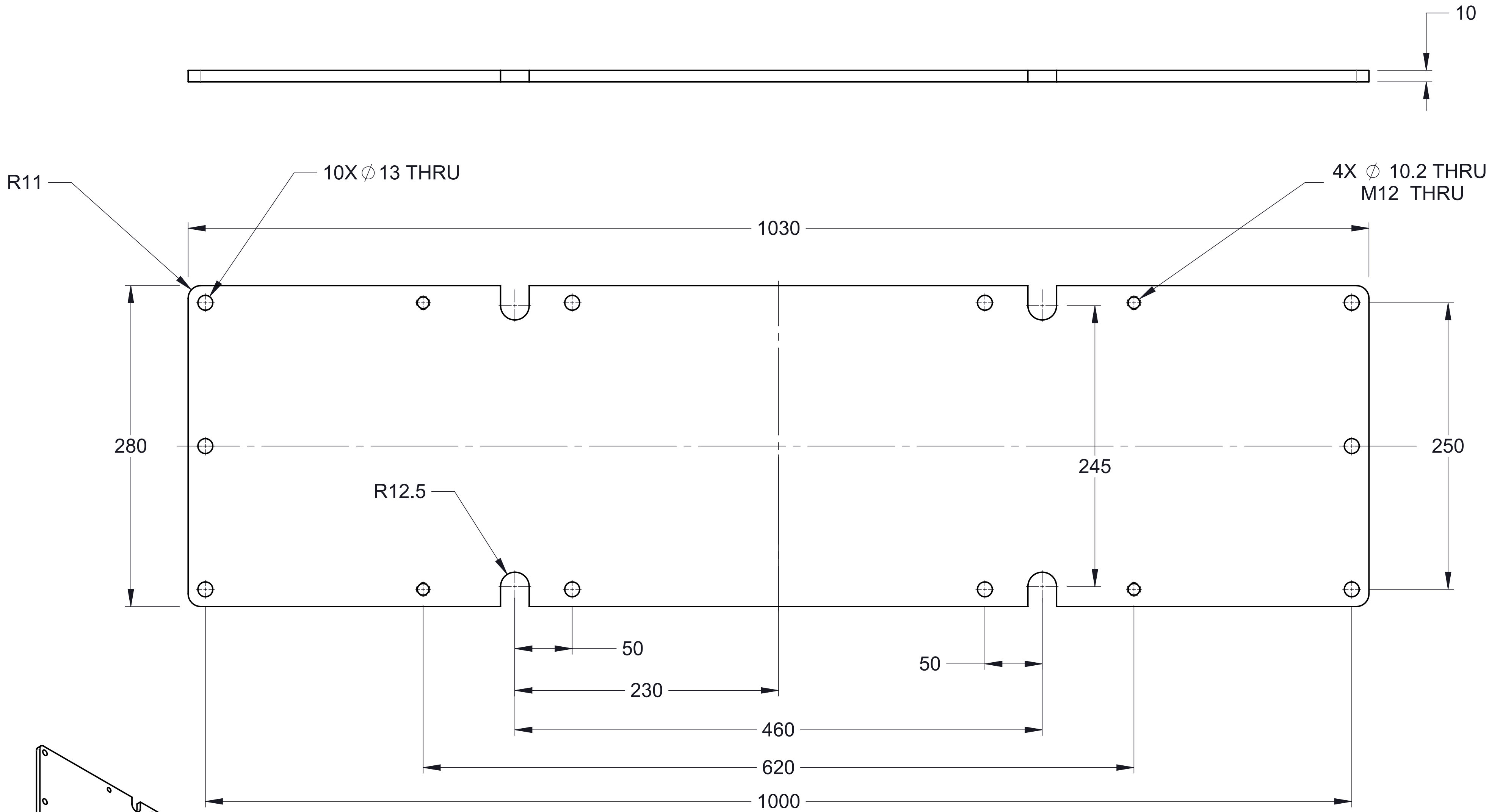
DESCRIPTION: GEARBOX CASING

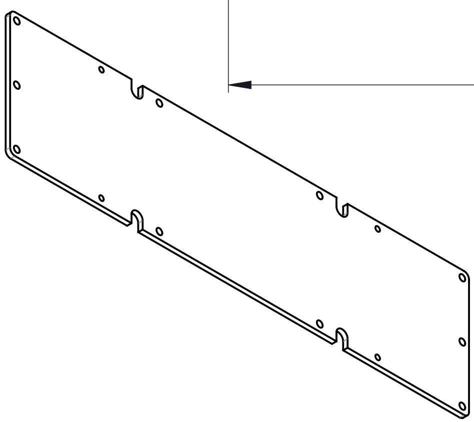
MATERIAL: Plain Carbon Steel

| PART: | AUTHOR: | DRAWN DATE: | DWG REV.: | MODEL REV.: |
|---|---|---|---|---|
| 1 GEARBOX CASING | ATS | | A | A |

# Appendix X.3.2

**Detailed Drawing of Part No. 2 Inspection Cover of Best Concept Design**

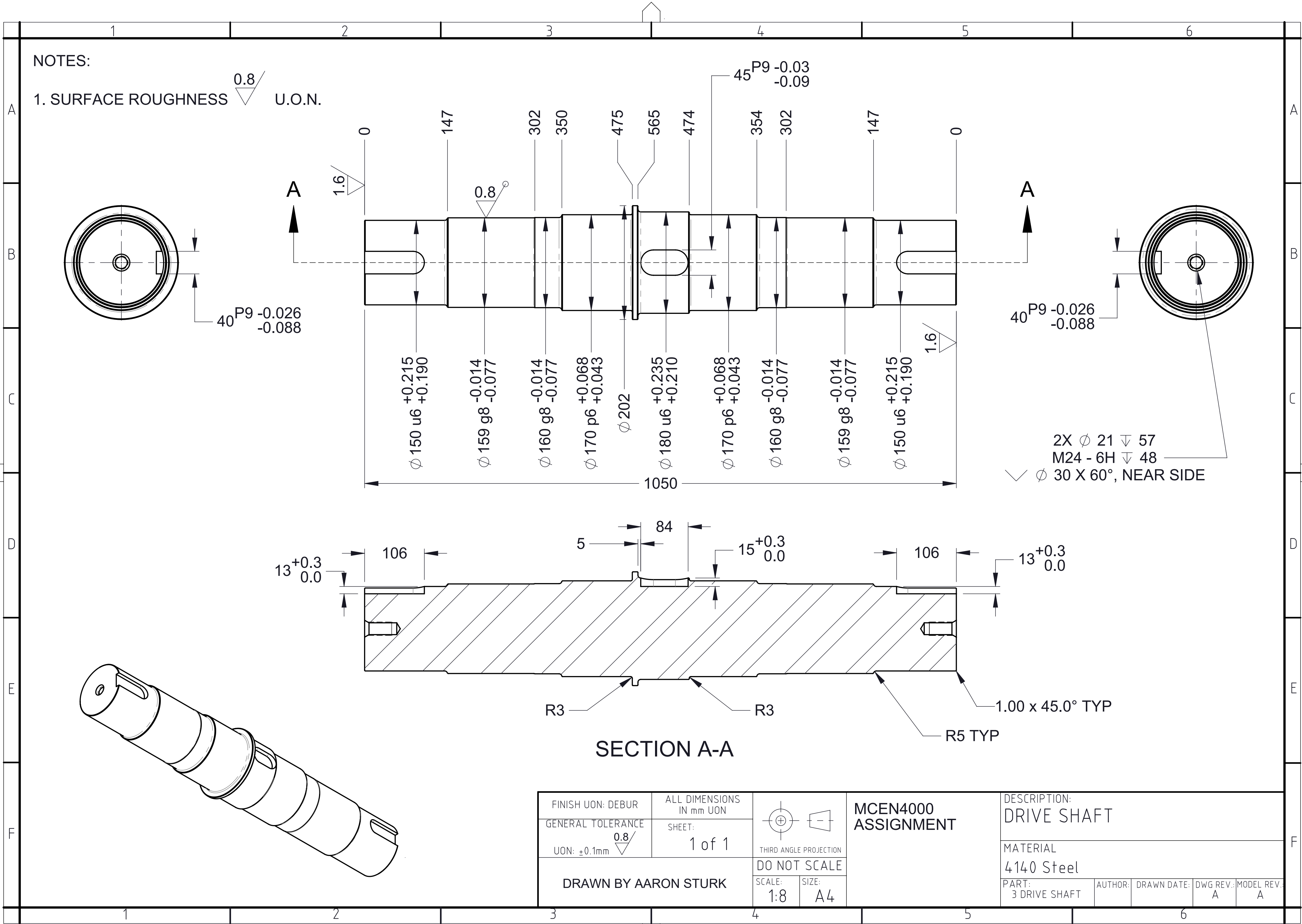


| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: INSPECTION COVER |
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 1 of 1 | DO NOT SCALE | | MATERIAL Plain Carbon Steel |
| DRAWN BY AARON STURK | | SCALE: 1:5 / SIZE: A4 | | PART: 2 INSPECTION COVER / AUTHOR: / DRAWN DATE: / DWG REV.: A / MODEL REV.: A |

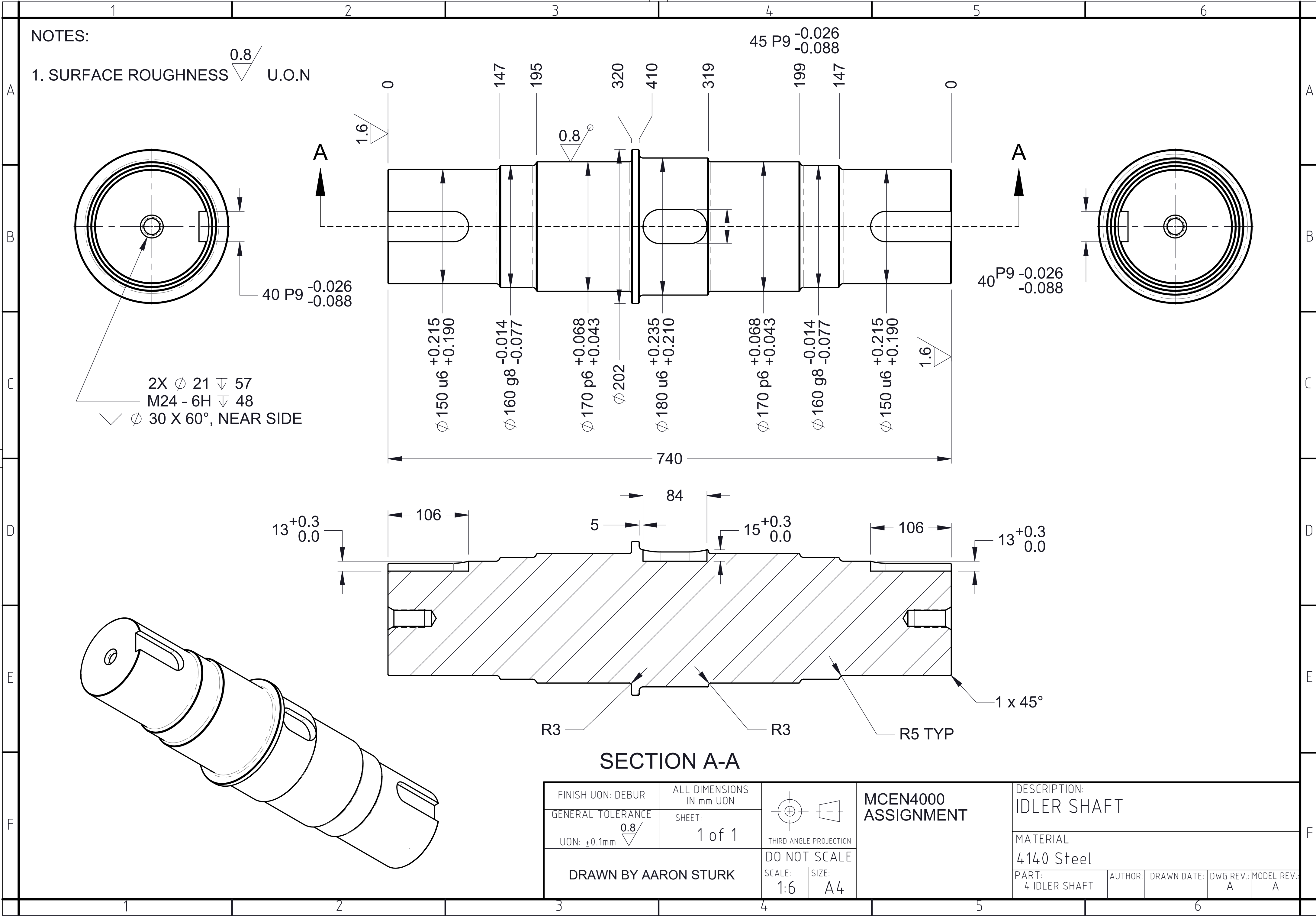
# Appendix X.3.3

**Detailed Drawing of Part No. 3 Drive Shaft of Best Concept Design**


NOTES:
1. SURFACE ROUGHNESS 0.8 U.O.N.
45P9 -0.03 -0.09
0
147
302
350
475
565
474
354
302
147
0
1.6
0.8
A
A
40P9 -0.026 -0.088
40P9 -0.026 -0.088
⌀150 u6 +0.215 +0.190
⌀159 g8 -0.014 -0.077
⌀160 g8 -0.014 -0.077
⌀170 p6 +0.068 +0.043
⌀202
⌀180 u6 +0.235 +0.210
⌀170 p6 +0.068 +0.043
⌀160 g8 -0.014 -0.077
⌀159 g8 -0.014 -0.077
⌀150 u6 +0.215 +0.190
1.6
2X ⌀ 21 ↧ 57
M24 - 6H ↧ 48
⌵ ⌀ 30 X 60°, NEAR SIDE
1050
84
5
15+0.3 0.0
106
106
13+0.3 0.0
13+0.3 0.0
R3
R3
1.00 x 45.0° TYP
R5 TYP
SECTION A-A
FINISH UON: DEBUR
GENERAL TOLERANCE
UON: ±0.1mm 0.8
ALL DIMENSIONS IN mm UON
SHEET:
1 of 1
THIRD ANGLE PROJECTION
DO NOT SCALE
SCALE: 1:8
SIZE: A4
DRAWN BY AARON STURK
MCEN4000 ASSIGNMENT
DESCRIPTION:
DRIVE SHAFT
MATERIAL
4140 Steel
PART:
3 DRIVE SHAFT
AUTHOR:
DRAWN DATE:
DWG REV.: A
MODEL REV.: A

# Appendix X.3.4

**Detailed Drawing of Part No. 4 Idler Shaft of Best Concept Design**

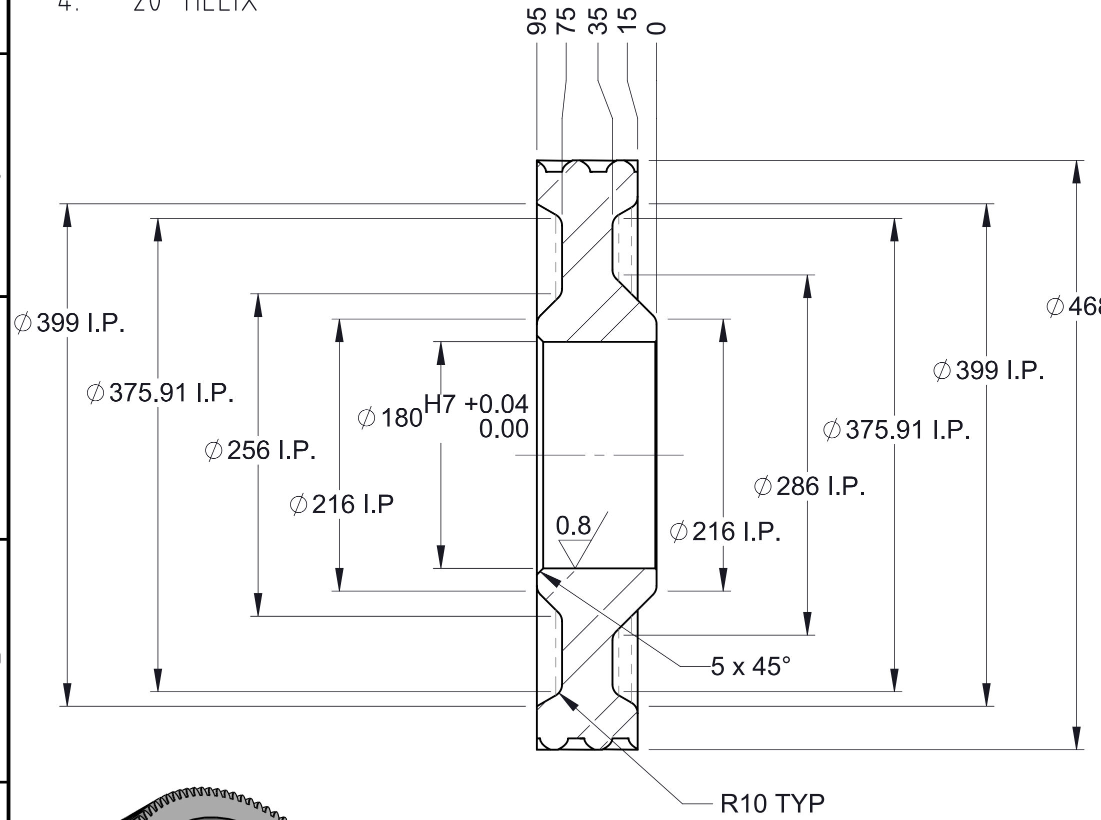


NOTES:
1. SURFACE ROUGHNESS 0.8 U.O.N
0
147
195
320
410
319
199
147
0
45 P9 -0.026 -0.088
1.6
0.8
A
A
40 P9 -0.026 -0.088
40 P9 -0.026 -0.088
⌀150 u6 +0.215 +0.190
⌀160 g8 -0.014 -0.077
⌀170 p6 +0.068 +0.043
⌀202
⌀180 u6 +0.235 +0.210
⌀170 p6 +0.068 +0.043
⌀160 g8 -0.014 -0.077
⌀150 u6 +0.215 +0.190
1.6
2X ⌀ 21 ↧ 57
M24 - 6H ↧ 48
⌵ ⌀ 30 X 60°, NEAR SIDE
740
84
106
5
13 +0.3 0.0
15 +0.3 0.0
106
13 +0.3 0.0
1 x 45°
R3
R3
R5 TYP
SECTION A-A
FINISH UON: DEBUR
GENERAL TOLERANCE
UON: ±0.1mm 0.8
ALL DIMENSIONS IN mm UON
SHEET:
1 of 1
THIRD ANGLE PROJECTION
DO NOT SCALE
SCALE: 1:6
SIZE: A4
DRAWN BY AARON STURK
MCEN4000 ASSIGNMENT
DESCRIPTION:
IDLER SHAFT
MATERIAL
4140 Steel
PART:
4 IDLER SHAFT
AUTHOR:
DRAWN DATE:
DWG REV.: A
MODEL REV.: A

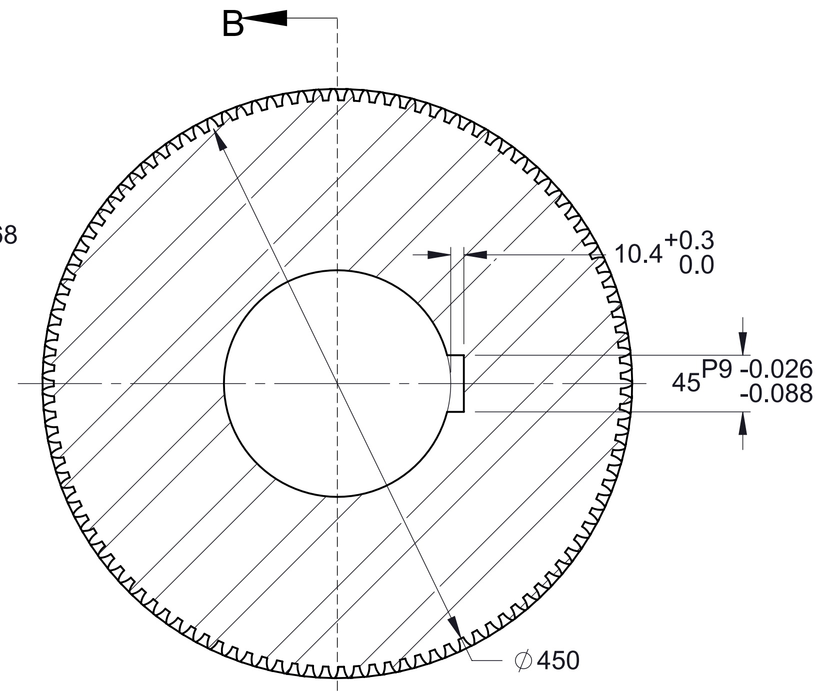
# Appendix X.3.5

**Detailed Drawing of Part No. 5 Drive Gear of Best Concept Design**

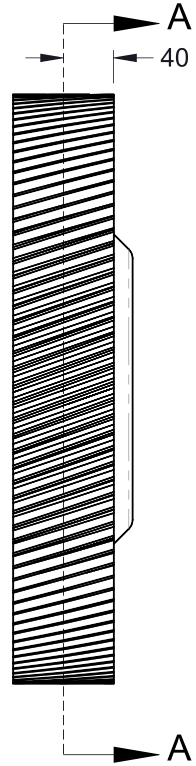
NOTES:
1. 115 TOOTH
2. 4 MOD
3. 20° PA
4. 20° HELIX

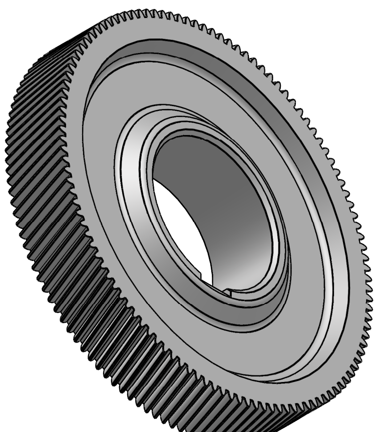



SECTION B-B




SECTION A-A



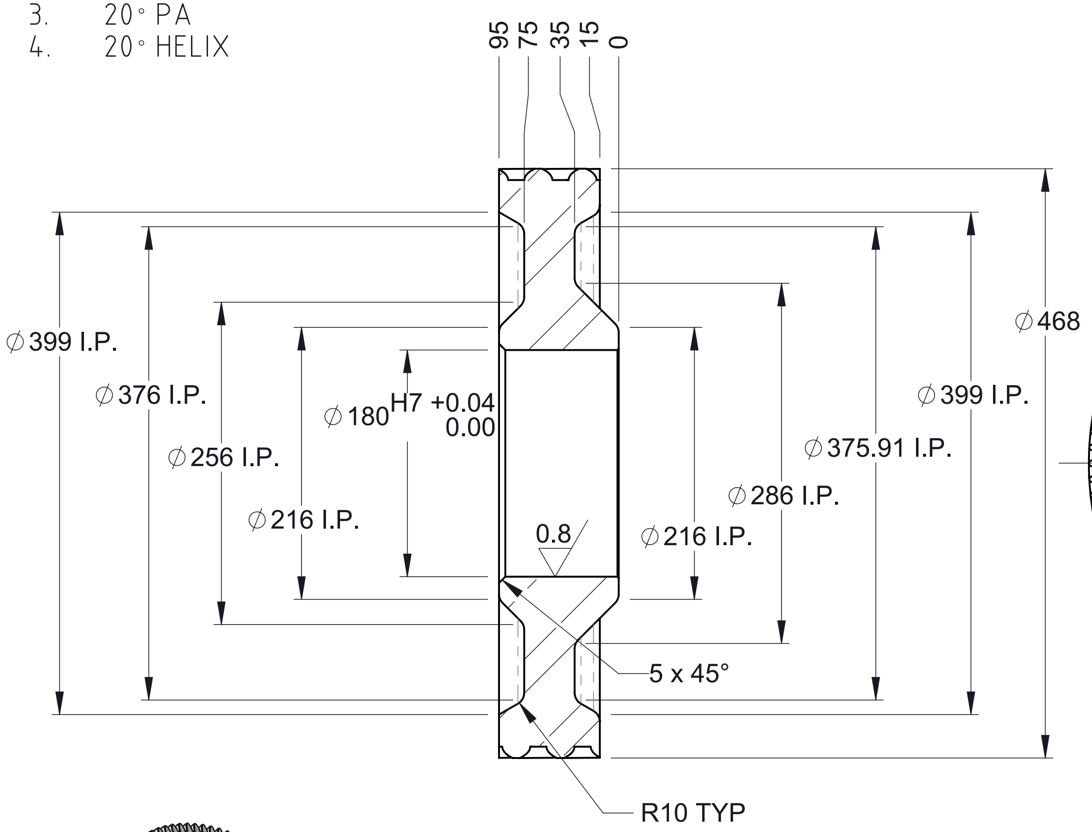



| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: DRIVE GEAR - 115 TOOTH, 4 MOD, 20° PA, 20° HELIX |
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 1 of 1 | DO NOT SCALE | | MATERIAL 4140 Steel |
| DRAWN BY AARON STURK | | SCALE: 1:6 / SIZE: A4 | | PART: 5 DRIVE GEAR / AUTHOR: / DRAWN DATE: / DWG REV.: A / MODEL REV.: A |

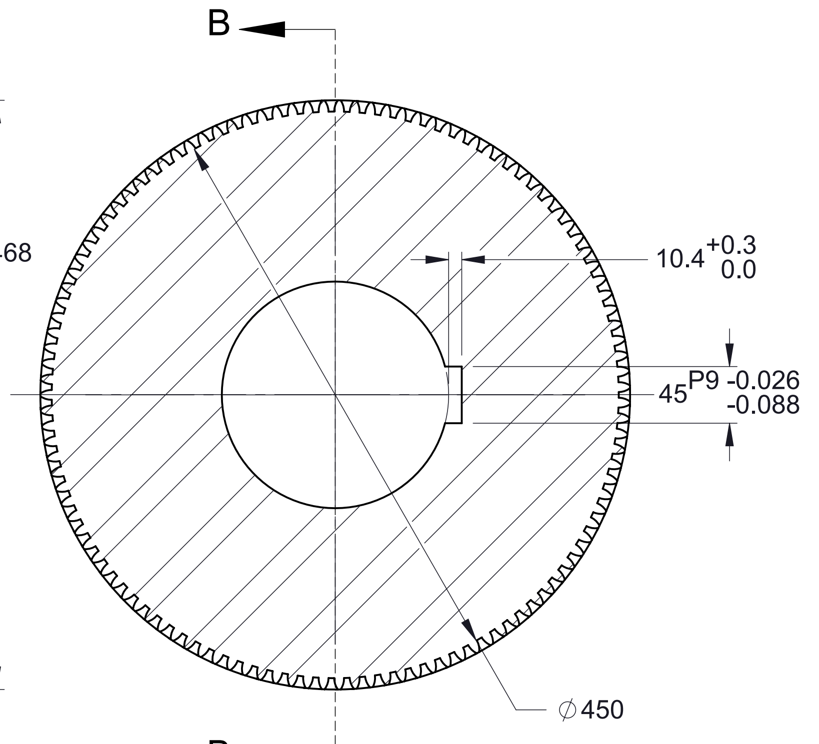
# Appendix X.3.6

**Detailed Drawing of Part No. 6 Idler Gear of Best Concept Design**

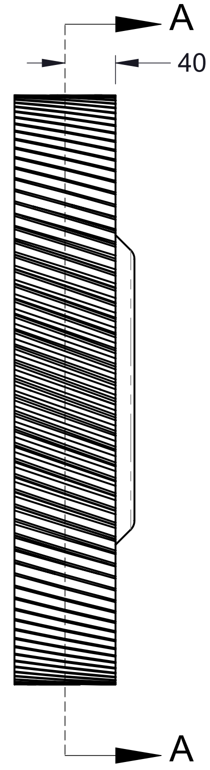
NOTES:
1. 115 TOOTH
2. 4 MOD
3. 20° PA
4. 20° HELIX

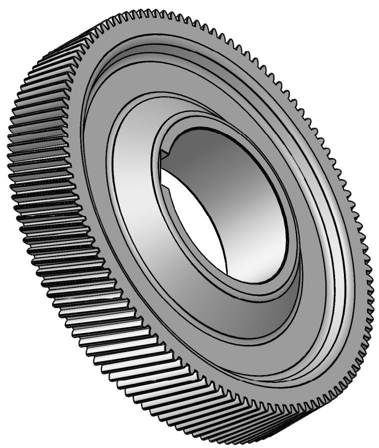



SECTION B-B




SECTION A-A

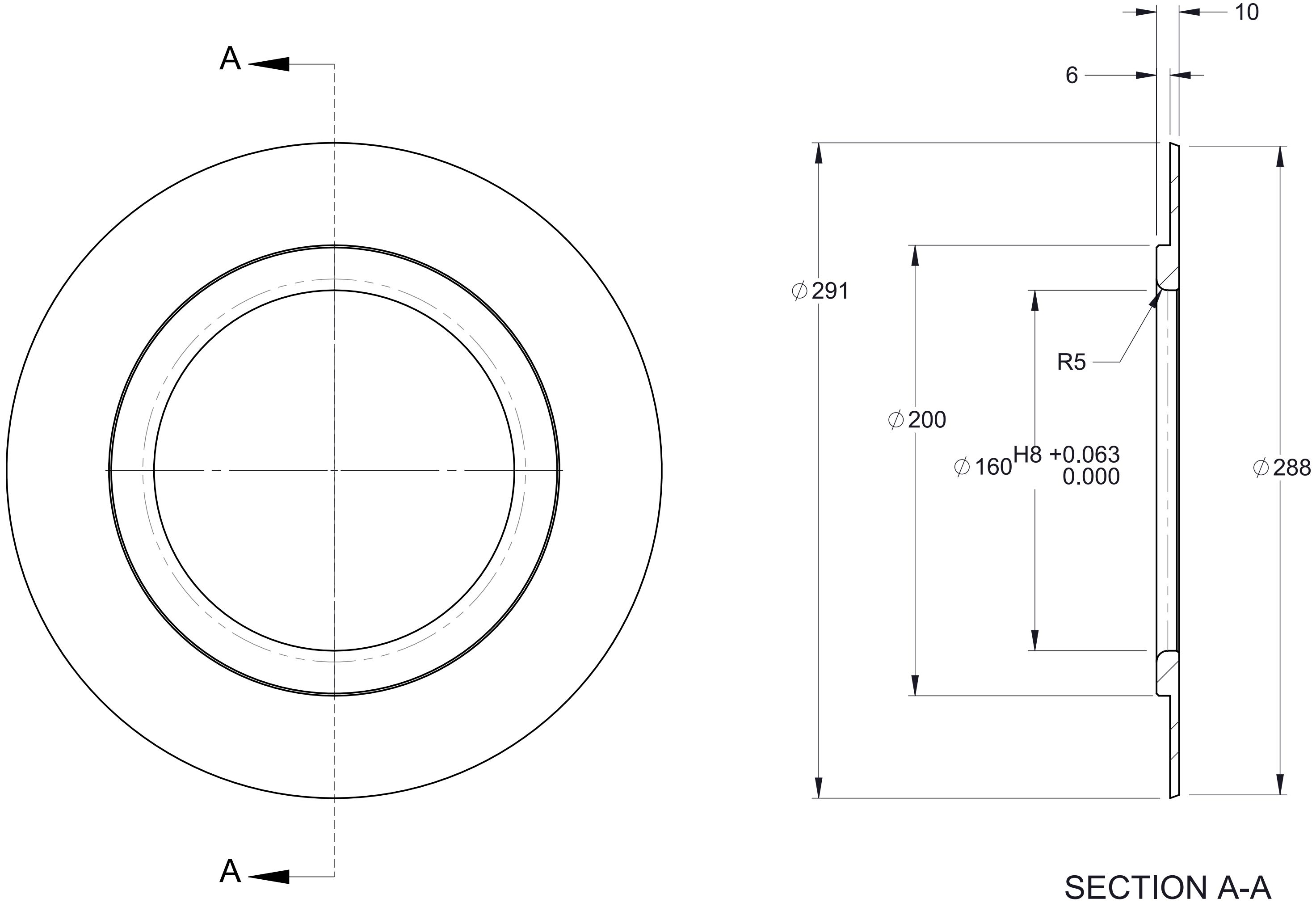


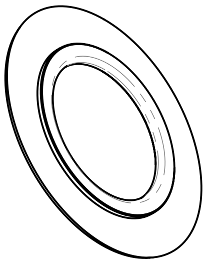



FINISH UON: DEBUR
GENERAL TOLERANCE
UON: ±0.1mm 1.6
ALL DIMENSIONS IN mm UON
SHEET: 1 of 1
THIRD ANGLE PROJECTION
DO NOT SCALE
SCALE: 1:6
SIZE: A4
DRAWN BY AARON STURK
MCEN4000 ASSIGNMENT
DESCRIPTION: IDLER GEAR - 115 TOOTH, 4 MOD, 20° PA, 20° HELIX
MATERIAL: 4140 Steel
PART: 6 IDLER GEAR
AUTHOR:
DRAWN DATE:
DWG REV.: A
MODEL REV.: A

# Appendix X.3.7

**Detailed Drawing of Part No. 8 Flinger of Best Concept Design**

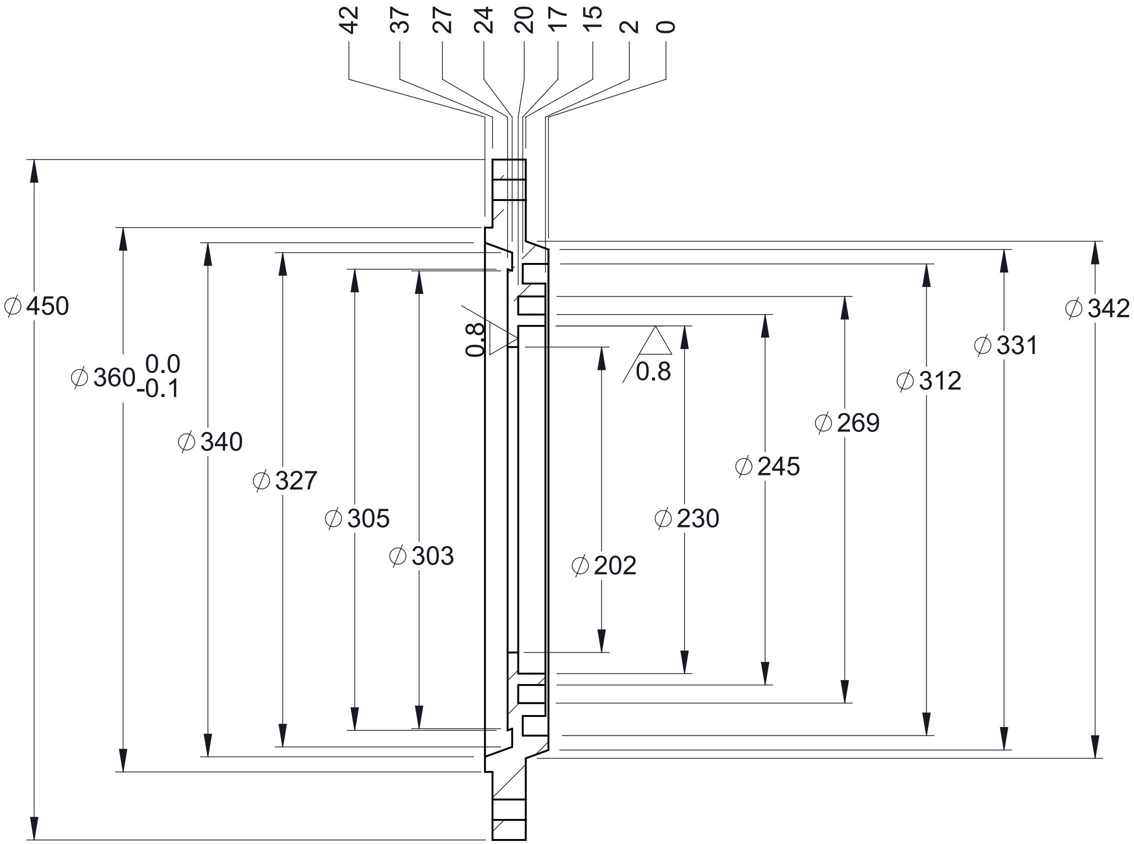


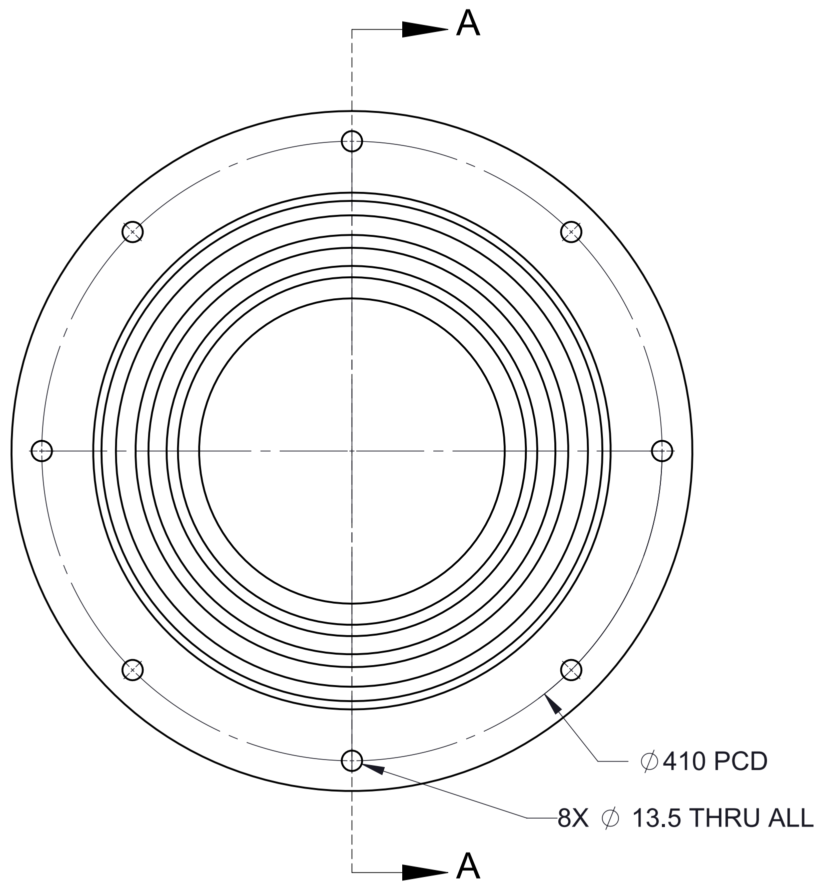
| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: FLINGER |
| GENERAL TOLERANCE 1.6 UON: ±0.1mm | SHEET: 1 of 1 | DO NOT SCALE | | MATERIAL Plain Carbon Steel |
| DRAWN BY AARON STURK | | SCALE: 1:3 / SIZE: A4 | | PART: 8 FLINGER / AUTHOR: / DRAWN DATE: / DWG REV.: A / MODEL REV.: A |

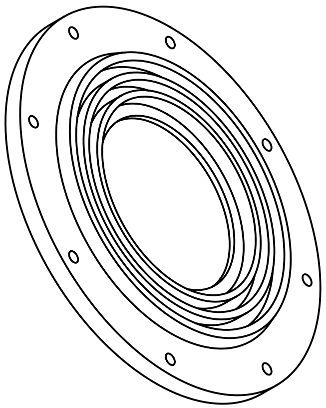
# Appendix X.3.8

**Detailed Drawing of Part No. 9 Bearing Retainer of Best Concept Design**




SECTION A-A

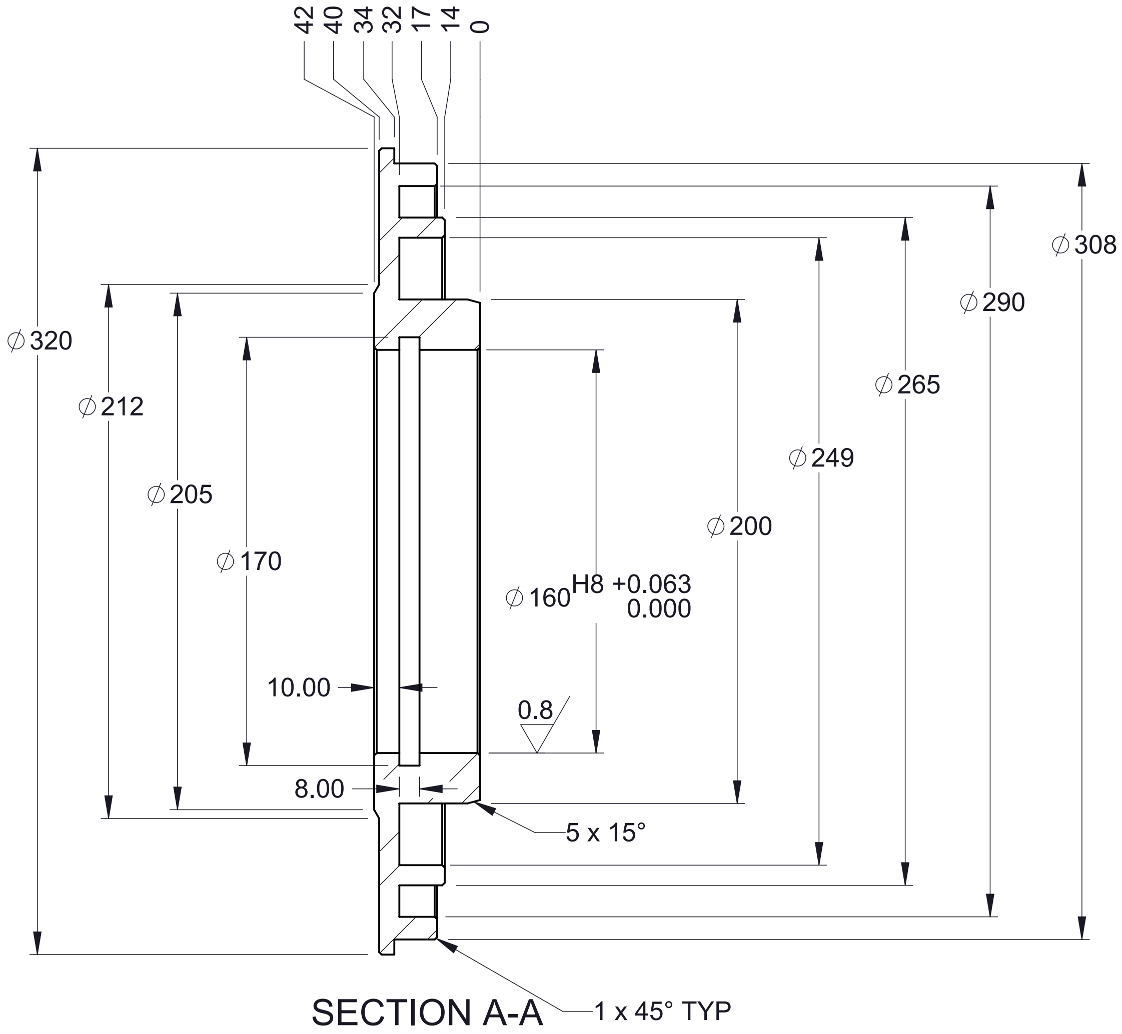


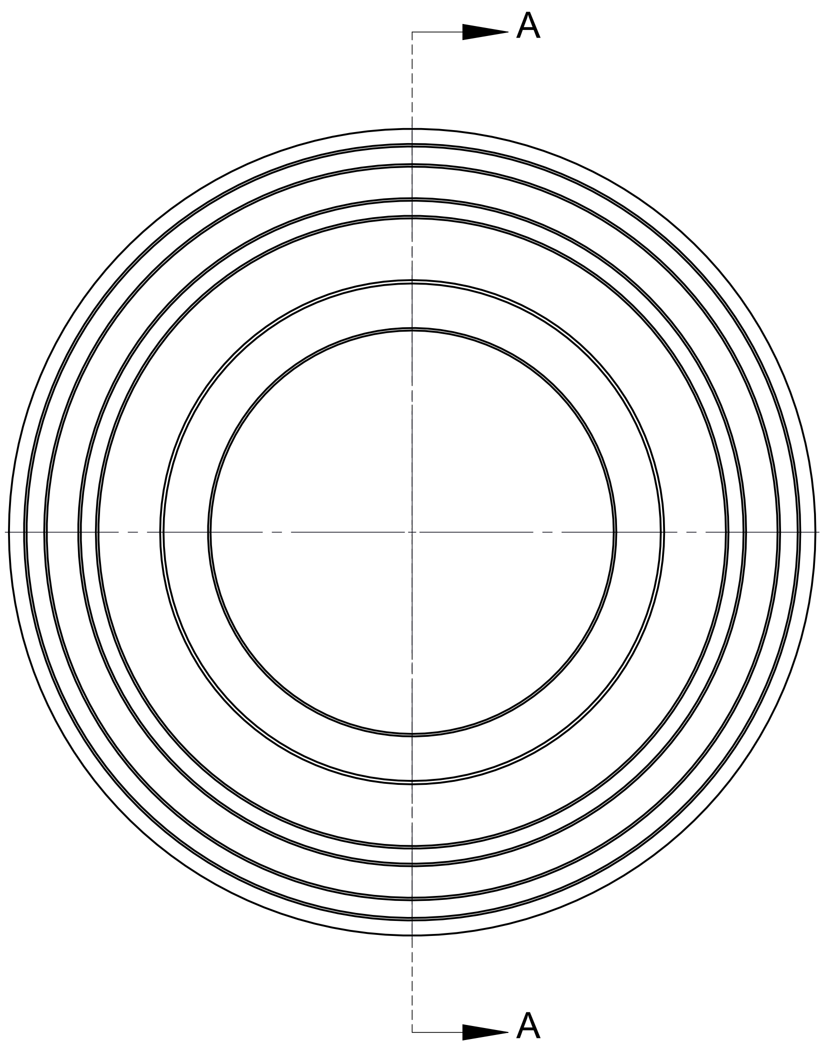



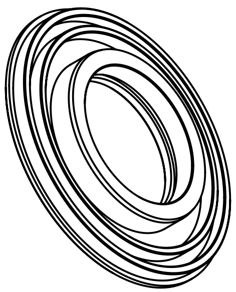
| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: BEARING RETAINER |
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 1 of 1 | DO NOT SCALE | | MATERIAL Plain Carbon Steel |
| DRAWN BY AARON STURK | | SCALE: 1:5 SIZE: A4 | | PART: 9 BEARING RETAINER; AUTHOR:; DRAWN DATE:; DWG REV.: A; MODEL REV.: A |

# Appendix X.3.9

**Detailed Drawing of Part No. 12 Labyrinth Seal of Best Concept Design**



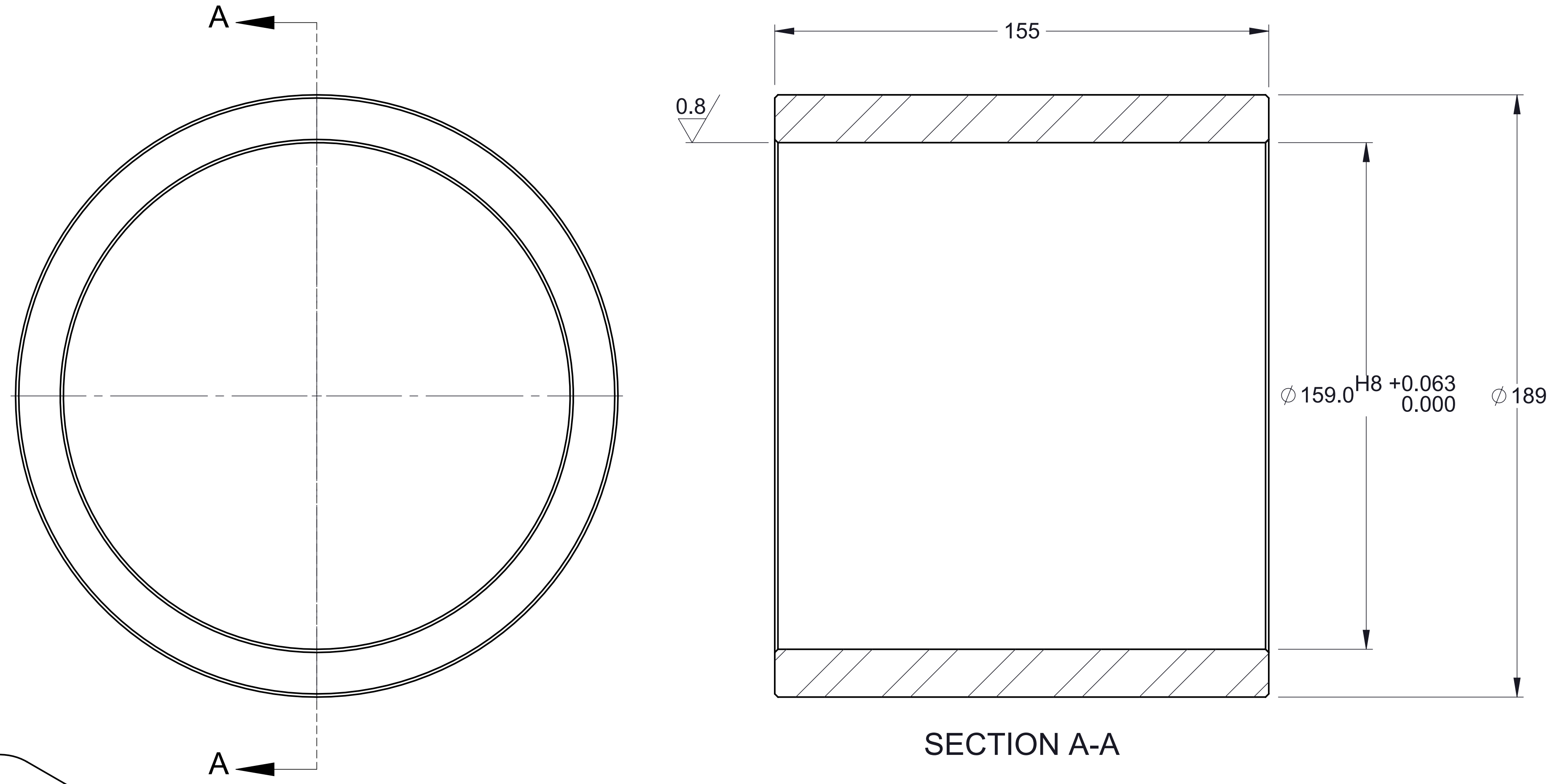



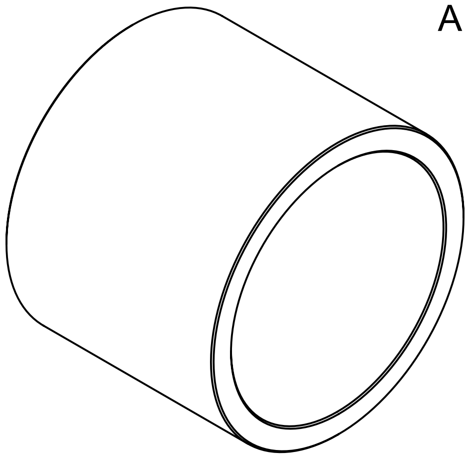



| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: LABYRINTH SEAL |
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 1 of 1 | DO NOT SCALE | | MATERIAL Plain Carbon Steel |
| DRAWN BY AARON STURK | | SCALE: 1:3 / SIZE: A4 | | PART: 12 LABYRINTH SEAL / AUTHOR: / DRAWN DATE: / DWG REV.: A / MODEL REV.: A |

# Appendix X.3.10

**Detailed Drawing of Part No. 13 Spacer of Best Concept Design**



FINISH UON: DEBUR

GENERAL TOLERANCE UON: ±0.1mm 1.6

ALL DIMENSIONS IN mm UON

SHEET: 1 of 1

THIRD ANGLE PROJECTION

DO NOT SCALE

SCALE: 1:2

SIZE: A4

DRAWN BY AARON STURK

MCEN4000 ASSIGNMENT

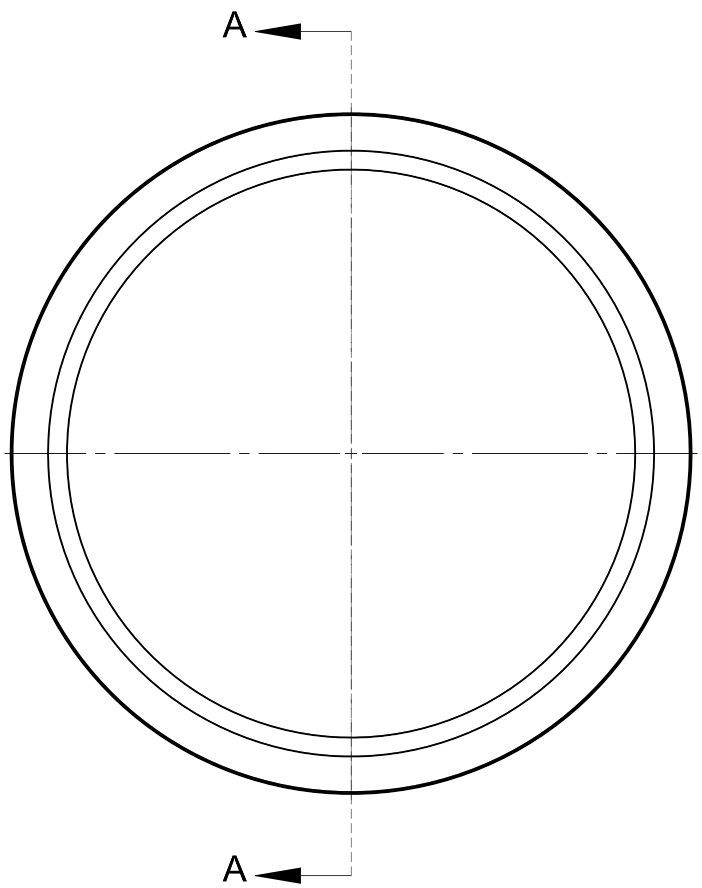
DESCRIPTION: SPACER

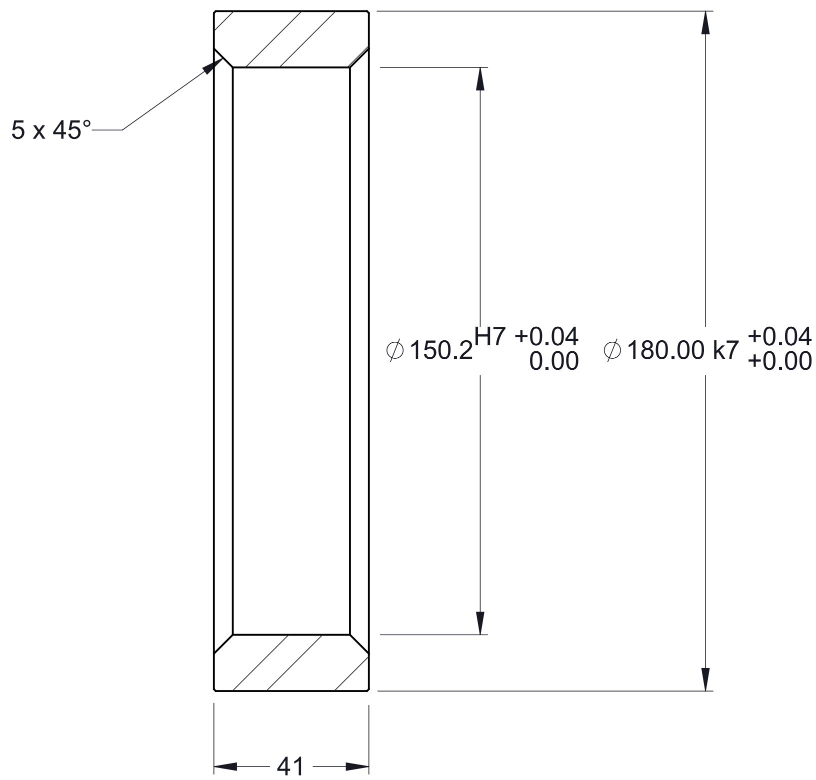
MATERIAL: Plain Carbon Steel

| PART: | AUTHOR: | DRAWN DATE: | DWG REV.: | MODEL REV.: |
|---|---|---|---|---|
| 13 SPACER | | | A | A |

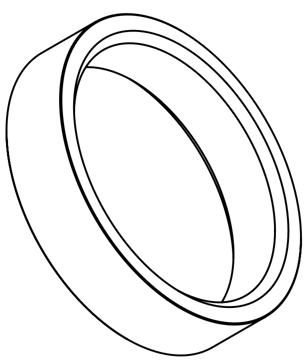
# Appendix X.3.11

**Detailed Drawing of Part No. 14 Location Bush of Best Concept Design**



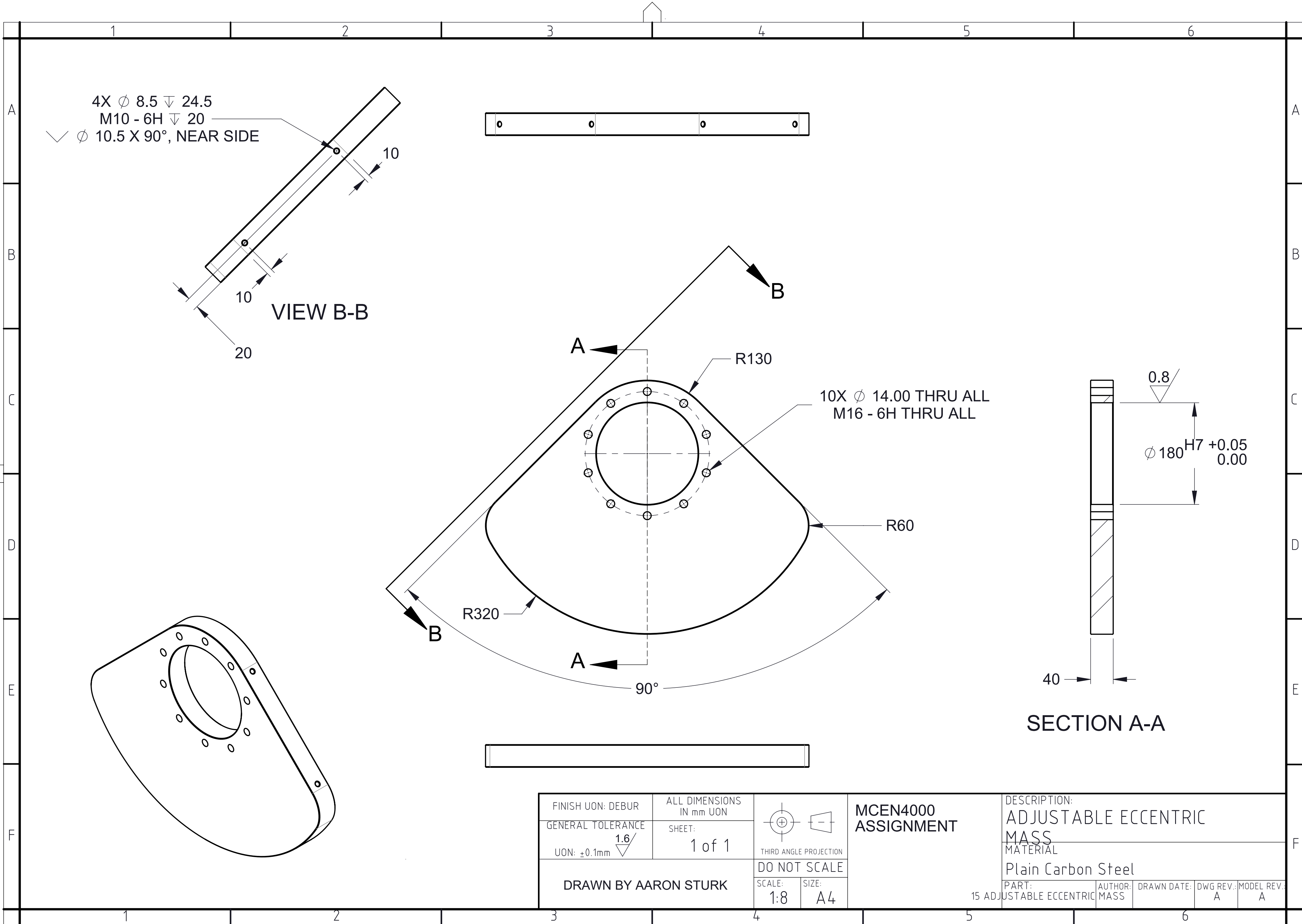

SECTION A-A



| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: LOCATION BUSH |
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 1 of 1 | DO NOT SCALE | | MATERIAL: Plain Carbon Steel |
| DRAWN BY AARON STURK | | SCALE: 1:2 / SIZE: A4 | | PART: 14 LOCATION BUSH / AUTHOR: / DRAWN DATE: / DWG REV.: A / MODEL REV.: A |

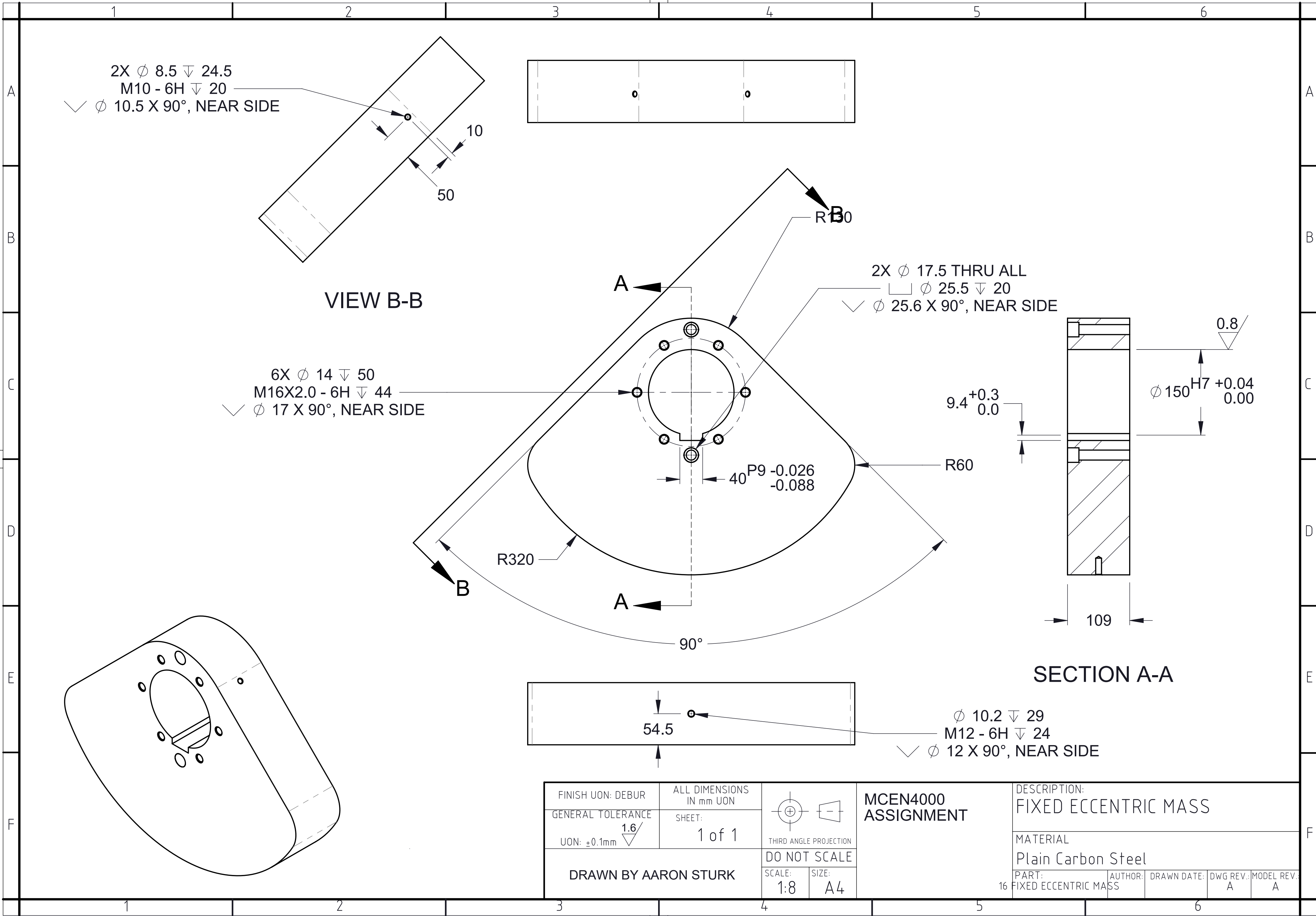
# Appendix X.3.12

**Detailed Drawing of Part No. 15 Adjustable Eccentric Mass of Best Concept Design**


4X ∅ 8.5 ↧ 24.5
M10 - 6H ↧ 20
⌵ ∅ 10.5 X 90°, NEAR SIDE
10
10
20
VIEW B-B
A
B
B
A
R130
10X ∅ 14.00 THRU ALL
M16 - 6H THRU ALL
R60
R320
90°
0.8
∅ 180H7 +0.05 0.00
40
SECTION A-A
FINISH UON: DEBUR
GENERAL TOLERANCE
UON: ±0.1mm
1.6
ALL DIMENSIONS IN mm UON
SHEET:
1 of 1
THIRD ANGLE PROJECTION
DO NOT SCALE
SCALE: 1:8
SIZE: A4
DRAWN BY AARON STURK
MCEN4000 ASSIGNMENT
DESCRIPTION:
ADJUSTABLE ECCENTRIC MASS
MATERIAL
Plain Carbon Steel
PART:
15 ADJUSTABLE ECCENTRIC MASS
AUTHOR:
DRAWN DATE:
DWG REV.: A
MODEL REV.: A

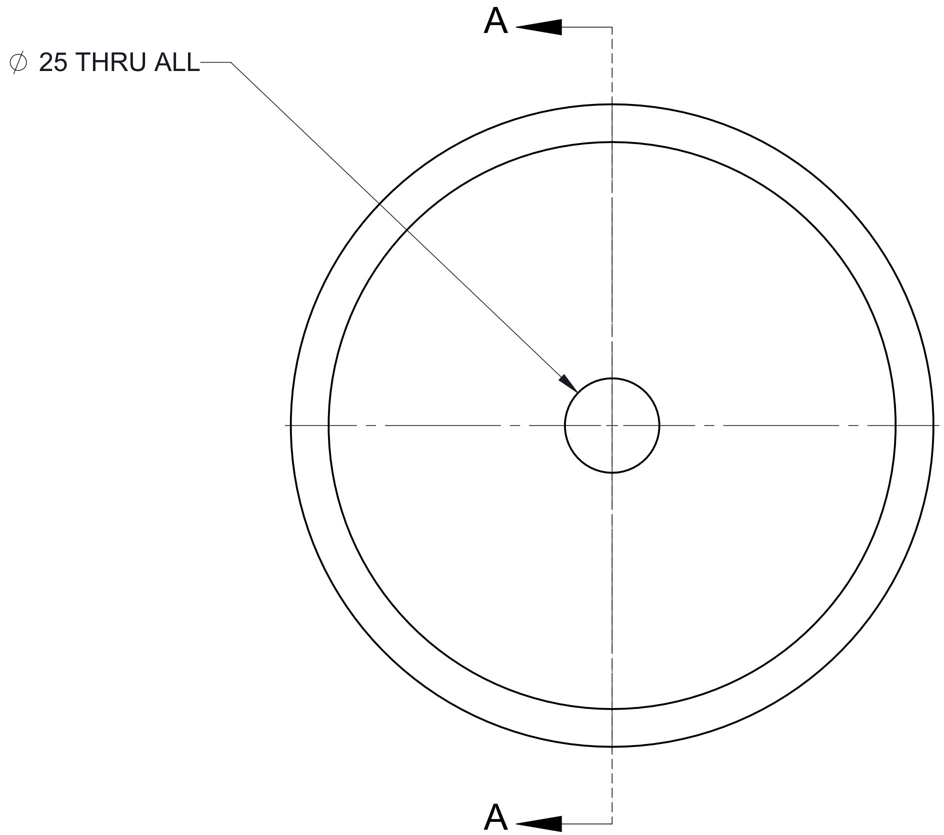
# Appendix X.3.13

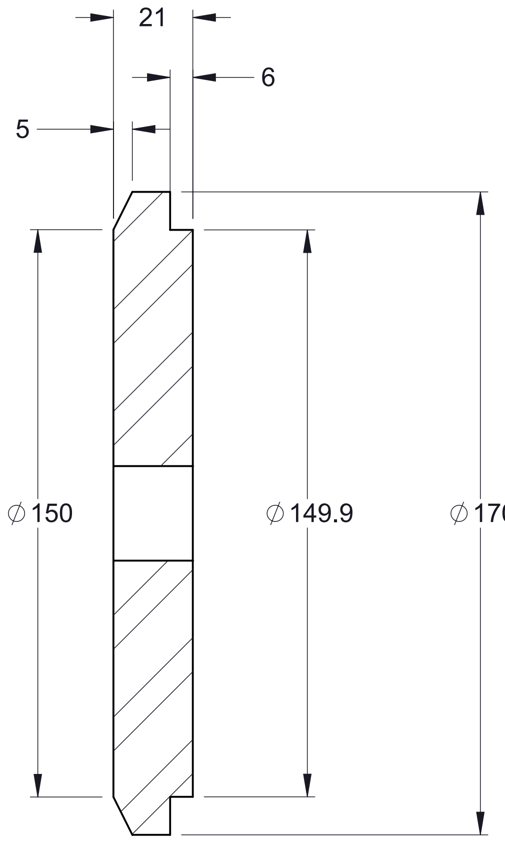
**Detailed Drawing of Part No. 16 Fixed Eccentric Mass of Best Concept Design**


2X ∅ 8.5 ↧ 24.5
M10 - 6H ↧ 20
∅ 10.5 X 90°, NEAR SIDE
10
50
VIEW B-B
R150
2X ∅ 17.5 THRU ALL
∅ 25.5 ↧ 20
∅ 25.6 X 90°, NEAR SIDE
6X ∅ 14 ↧ 50
M16X2.0 - 6H ↧ 44
∅ 17 X 90°, NEAR SIDE
40P9 -0.026 -0.088
R60
R320
90°
0.8
∅150H7 +0.04 0.00
9.4 +0.3 0.0
109
SECTION A-A
54.5
∅ 10.2 ↧ 29
M12 - 6H ↧ 24
∅ 12 X 90°, NEAR SIDE
FINISH UON: DEBUR
GENERAL TOLERANCE
UON: ±0.1mm
1.6
ALL DIMENSIONS IN mm UON
SHEET:
1 of 1
THIRD ANGLE PROJECTION
DO NOT SCALE
SCALE: 1:8
SIZE: A4
DRAWN BY AARON STURK
MCEN4000 ASSIGNMENT
DESCRIPTION:
FIXED ECCENTRIC MASS
MATERIAL
Plain Carbon Steel
PART:
16 FIXED ECCENTRIC MASS
AUTHOR:
DRAWN DATE:
DWG REV.: A
MODEL REV.: A

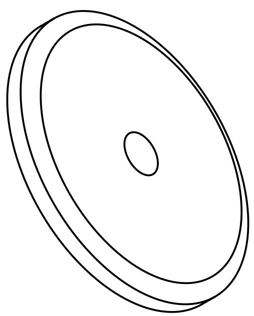
# Appendix X.3.14

**Detailed Drawing of Part No. 17 Locking Cap of Best Concept Design**




SECTION A-A



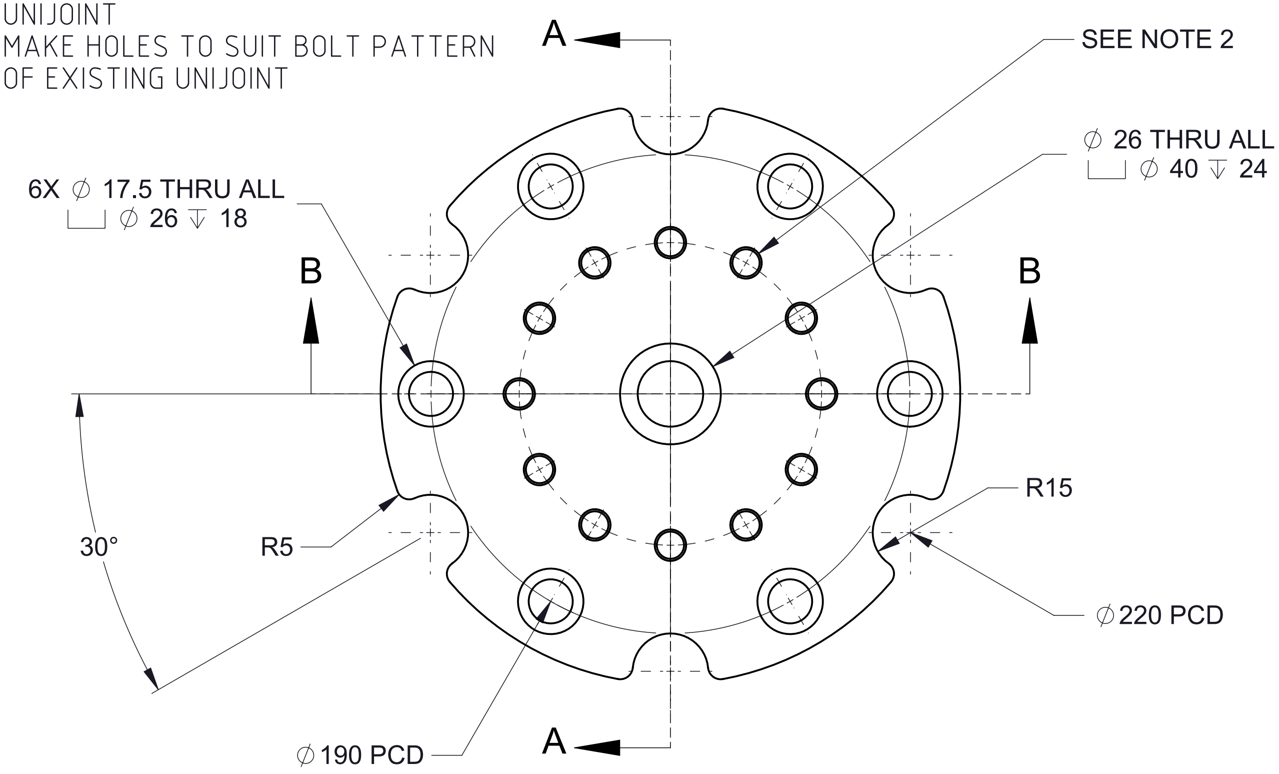
| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: LOCKING CAP |
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 1 of 1 | | | MATERIAL Plain Carbon Steel |
| DRAWN BY AARON STURK | | DO NOT SCALE | | |
| | | SCALE: 1:2 | SIZE: A4 | PART: 17 LOCKING CAP |

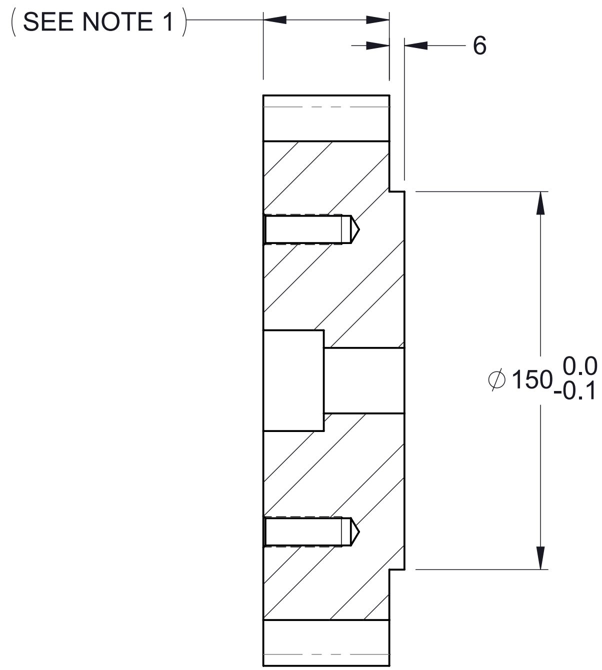
| AUTHOR: | DRAWN DATE: | DWG REV.: | MODEL REV.: |
|---|---|---|---|
| | | A | A |

# Appendix X.3.15

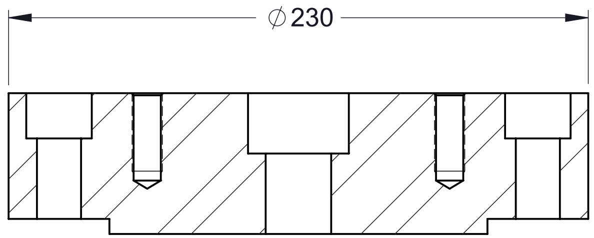
**Detailed Drawing of Part No. 18 Drive Adapter of Best Concept Design**

NOTES:
1. MAKE LENGTH TO SUIT EXISTING DRIVE UNIJOINT
2. MAKE HOLES TO SUIT BOLT PATTERN OF EXISTING UNIJOINT

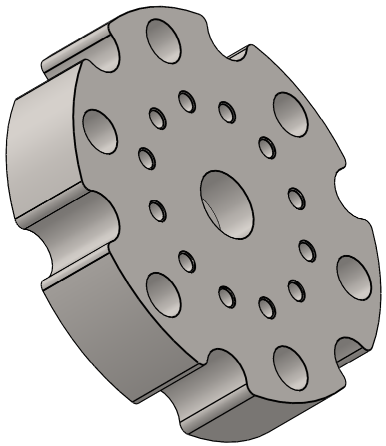



SECTION A-A




SECTION B-B



| | | | | |
|---|---|---|---|---|
| FINISH UON: DEBUR | ALL DIMENSIONS IN mm UON | THIRD ANGLE PROJECTION | MCEN4000 ASSIGNMENT | DESCRIPTION: DRIVE ADAPTER |
| GENERAL TOLERANCE UON: ±0.1mm 1.6 | SHEET: 1 of 1 | DO NOT SCALE | | MATERIAL Plain Carbon Steel |
| DRAWN BY AARON STURK | | SCALE: 1:3 / SIZE: A4 | | PART: 18 DRIVE ADAPTER / AUTHOR: / DRAWN DATE: / DWG REV.: A / MODEL REV.: A |

# Appendix Y.1

**DFM Concurrent Costing Analysis Report of Part No. 1 Gearbox Casing of Best Concept Design**

## DFMA® - Boothroyd Dewhurst, Inc.
# DFM Concurrent Costing
# Executive Summary

Friday, 14 October 2022

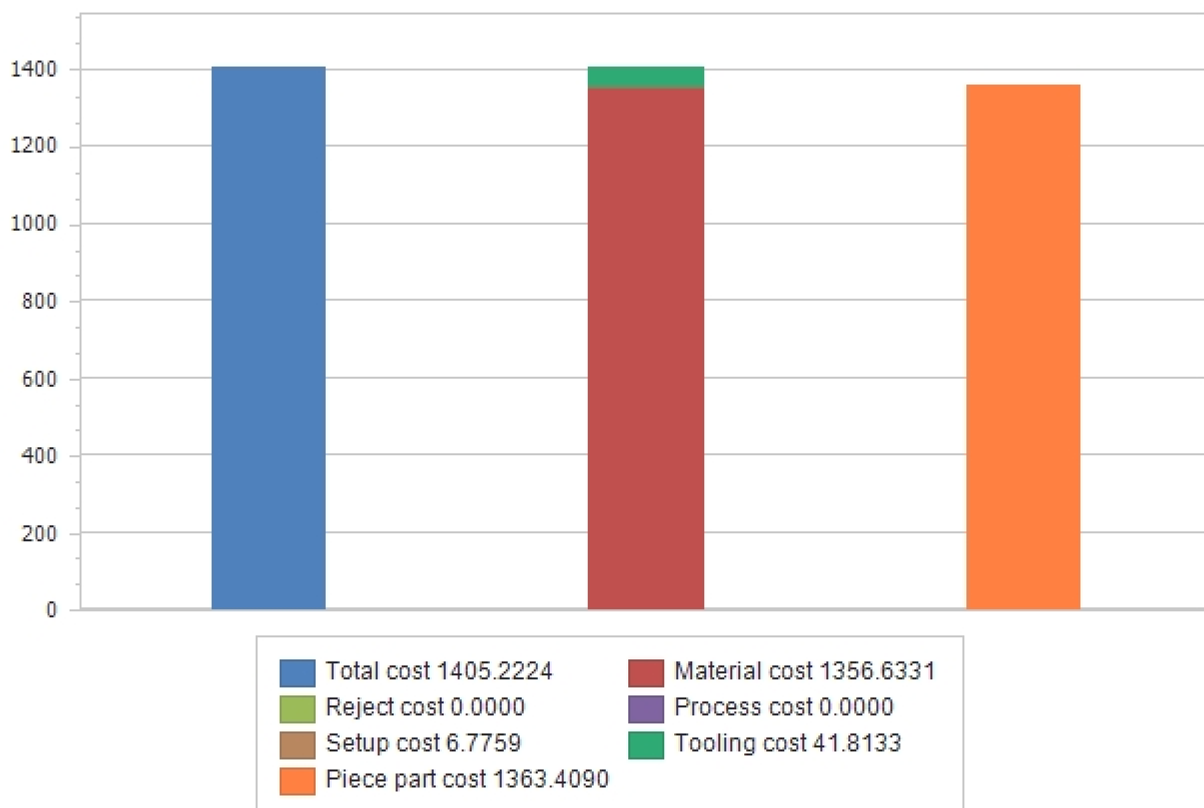
Gearbox Casing.dfmx

Analysis Name: 1 GEARBOX CASING
Part name: 1 GEARBOX CASING
Part number:

Material name: Generic low carbon steel
Manufacturing process: Sand casting, automatic
Manufacturing profile: 20A BDI North America

| | |
|---|---|
| Product life volume | 1,500 |
| Batch size | 187 |
| Total cost, $ | 1405.2224 |
| Piece part cost, $ | 1363.4090 |
| Initial tooling investment, $ | 62,720 |

**The chart shows a breakdown of cost per part, $**



# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Notes

Friday, 14 October 2022

Gearbox Casing.dfmx

Analysis Name: 1 GEARBOX CASING

Part name: 1 GEARBOX CASING

Part number:

Material name: Generic low carbon steel

Manufacturing process: Sand casting, automatic

Manufacturing profile: 20A BDI North America

## Setup/load/unload

Jig to be fabricated to allow for machining of base/datum surface.

## Rough and finish cylindrical bore

First bore for bearing recess.

## Rough and finish cylindrical bore

Second bearing recess.

## Tap multiple holes (Metric, fine)

Drill and tap cover plate holes.

## Finish face mill

This process mills the top faces of the hold down bolts to ensure flat face for tensioning of bolts.

## Finish face mill

Inspection cover recess

## Tap multiple holes (UNC)

Plugs and breather holes.

## Tap multiple holes (UNF)

Oil fil hole mounted on side of casing.

# DFM Concurrent Costing Responses

Friday, 14 October 2022

Gearbox Casing.dfmx

Analysis Name: 1 GEARBOX CASING
Part name: 1 GEARBOX CASING
Part number:

Material name: Generic low carbon steel
Manufacturing process: Sand casting, automatic
Manufacturing profile: 20A BDI North America

## Generic low carbon steel sand cast part

| Part | |
|---|---|
| Part name | 1 GEARBOX CASING |
| Part number | |
| Life volume | 1500 |
| Envelope shape | Solid block |
| Part length, mm | 1389.697 |
| Part width, mm | 500.000 |
| Part height, mm | 730.000 |
| Average thickness, mm | 107.747 |
| Forming direction | Z |

## Automatic sand casting process

| Part basic data | |
|---|---|
| Batch size | 187 |
| Overall plant efficiency, % | 85.00 |
| Material cost, $/kg | 0.838 |
| Material scrap value, $/kg | 0.110 |
| Pattern material | Stainless steel |
| Number of impressions | 1 |
| Number of different cores used | 0 |

| Part geometry | |
|---|---|
| Volume, $cm^3$ | 109307.511 |
| Part weight, kg | 856.245 |
| Projected area, $cm^2$ | 6601.062 |
| Outer perimeter, mm | 3779.394 |

| Pattern complexity | |
|---|---|
| Surface patches | 50 |

| Cast part | |
|---|---|
| Process rate per worker, $/hr | 70.00 |
| Setup rate, $/hr | 70.00 |
| Setup time, man-hr | 16.00 |
| Rejects, % | 0.00 |
| Impression life | 180000 |
| Pattern manufacturing rate, $/hr | 36.00 |
| Pattern manufacturing time, hr | 1742.22 |
| Operation time per part, worker seconds | 276.92 |
| Part material cost, $ | 1326.8010 |
| Mold sand cost, $ | 29.8321 |

| Shakeout part | |
|---|---|
| Process rate, $/hr | 25.00 |
| Rejects, % | 0.00 |
| Operation time per part, s | 1051.62 |

| Cutoff and trim | |
|---|---|
| Process rate, $/hr | 25.00 |
| Rejects, % | 0.00 |
| Operation time per part, s | 1639.90 |

| Shot blast | |
|---|---|
| Process rate, $/hr | 25.00 |
| Rejects, % | 2.00 |
| Operation time per part, s | 536.06 |

| Cincinnati Falcon TC-300/1000 turning center |
|---|

| Basic data | |
|---|---|
| Batch size | 187 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |

| Machine tool data | |
|---|---|
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 20.40 |
| Operator rate, $/hr | 25.00 |
| Process rate, $/hr | 32.90 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |

| Live tool data | |
|---|---|
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |

| Result | |
|---|---|
| Cycle time per part, s | 157.40 |
| Total setup time, hr | 0.39 |

## Setup/load/unload

| Work handling | |
|---|---|
| Workholding device | Collet |
| Number of reversals | 0 |
| Load/unload time, s | 78.70 |
| Additional down-time, s | 78.70 |

**Machine setup**

| | |
|---|---|
| Machine rate during setup, $/hr | 16.90 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 46.90 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |

| **Other costs** | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

## Haas HMC HS-3

| **Basic data** | |
|---|---|
| Batch size | 187 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |

| **Machine tool data** | |
|---|---|
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 29.50 |
| Operator rate, $/hr | 25.00 |
| Process rate, $/hr | 42.00 |
| Power available, kW | 15.66 |
| Tool positioning or index time, s | 5.00 |
| Tool change time, s | 13.00 |
| Maximum spindle speed, rpm | 5000.00 |
| Maximum depth of cut, mm | 5.080 |

| **Result** | |
|---|---|
| Cycle time per part, s | 0.00 |
| Total setup time, hr | 2.30 |

## Setup/load/unload

**Work handling**

| | |
|---|---|
| Workholding device | Jig |
| Number of reversals | 1 |
| Load/unload time, s | 149.28 |
| Reversal time, s | 217.93 |
| **Machine setup** | |
| Machine rate during setup, $/hr | 26.00 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 56.00 |
| Basic setup time, hr | 0.35 |
| Setup time per tool, hr | 0.15 |
| **Other costs** | |
| Tool, fixture or program cost, $ | 0 |

## Finish face mill

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 500.000 |
| Length of surface to be milled (lc), mm | 940.000 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Cutter diameter, mm | 304.800 |
| Number of teeth | 20.000 |
| Cutting speed, m/min | 374.624 |
| Feed per tooth, mm | 0.066 |
| Feed speed, mm/s | 8.638 |
| Number of passes | 2.000 |
| Width per pass, mm | 250.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 391 |

| Results | |
|---|---|
| Operation time, s | 300.0000 |

| Rough multiple slot end mill | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 168.000 |
| Length of surface to be milled (lc), mm | 432.500 |
| Total depth of material removed (dt), mm | 100.000 |
| Number of features milled | 2 |

| Machining data | |
|---|---|
| Tool diameter, mm | 50.800 |
| Number of teeth | 4.000 |
| Cutting speed, m/min | 96.317 |
| Feed per tooth, mm | 0.178 |
| Feed speed, mm/s | 7.152 |
| Vertical passes | 20.000 |
| Depth per pass, mm | 5.000 |
| Horizontal passes | 4.000 |
| Width per pass, mm | 42.000 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 15.66 |
| Power required, kW | 6.15 |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 603 |

| Results | |
|---|---|
| Operation time, s | 11674.0000 |
| Total volume removed, $cm^3$ | 14532.032 |

| Finish multiple slot end mill | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 168.000 |
| Length of surface to be milled (lc), mm | 432.500 |
| Number of features milled | 2 |
| Surface roughness | 250 µin. 6.3 µm |
| **Machining data** | |
| Tool diameter, mm | 50.800 |
| Number of teeth | 4.000 |
| Cutting speed, m/min | 128.101 |
| Feed per tooth, mm | 0.269 |
| Feed speed, mm/s | 14.413 |
| Number of passes | 4.000 |
| Width per pass, mm | 42.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 803 |
| **Results** | |
| Operation time, s | 310.0000 |

| Finish multiple slot end mill | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 0.000 |
| Length of surface to be milled (lc), mm | 0.000 |
| Number of features milled | 2 |

| | |
|---|---|
| Surface roughness | 125 µin. 3.1 µm |
| WARNING | enter dimensions |

## Drill multiple holes

| | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 37.000 |
| Length of drilled holes (lh), mm | 40.000 |
| Number of identical holes drilled | 14 |
| Number of holes drilled simultaneously | 1 |
| **Machining data** | |
| Cutting speed, m/min | 41.832 |
| Feed per revolution, mm | 0.684 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 15.66 |
| Power required, kW | 15.66 |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 360 |
| **Results** | |
| Operation time, s | 335.0000 |
| Total volume removed, cm³ | 602.120 |

## Rough and finish cylindrical bore

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 340.000 |
| Diameter of machined surface (dm), mm | 330.000 |
| Length of machined surface (lm), mm | 262.000 |
| Finish cut allowance on radius, mm | 2.000 |
| Surface roughness | 32 µin. 0.8 µm |

| | |
|---|---|
| WARNING | dw must be less than dm |

| **Results** | |
|---|---|
| Total volume removed, cm³ | 3686.908 |

| **Rough and finish cylindrical bore** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 340.000 |
| Diameter of machined surface (dm), mm | 330.000 |
| Length of machined surface (lm), mm | 232.000 |
| Finish cut allowance on radius, mm | 2.000 |
| Surface roughness | 32 µin. 0.8 µm |
| WARNING | dw must be less than dm |

| **Results** | |
|---|---|
| Total volume removed, cm³ | 3264.743 |

| **Drill multiple holes** | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 10.500 |
| Length of drilled holes (lh), mm | 40.250 |
| Number of identical holes drilled | 16 |
| Number of holes drilled simultaneously | 1 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 23.877 |
| Feed per revolution, mm | 0.195 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 15.66 |

| | |
|---|---|
| Power required, kW | 0.72 |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 724 |
| **Results** | |
| Operation time, s | 448.0000 |
| Total volume removed, cm³ | 55.764 |

| **Tap multiple holes (Metric, fine)** | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 12.000 |
| Length to be tapped (lt), mm | 40.250 |
| Number of holes tapped | 16 |
| Holes tapped simultaneously | 0 |
| **Machining data** | |
| Thread pitch, mm | 1.500 |
| Cutting speed, m/min | 7.422 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 5000 |
| **Results** | |
| Operation time, s | 0.0000 |

| **Drill multiple holes** | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 10.000 |
| Length of drilled holes (lh), mm | 360.000 |
| Number of identical holes drilled | 2 |

| | |
|---|---|
| Number of holes drilled simultaneously | 1 |
| **Machining data** | |
| Cutting speed, m/min | 4.674 |
| Feed per revolution, mm | 0.102 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 15.66 |
| Power required, kW | 0.07 |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 149 |
| **Results** | |
| Operation time, s | 3310.0000 |
| Total volume removed, $cm^3$ | 56.549 |

| **Finish face mill** | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 1330.000 |
| Length of surface to be milled (lc), mm | 1873.900 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Cutter diameter, mm | 304.800 |
| Number of teeth | 20.000 |
| Cutting speed, m/min | 374.624 |
| Feed per tooth, mm | 0.066 |
| Feed speed, mm/s | 8.638 |
| Number of passes | 5.000 |
| Width per pass, mm | 266.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |

| | |
|---|---|
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 391 |
| **Results** | |
| Operation time, s | 1302.0000 |

## Drill multiple holes

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 10.250 |
| Length of drilled holes (lh), mm | 40.250 |
| Number of identical holes drilled | 16 |
| Number of holes drilled simultaneously | 1 |
| **Machining data** | |
| Cutting speed, m/min | 23.711 |
| Feed per revolution, mm | 0.191 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 15.66 |
| Power required, kW | 0.68 |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 736 |
| **Results** | |
| Operation time, s | 449.0000 |
| Total volume removed, $cm^3$ | 53.140 |

## Tap multiple holes (Metric, fine)

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 12.000 |
| Length to be tapped (lt), mm | 40.250 |

| | |
|---|---|
| Number of holes tapped | 16 |
| Holes tapped simultaneously | 1 |
| **Machining data** | |
| Thread pitch, mm | 1.500 |
| Cutting speed, m/min | 7.422 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 5000 |
| **Results** | |
| Operation time, s | 104.0000 |

| **Finish face mill** | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 1330.000 |
| Length of surface to be milled (lc), mm | 1873.900 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Cutter diameter, mm | 304.800 |
| Number of teeth | 20.000 |
| Cutting speed, m/min | 374.624 |
| Feed per tooth, mm | 0.066 |
| Feed speed, mm/s | 8.638 |
| Number of passes | 5.000 |
| Width per pass, mm | 266.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 391 |

| Results | |
|---|---|
| Operation time, s | 1302.0000 |

## Finish face mill

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 130.000 |
| Length of surface to be milled (lc), mm | 1050.000 |
| Surface roughness | 32 µin. 0.8 µm |

| Machining data | |
|---|---|
| Cutter diameter, mm | 195.000 |
| Number of teeth | 13.000 |
| Cutting speed, m/min | 374.624 |
| Feed per tooth, mm | 0.058 |
| Feed speed, mm/s | 7.697 |
| Number of passes | 1.000 |
| Width per pass, mm | 130.000 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 611 |

| Results | |
|---|---|
| Operation time, s | 168.0000 |

## Drill multiple holes

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 10.500 |
| Length of drilled holes (lh), mm | 24.000 |

| | |
|---|---|
| Number of identical holes drilled | 10 |
| Number of holes drilled simultaneously | 1 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 27.873 |
| Feed per revolution, mm | 0.213 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 15.66 |
| Power required, kW | 0.92 |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 845 |

| **Results** | |
|---|---|
| Operation time, s | 183.0000 |
| Total volume removed, $cm^3$ | 20.782 |

| **Tap multiple holes (Metric, fine)** | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 12.000 |
| Length to be tapped (lt), mm | 24.000 |
| Number of holes tapped | 10 |
| Holes tapped simultaneously | 1 |

| **Machining data** | |
|---|---|
| Thread pitch, mm | 1.500 |
| Cutting speed, m/min | 7.422 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 5000 |

**Results**

| | |
|---|---|
| Operation time, s | 67.0000 |

| Tap multiple holes (UNC) | |
|---|---|
| Tool change needed? | No |
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 12.000 |
| Length to be tapped (lt), mm | 24.500 |
| Number of holes tapped | 4 |
| Holes tapped simultaneously | 1 |
| **Machining data** | |
| Threads per inch | 11.000 |
| Cutting speed, m/min | 11.522 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 306 |
| **Results** | |
| Operation time, s | 40.0000 |

| Tap multiple holes (UNC) | |
|---|---|
| Tool change needed? | No |
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 33.400 |
| Length to be tapped (lt), mm | 50.000 |
| Number of holes tapped | 4 |
| Holes tapped simultaneously | 1 |
| **Machining data** | |
| Threads per inch | 7.000 |

| | |
|---|---|
| Cutting speed, m/min | 8.589 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 82 |
| **Results** | |
| Operation time, s | 120.0000 |

| **Tap multiple holes (UNF)** | |
|---|---|
| Tool change needed? | No |
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 10.000 |
| Length to be tapped (lt), mm | 237.700 |
| Number of holes tapped | 2 |
| Holes tapped simultaneously | 1 |
| **Machining data** | |
| Threads per inch | 20.000 |
| Cutting speed, m/min | 16.993 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 5000 |
| Spindle speed required, rpm | 541 |
| **Results** | |
| Operation time, s | 94.0000 |

## DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing
# Cost Breakdown

Friday, 14 October 2022

Gearbox Casing.dfmx

Analysis Name: 1 GEARBOX CASING
Part name: 1 GEARBOX CASING
Part number:
Part weight: 856.245 kg

Material name: Generic low carbon steel
Manufacturing process: Sand casting, automatic
Manufacturing profile: 20A BDI North America

| Cost per part, $ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process Chart** | **Batch size** | **Material** | **Setup** | **Process** | **Rejects** | **Piece part** | **Tooling** | **Total** | **Operation time per part, s** | **Initial tooling investment** |
| **Generic low carbon steel sand cast part** | | **1356.6331** | **6.7759** | | | **1363.4090** | **41.8133** | **1405.2224** | | **62,720** |
| **Automatic sand casting process** | **187** | **1356.6331** | **5.9893** | **151.4028** | **28.8885** | **1542.9137** | **41.8133** | **1584.7271** | **3227.58** | **62,720** |
| Cast part | | 1356.6331 | 5.9893 | 125.0336 | | 1487.6560 | 41.8133 | 1529.4694 | | 62,720 |
| Shakeout part | | | | 8.5917 | | 8.5917 | | 8.5917 | 1051.62 | |
| Cutoff and trim | | | | 13.3979 | | 13.3979 | | 13.3979 | 1639.90 | |
| Shot blast | | | | 4.3796 | 28.8885 | 33.2681 | | 33.2681 | 536.06 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.0978** | **1.6923** | **7.2574** | **9.0476** | | **9.0476** | **157.40** | |
| Setup/load/unload | | | 0.0978 | 1.6923 | | 1.7901 | | 1.7901 | 78.70 | |
| **Haas HMC HS-3** | | | **0.6888** | | | **0.6888** | | **0.6888** | | |
| Setup/load/unload | | | 0.6888 | 5.0401 | | 5.7289 | | 5.7289 | 367.21 | |
| Finish face mill | | | | 5.2429 | | 5.2429 | | 5.2429 | 300.00 | |
| Rough multiple slot end mill | | | | 202.4684 | | 202.4684 | | 202.4684 | 11674.00 | |
| Finish multiple slot end mill | | | | 5.3028 | | 5.3028 | | 5.3028 | 310.00 | |
| Finish multiple slot end mill | | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Drill multiple holes | | | | 4.6142 | | 4.6142 | | 4.6142 | 335.00 | |
| Rough and finish cylindrical bore | | | | | | | | | | |
| Rough and finish cylindrical bore | | | | | | | | | | |
| Drill multiple holes | | | | 6.6054 | | 6.6054 | | 6.6054 | 448.00 | |
| Tap multiple holes (Metric, fine) | | | | | | | | | | |
| Drill multiple holes | | | | 50.1704 | | 50.1704 | | 50.1704 | 3310.00 | |
| Finish face mill | | | | 22.7856 | | 22.7856 | | 22.7856 | 1302.00 | |
| Drill multiple holes | | | | 6.6219 | | 6.6219 | | 6.6219 | 449.00 | |
| Tap multiple holes (Metric, fine) | | | | 1.4275 | | 1.4275 | | 1.4275 | 104.00 | |
| Finish face mill | | | | 22.7856 | | 22.7856 | | 22.7856 | 1302.00 | |
| Finish face mill | | | | 2.9368 | | 2.9368 | | 2.9368 | 168.00 | |
| Drill multiple holes | | | | 2.6448 | | 2.6448 | | 2.6448 | 183.00 | |
| Tap multiple holes (Metric, fine) | | | | 0.9196 | | 0.9196 | | 0.9196 | 67.00 | |
| Tap multiple holes (UNC) | | | | 0.5629 | | 0.5629 | | 0.5629 | 40.00 | |
| Tap multiple holes (UNC) | | | | 1.7144 | | 1.7144 | | 1.7144 | 120.00 | |
| Tap multiple holes (UNF) | | | | 1.3594 | | 1.3594 | | 1.3594 | 94.00 | |

## DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing

# Totals

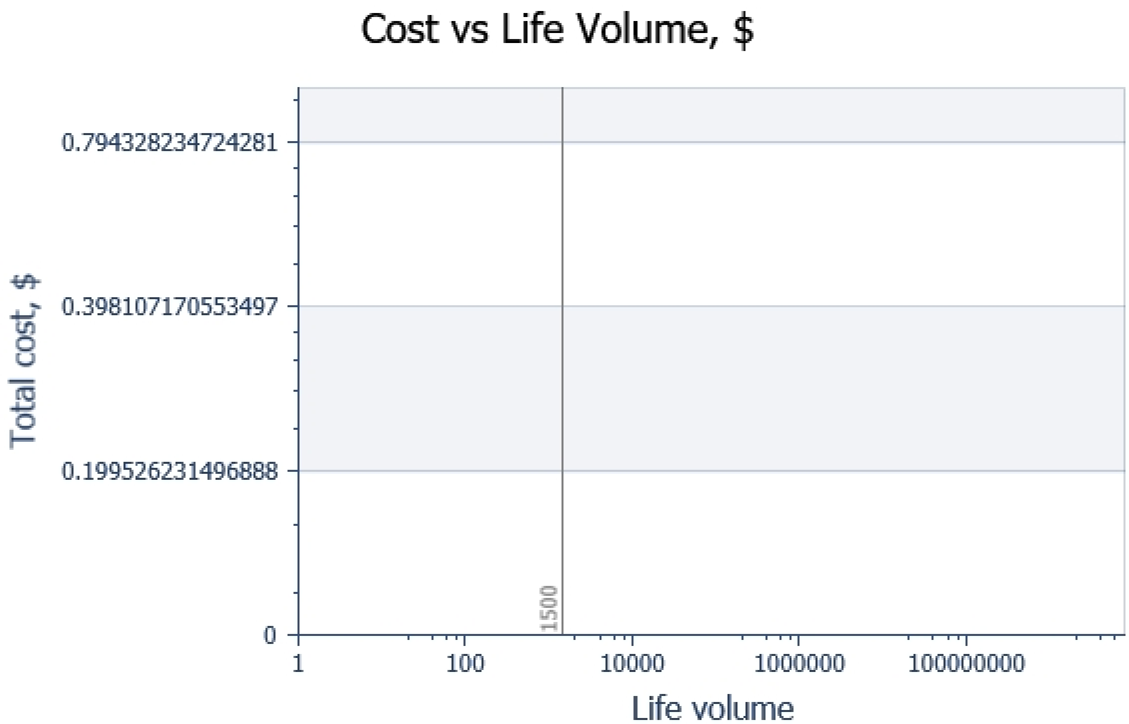
Friday, 14 October 2022

Gearbox Casing.dfmx

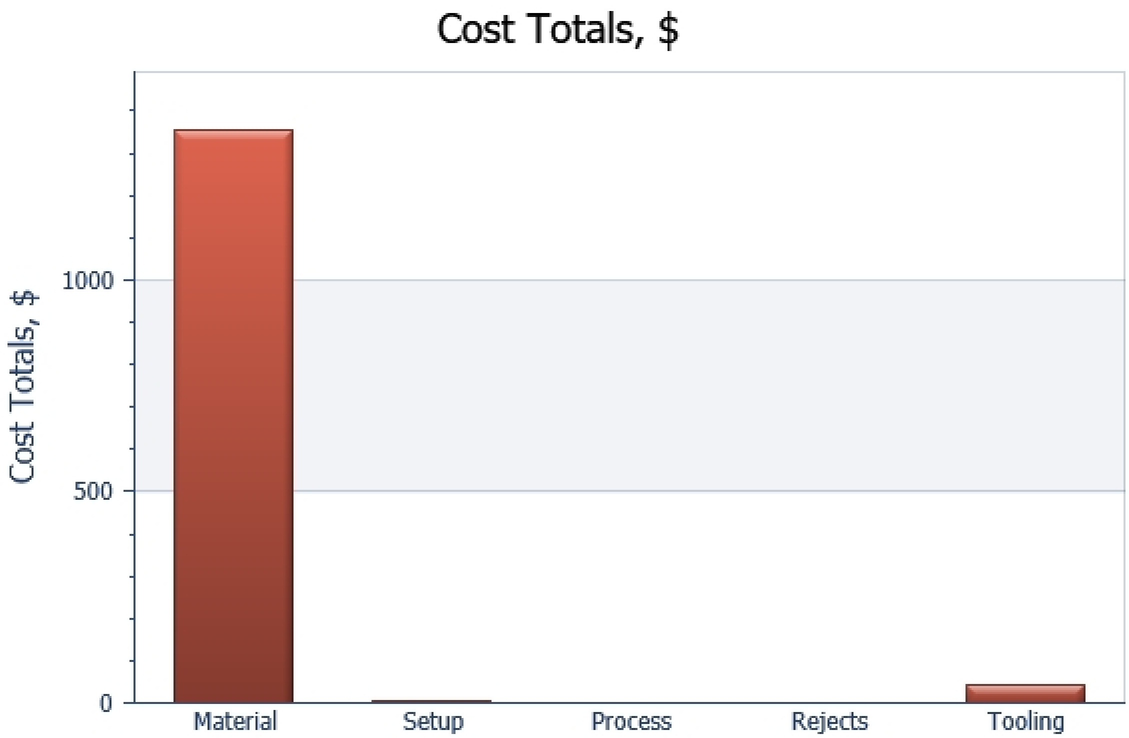
| **Analysis Name** | **1 GEARBOX CASING** |
|---|---|
| Part name | 1 GEARBOX CASING |
| Part number | |
| Material | Generic low carbon steel |
| Manufacturing process | Sand casting, automatic |
| Manufacturing profile | 20A BDI North America |

| Cost per part, $ | Value |
|---|---|
| Material | 1356.6331 |
| Setup | 6.7759 |
| Process | 0.0000 |
| Rejects | 0.0000 |
| Piece part | 1363.4090 |
| Tooling | 41.8133 |
| Total | 1405.2224 |
| Initial tooling investment | 62720.0143 |

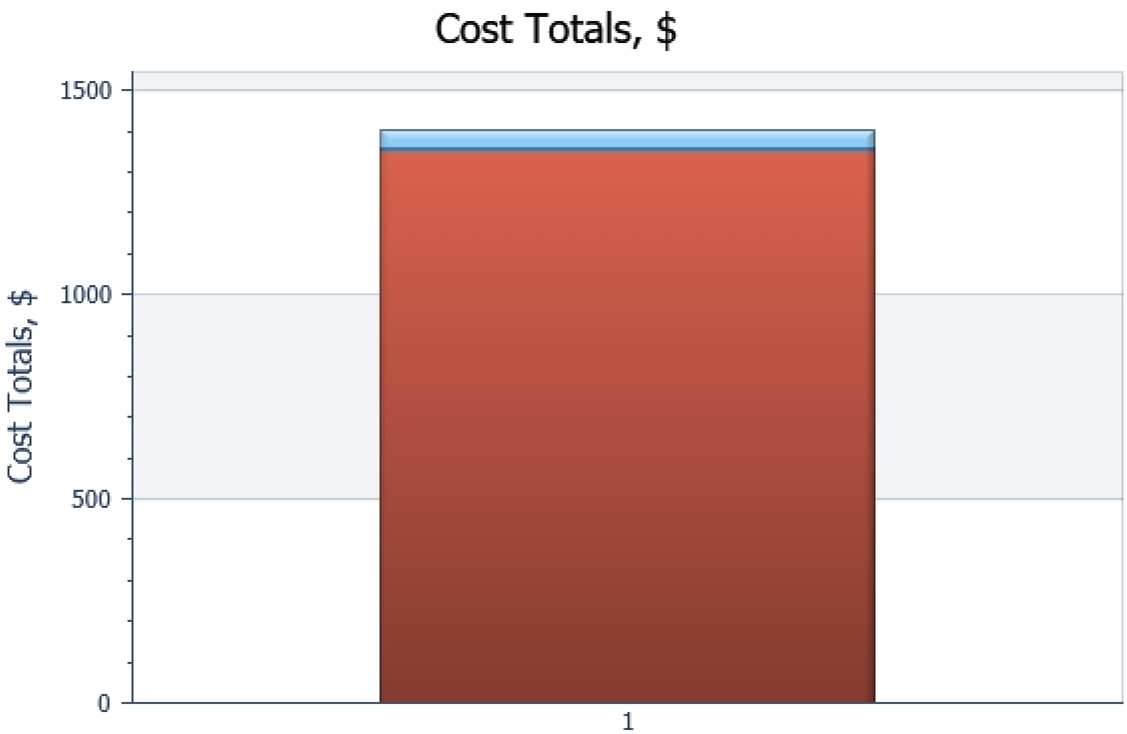
| | |
|---|---|
| Life volume | 1,500 |
| Batch size | 187 |
| Part weight | 856.245 |



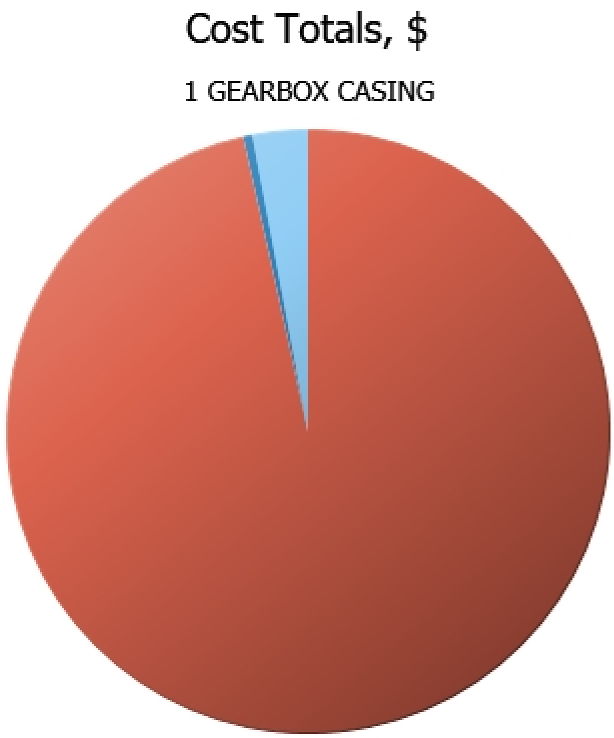

| Cost per part, $ | 1 GEARBOX CASING Sand casting, automatic Generic low carbon steel |
|---|---|
| Life volume | 1,500 |
| Material | 1356.6331 |
| Setup | 6.7759 |
| Process | ∞ |
| Rejects | ∞ |
| Piece part | ∞ |
| Tooling | 41.8133 |
| Total | ∞ |
| Initial tooling investment | 62720.0143 |




| Cost per part, $ | 1 GEARBOX CASING<br>Sand casting, automatic<br>Generic low carbon steel |
|---|---|
| Life volume | 1,500 |
| Material | 1356.6331 |
| Setup | 6.7759 |
| Process | ∞ |
| Rejects | ∞ |
| Piece part | ∞ |
| Tooling | 41.8133 |
| Total | ∞ |
| Initial tooling investment | 62720.0143 |




| | Cost per part, $ | 1 1 GEARBOX CASING<br>Sand casting, automatic<br>Generic low carbon steel |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 1356.6331 |
| | Setup | 6.7759 |
| | Process | ∞ |
| | Rejects | ∞ |
| | Piece part | ∞ |
| | Tooling | 41.8133 |
| | Total | ∞ |
| | Initial tooling investment | 62720.0143 |




| | Cost per part, $ | 1 1 GEARBOX CASING<br>Sand casting, automatic<br>Generic low carbon steel |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 1356.6331 |
| | Setup | 6.7398 |
| | Process | ∞ |
| | Rejects | ∞ |
| | Piece part | ∞ |
| | Tooling | 41.8133 |
| | Total | ∞ |
| | Initial tooling investment | 62720.0143 |

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing
# Guide to Cost Reduction

Friday, 14 October 2022

Gearbox Casing.dfmx

Analysis Name: 1 GEARBOX CASING

Part name: 1 GEARBOX CASING

Part number:

Material name: Generic low carbon steel

Manufacturing process: Sand casting, automatic

Manufacturing profile: 20A BDI North America

For the product life volume of 1500 and the batch size of 187 you have specified, the tooling costs form 2.98% of the total cost of 1,405.22. The chart provides an indication of the contributions to this total cost made by various factors. Note that, if there are cores needed, the total contributions from all cores is shown.When considering changes to reduce cost you may wish to concentrate on the most significant cost contributors.


| Category | Savings, $ |
|---|---|
| Avoidable setups | 5.7289 |

# Appendix Y.2

**DFM Concurrent Costing Analysis Report of Part No. 2 Inspection Cover of Best Concept Design**

# DFM Concurrent Costing
# Executive Summary

Friday, 14 October 2022

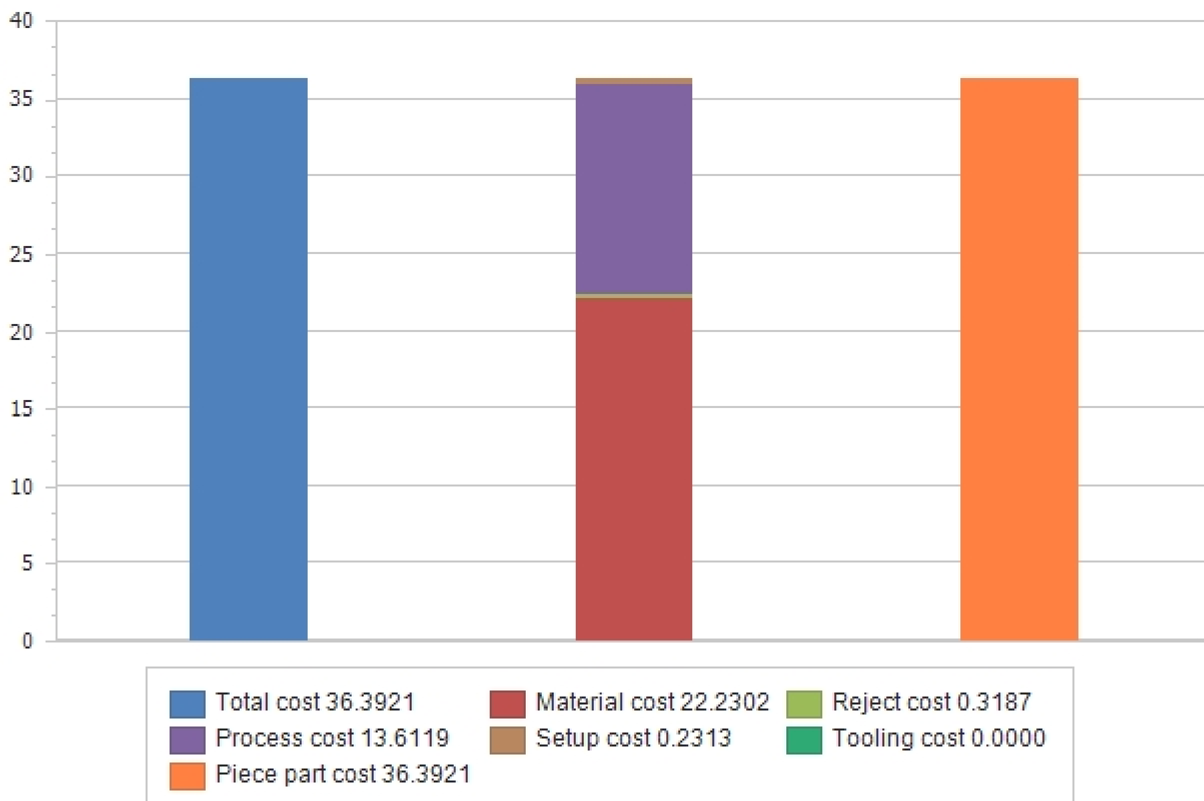
Inspection Cover.dfmx

Analysis Name: 2 INSPECTION COVER (2)
Part name: 2 INSPECTION COVER (2)
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Sheet metal laser cutting
Manufacturing profile: 20A BDI North America

| | |
|---|---|
| Product life volume | 1,500 |
| Batch size | 187 |
| Total cost, $ | 36.3921 |
| Piece part cost, $ | 36.3921 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Notes

Friday, 14 October 2022

Inspection Cover.dfmx

Analysis Name: 2 INSPECTION COVER (2)

Part name: 2 INSPECTION COVER (2)

Part number:

Material name: Low carbon steel, cold rolled, commercial quality

Manufacturing process: Sheet metal laser cutting

Manufacturing profile: 20A BDI North America

# DFM Concurrent Costing

## Responses

Friday, 14 October 2022

Inspection Cover.dfmx

Analysis Name: 2 INSPECTION COVER (2)
Part name: 2 INSPECTION COVER (2)
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Sheet metal laser cutting
Manufacturing profile: 20A BDI North America

## Low carbon steel, cold rolled, commercial quality sheet metal part

| Part | |
|---|---|
| Part name | 2 INSPECTION COVER (2) |
| Part number | |
| Life volume | 1500 |
| Envelope shape | Solid block |
| Part length, mm | 1030.000 |
| Part width, mm | 280.000 |
| Part height, mm | 10.000 |
| Average thickness, mm | 9.844 |
| Forming direction | Z |

## Laser cutting process

| Basic data | |
|---|---|
| Batch size | 187 |
| Overall plant efficiency, % | 85.00 |
| Material cost, $/kg | 0.904 |
| Material scrap value, $/kg | 0.110 |
| Gage thickness, mm | 9.844 |
| Automatic sheet size selection? | Yes |
| Sheet size | 2134 x 1219 mm |
| Part to part clearance, mm | 16.355 |
| Part to sheet edge clearance, mm | 16.355 |
| Parts along sheet length | 2 |
| Parts along sheet width | 4 |
| Parts per sheet | 8 |

| Part basic data | |
|---|---|
| Area of part, cm² | 2739.800 |
| Unfolded length, mm | 1030.000 |
| Unfolded width, mm | 280.000 |
| Length overlap, mm | 0.000 |
| Width overlap, mm | 0.000 |
| Mutually exclusive overlaps? | Yes |

| Additional setups | |
|---|---|
| Hole punching | 0 |
| Form feature punching | 0 |
| Combination punch operation | 0 |
| Die bend forming | 0 |
| Press brake | 0 |

| Primary loading data | |
|---|---|
| Crane primary loading | Yes |
| Crane operation time, s | 260.00 |
| Sheets loaded simultaneously | 1 |
| Sheets stacked | 1 |

| Processing data | |
|---|---|
| Cutting conditions | Best quality |
| Cutting speed, mm/min | 1403.13 |
| Piercing time, s | 5.85 |

| Primary unloading data | |
|---|---|
| Unloaded as sheet | Yes |
| Crane primary unloading | Yes |
| Crane operation time, s | 260.00 |
| Sheets unloaded simultaneously | 1 |

| Laser cut data | |
|---|---|
| External cut perimeter, mm | 2700.000 |
| Number of holes | 56 |

| | |
|---|---|
| Perimeter of holes, mm | 2254.255 |

## Cincinnati CL-6 Laser System

| **Machine selection** | |
|---|---|
| Automatic selection? | Yes |

| **Laser cutting machine characteristics** | |
|---|---|
| Laser power, Watts | 2000.00 |
| Number of cutting heads | 1 |
| Tool positioning time, s | 0.30 |
| Maximum sheet length, mm | 3048 |
| Maximum sheet width, mm | 1524 |

| **Processing data** | |
|---|---|
| Machine rate, $/hr | 22.20 |
| Operator rate, $/hr | 25.00 |
| Number of machines per operator | 1.00 |
| Process rate, $/hr | 47.20 |
| Rejects, % | 0.50 |
| Piercing operations | 59 |

| **Result** | |
|---|---|
| Process time per part, s | 639.59 |

## Load and unload

| **Operation result** | |
|---|---|
| Operation time per part, s | 65.00 |

| **Machine setup data** | |
|---|---|
| Machine rate during setup, $/hr | 18.70 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 48.70 |
| Setup time, hr | 0.50 |

| Laser cut tooling data | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

## Laser cut operation

| Operation result | |
|---|---|
| Operation time per part, s | 574.59 |

## Generic small manual drill press

| Basic data | |
|---|---|
| Batch size | 187 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |

| Machine tool data | |
|---|---|
| Number of machines per operator | 1.00 |
| Machine rate, $/hr | 5.00 |
| Operator rate, $/hr | 25.00 |
| Process rate, $/hr | 30.00 |
| Power available, kW | 0.82 |
| Tool positioning or index time, s | 9.00 |
| Tool change time, s | 12.00 |
| Maximum spindle speed, rpm | 2000.00 |

| Result | |
|---|---|
| Cycle time per part, s | 382.00 |
| Total setup time, hr | 0.60 |

## Setup/load/unload

| Work handling | |
|---|---|
| Workholding device | Jig |
| Number of reversals | 0 |

| | |
|---|---|
| Load/unload time, s | 49.00 |
| **Machine setup** | |
| Machine rate during setup, $/hr | 1.50 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 31.50 |
| Basic setup time, hr | 0.24 |
| Setup time per tool, hr | 0.12 |
| **Other costs** | |
| Tool, fixture or program cost, $ | 0 |

| **Drill multiple holes** | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 10.250 |
| Length of drilled holes (lh), mm | 10.000 |
| Number of identical holes drilled | 4 |
| Number of holes drilled simultaneously | 1 |
| **Machining data** | |
| Cutting speed, m/min | 22.087 |
| Feed per revolution, mm | 0.245 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 0.82 |
| Power required, kW | 0.82 |
| Spindle speed available, rpm | 2000 |
| Spindle speed required, rpm | 686 |
| **Results** | |
| Operation time, s | 67.0000 |
| Total volume removed, $cm^3$ | 3.301 |

| Tap multiple holes (Metric, fine) | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 12.000 |
| Length to be tapped (lt), mm | 10.000 |
| Number of holes tapped | 4 |
| Holes tapped simultaneously | 1 |
| **Machining data** | |
| Thread pitch, mm | 1.750 |
| Cutting speed, m/min | 2.969 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 2000 |
| Spindle speed required, rpm | 2000 |
| **Results** | |
| Operation time, s | 50.0000 |

| Drill multiple holes | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 12.000 |
| Length of drilled holes (lh), mm | 10.000 |
| Number of identical holes drilled | 10 |
| Number of holes drilled simultaneously | 1 |
| **Machining data** | |
| Cutting speed, m/min | 18.479 |
| Feed per revolution, mm | 0.250 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |

| | |
|---|---|
| Power available, kW | 0.82 |
| Power required, kW | 0.82 |
| Spindle speed available, rpm | 2000 |
| Spindle speed required, rpm | 490 |

| **Results** | |
|---|---|
| Operation time, s | 216.0000 |
| Total volume removed, $cm^3$ | 11.310 |

# DFMA® - Boothroyd Dewhurst, Inc.

## DFM Concurrent Costing

## Cost Breakdown

Friday, 14 October 2022

Inspection Cover.dfmx

Analysis Name: 2 INSPECTION COVER (2)
Part name: 2 INSPECTION COVER (2)
Part number:
Part weight: 21.128 kg

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Sheet metal laser cutting
Manufacturing profile: 20A BDI North America

| Cost per part, $ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process Chart** | **Batch size** | **Material** | **Setup** | **Process** | **Rejects** | **Piece part** | **Tooling** | **Total** | **Operation time per part, s** | **Initial tooling investment** |
| **Low carbon steel, cold rolled, commercial quality sheet metal part** | | **22.2302** | **0.2313** | **13.6119** | **0.3187** | **36.3921** | | **36.3921** | **1021.59** | |
| **Laser cutting process** | **187** | **22.2302** | **0.1302** | **9.8656** | **0.1496** | **32.3756** | | **32.3756** | **639.59** | |
| Cincinnati CL-6 Laser System | | | 0.1302 | 9.8656 | 0.1496 | 10.1454 | | 10.1454 | 639.59 | |
| Load and unload | | | 0.1302 | 1.0026 | | 1.1328 | | 1.1328 | 65.00 | |
| Laser cut operation | | | | 8.8630 | | 8.8630 | | 8.8630 | 574.59 | |
| **Generic small manual drill press** | | | **0.1011** | **3.7463** | **0.1692** | **4.0166** | | **4.0166** | **382.00** | |
| Setup/load/unload | | | 0.1011 | 0.4804 | | 0.5815 | | 0.5815 | 49.00 | |
| Drill multiple holes | | | | 0.6570 | | 0.6570 | | 0.6570 | 67.00 | |
| Tap multiple holes (Metric, fine) | | | | 0.4902 | | 0.4902 | | 0.4902 | 50.00 | |
| Drill multiple holes | | | | 2.1188 | | 2.1188 | | 2.1188 | 216.00 | |

# DFM Concurrent Costing

## Totals

Friday, 14 October 2022

Inspection Cover.dfmx

| Analysis Name | 2 INSPECTION COVER (2) |
|---|---|
| Part name | 2 INSPECTION COVER (2) |
| Part number | |
| Material | Low carbon steel, cold rolled, commercial quality |
| Manufacturing process | Sheet metal laser cutting |
| Manufacturing profile | 20A BDI North America |

| Cost per part, $ | Value |
|---|---|
| Material | 22.2302 |
| Setup | 0.2313 |
| Process | 13.6119 |
| Rejects | 0.3187 |
| Piece part | 36.3921 |
| Tooling | 0.0000 |
| Total | 36.3921 |
| Initial tooling investment | 0.0000 |

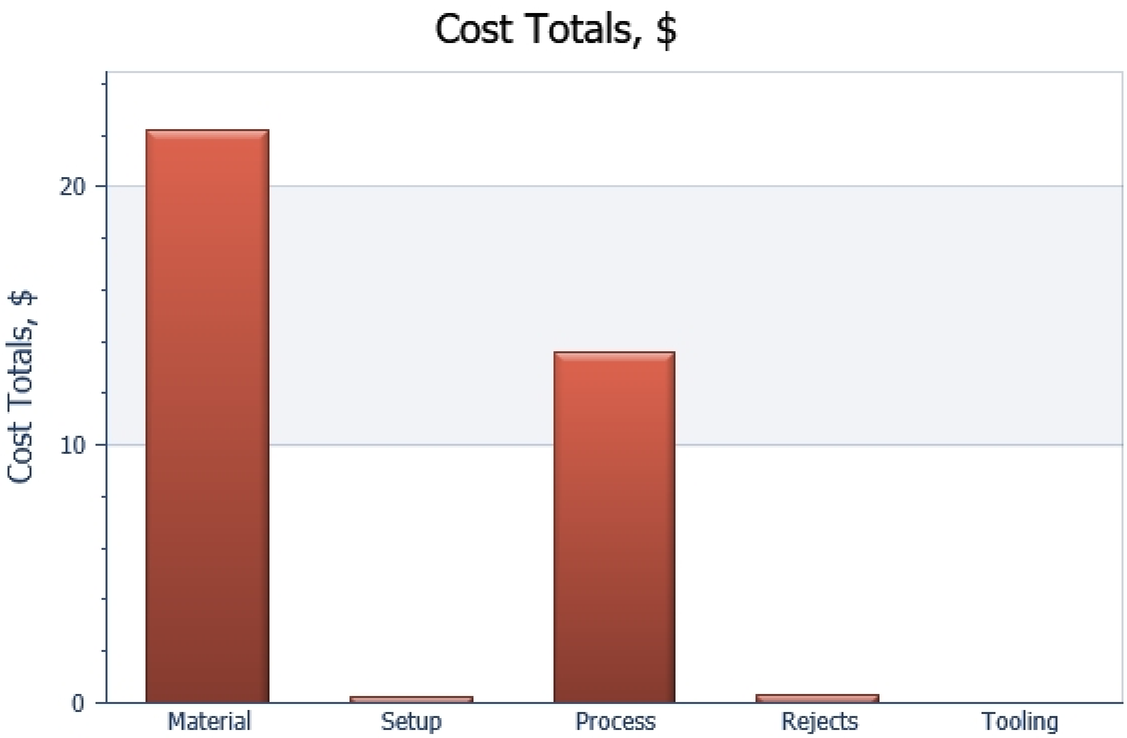
| | |
|---|---|
| Life volume | 1,500 |
| Batch size | 187 |
| Part weight | 21.128 |

# Cost vs. Life Volume

Friday, 14 October 2022

Inspection Cover.dfmx


| Cost per part, $ | 2 INSPECTION COVI (2)<br>Sheet metal laser cutting<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 1,500 |
| Material | 22.2302 |
| Setup | 0.2313 |
| Process | 13.6119 |
| Rejects | 0.3187 |
| Piece part | 36.3921 |
| Tooling | 0.0000 |
| Total | 36.3921 |
| Initial tooling investment | 0.0000 |



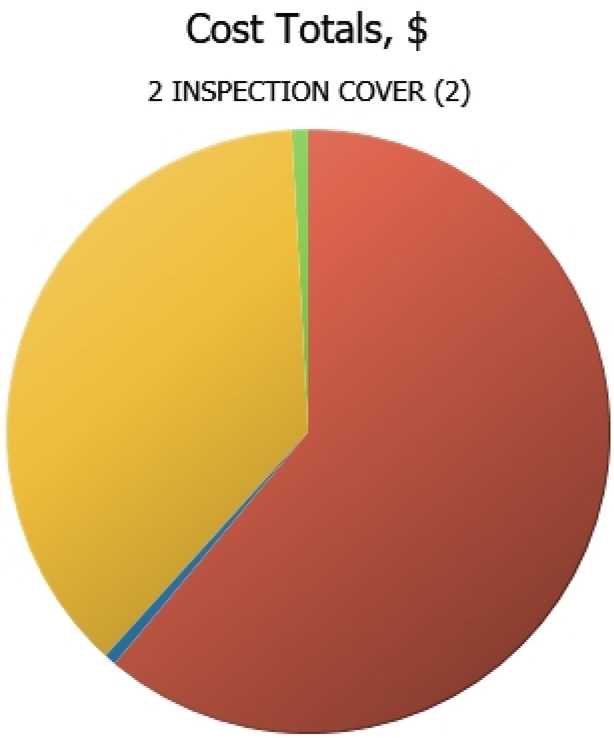

| Cost per part, $ | 2 INSPECTION COVI (2) Sheet metal laser cutting Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 1,500 |
| Material | 22.2302 |
| Setup | 0.2313 |
| Process | 13.6119 |
| Rejects | 0.3187 |
| Piece part | 36.3921 |
| Tooling | 0.0000 |
| Total | 36.3921 |
| Initial tooling investment | 0.0000 |

# Cost Totals

Friday, 14 October 2022

Inspection Cover.dfmx


| | Cost per part, $ | 1 2 INSPECTION COVER (2)<br>Sheet metal laser cutting<br>Low carbon steel, cold rolled, commercial quality |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 22.2302 |
| | Setup | 0.2313 |
| | Process | 13.6119 |
| | Rejects | 0.3187 |
| | Piece part | 36.3921 |
| | Tooling | 0.0000 |
| | Total | 36.3921 |
| | Initial tooling investment | 0.0000 |




| | Cost per part, $ | 1 2 INSPECTION COVER (2)<br>Sheet metal laser cutting<br>Low carbon steel, cold rolled, commercial quality |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 22.2302 |
| | Setup | 0.2301 |
| | Process | 13.6119 |
| | Rejects | 0.3187 |
| | Piece part | 36.3909 |
| | Tooling | 0.0000 |
| | Total | 36.3909 |
| | Initial tooling investment | 0.0000 |

# DFM Concurrent Costing
# Guide to Cost Reduction

Friday, 14 October 2022

Inspection Cover.dfmx

Analysis Name: 2 INSPECTION COVER (2)

Part name: 2 INSPECTION COVER (2)

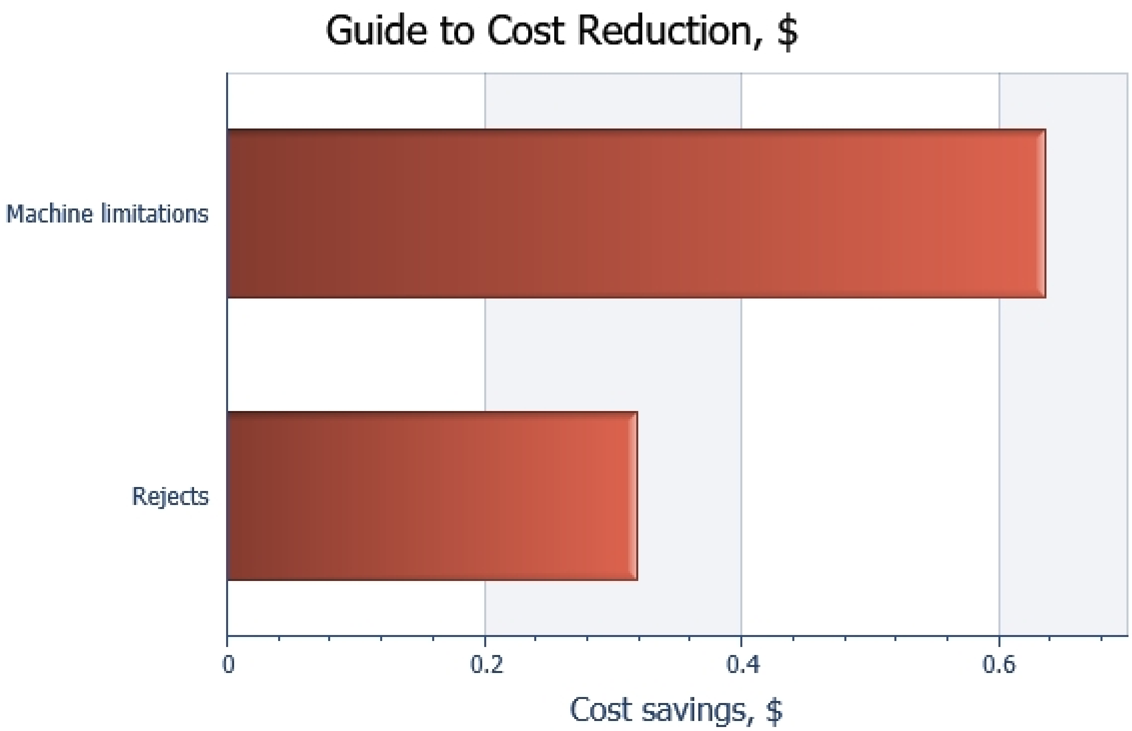
Part number:

Material name: Low carbon steel, cold rolled, commercial quality

Manufacturing process: Sheet metal laser cutting

Manufacturing profile: 20A BDI North America

For the product life volume of 1500 and the batch size of 187 you have specified, the tooling costs form 0.00% of the total cost of 36.39. The chart provides an indication of the contributions to this total cost made by various factors. Note that, if multiple operations of the same type are required, the total contributions from all operations of that type are shown. When considering changes to reduce cost you may wish to concentrate on the part features that affect the operations which are the largest cost contributors.




| Category | Savings, $ |
|---|---|
| Machine limitations | 0.6364 |
| Rejects | 0.3187 |

# Appendix Y.3

**DFM Concurrent Costing Analysis Report of Part No. 3 Drive Shaft of Best Concept Design**

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing
# Executive Summary

Friday, 14 October 2022

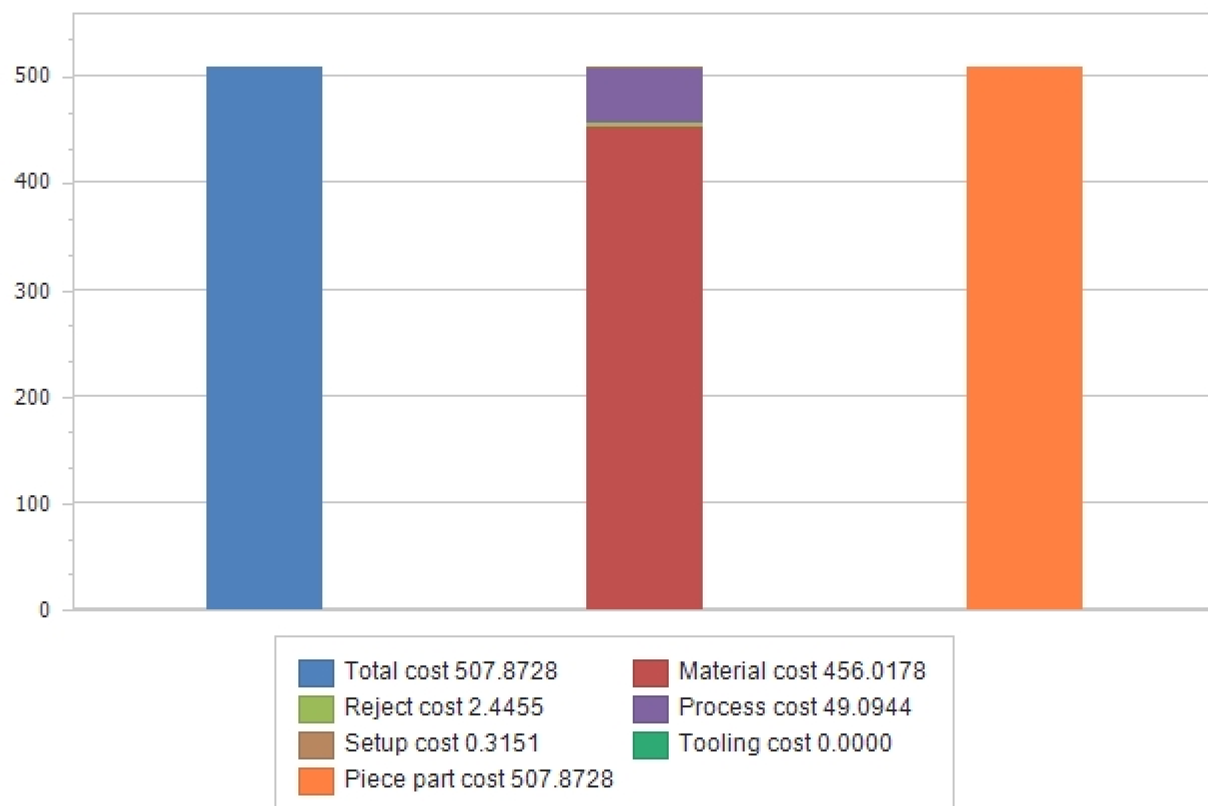
Drive Shaft.dfmx

Analysis Name: 16 17 DRIVE SHAFT
Part name: Shaft Stock
Part number: 1

Material name: Generic medium carbon steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

| | |
|---|---|
| Product life volume | 1,500 |
| Batch size | 187 |
| Total cost, $ | 507.8728 |
| Piece part cost, $ | 507.8728 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFM Concurrent Costing
## Notes

Friday, 14 October 2022

Drive Shaft.dfmx

Analysis Name: 16 17 DRIVE SHAFT

Material name: Generic medium carbon steel

Part name: Shaft Stock

Manufacturing process: Machined/cut from stock

Part number: 1

Manufacturing profile: 20A BDI China

### Load bar

Swapping bar around to rough the other half and setup for machining between centers.

### Finish multiple pocket end mill (live tool)

Pocketing the eccentric mass keyways.

### Rough and finish single pocket end mill (live tool)

Pocketing the gear keyway.

### Load bar

Preparing to tap M24 holes in one end. (Taking tail stock off and putting bar up on guides).

### Finish face

Finishing the end face.

### Load bar

Rotating the bar to tap the other shaft end M24 hole.

### Finish face

Finishing the end face.

# DFM Concurrent Costing Responses

Friday, 14 October 2022

Drive Shaft.dfmx

Analysis Name: 16 17 DRIVE SHAFT
Part name: Shaft Stock
Part number: 1

Material name: Generic medium carbon steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

## Generic medium carbon steel machined/cut from stock part

| Part | |
|---|---|
| Part name | Shaft Stock |
| Part number | 1 |
| Life volume | 1500 |
| Envelope shape | Solid cylinder |
| Part length, mm | 202.000 |
| Part width, mm | 202.000 |
| Part height, mm | 1050.000 |
| Average thickness, mm | 112.966 |
| Forming direction | X |

## Stock process

| Part basic data | |
|---|---|
| Batch size | 187 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Round bar or rod |
| Material hardness, Bhn | 250 |
| Material cost, $/kg | 1.168 |
| Material scrap value, $/kg | 0.110 |
| Cutoff method | Horizontal bandsaw |

| Part geometry | |
|---|---|
| Volume, cm³ | 21373.191 |
| Weight, kg | 167.424 |

## Workpiece

| | |
|---|---|
| **Bar dimensions** | |
| Bar stock length, m | 3.048 |

| | |
|---|---|
| **Workpiece geometry** | |
| Length, mm | 1060.000 |
| Diameter, mm | 210.000 |

## Horizontal bandsaw cutoff

| | |
|---|---|
| **Basic process data** | |
| Process rate, $/hr | 3.13 |
| Setup rate, $/hr | 3.13 |
| Setup time, hr | 0.25 |

| | |
|---|---|
| **Bar loading data** | |
| Bar loading time, s | 33.00 |

| | |
|---|---|
| **Bandsaw cutting data** | |
| Cutting rate, $cm^2$/min | 50.966 |
| Kerf, mm | 1.067 |

| | |
|---|---|
| **Operation time** | |
| Process time per part, s | 424.26 |

## Cincinnati Falcon TC-300/1000 turning center

| | |
|---|---|
| **Basic data** | |
| Batch size | 187 |
| Material hardness, Bhn | 250 |
| Rejects, % | 0.50 |

| | |
|---|---|
| **Machine tool data** | |
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 16.32 |
| Operator rate, $/hr | 3.13 |

| | |
|---|---|
| Process rate, $/hr | 17.88 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |

| **Live tool data** | |
|---|---|
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |

| **Result** | |
|---|---|
| Cycle time per part, s | 6778.50 |
| Total setup time, hr | 2.99 |

## Setup/load/unload

| **Work handling** | |
|---|---|
| Workholding device | Face plate (3 clamps) |
| Number of reversals | 1 |
| Load/unload time, s | 239.40 |
| Reversal time, s | 141.35 |

| **Machine setup** | |
|---|---|
| Machine rate during setup, $/hr | 16.32 |
| Setup operator rate, $/hr | 3.13 |
| Setup rate, $/hr | 19.45 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |

| **Other costs** | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

## Rough face

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 210.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Total depth to be removed (wm), mm | 2.000 |
| **Machining data** | |
| Cutting speed, m/min | 187.508 |
| Feed per revolution, mm | 0.258 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 2.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 6.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 50.0000 |
| Total volume removed, $cm^3$ | 69.272 |

## Single centerdrill

| | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Centerdrill diameter, dh, mm | 6.000 |
| Operation time, s | 8.4257 |
| Total volume removed, $cm^3$ | 0.028 |

## Rough cylindrical turn

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 210.000 |

| | |
|---|---|
| Diameter of machined surface (dm), mm | 205.000 |
| Length of machined surface (lm), mm | 485.000 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 174.650 |
| Feed per revolution, mm | 0.288 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 2.500 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 8.96 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 268 |

| **Results** | |
|---|---|
| Operation time, s | 391.0000 |
| Total volume removed, cm³ | 790.409 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 205.000 |
| Diameter of machined surface (dm), mm | 183.000 |
| Length of machined surface (lm), mm | 480.730 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 154.534 |
| Feed per revolution, mm | 0.349 |
| Number of passes | 3.000 |
| Depth of cut per pass, mm | 3.667 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 14.09 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 264 |

| Results | |
|---|---|
| Operation time, s | 998.0000 |
| Total volume removed, cm³ | 3222.905 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 183.000 |
| Diameter of machined surface (dm), mm | 173.000 |
| Length of machined surface (lm), mm | 358.720 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 139.903 |
| Feed per revolution, mm | 0.407 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.30 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 251 |

| Results | |
|---|---|
| Operation time, s | 218.0000 |
| Total volume removed, cm³ | 1002.992 |

| Rough cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 173.000 |
| Diameter of machined surface (dm), mm | 163.000 |
| Length of machined surface (lm), mm | 310.930 |
| **Machining data** | |
| Cutting speed, m/min | 139.903 |
| Feed per revolution, mm | 0.407 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.30 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 266 |
| **Results** | |
| Operation time, s | 180.0000 |
| Total volume removed, cm³ | 820.529 |

| Rough cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 163.000 |
| Diameter of machined surface (dm), mm | 162.000 |
| Length of machined surface (lm), mm | 165.570 |

| | |
|---|---|
| **Machining data** | |
| Cutting speed, m/min | 292.303 |
| Feed per revolution, mm | 0.129 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 0.500 |
| Special tooling cost, $ | 0.000 |

| | |
|---|---|
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 1.34 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 573 |

| | |
|---|---|
| **Results** | |
| Operation time, s | 142.0000 |
| Total volume removed, cm³ | 42.263 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 162.000 |
| Diameter of machined surface (dm), mm | 153.000 |
| Length of machined surface (lm), mm | 160.150 |

| | |
|---|---|
| **Machining data** | |
| Cutting speed, m/min | 144.780 |
| Feed per revolution, mm | 0.386 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 4.500 |
| Special tooling cost, $ | 0.000 |

| | |
|---|---|
| **Machine limitations** | |
| Power available, kW | 20.88 |

| | |
|---|---|
| Maximum power required, kW | 17.93 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 293 |
| **Results** | |
| Operation time, s | 92.0000 |
| Total volume removed, cm³ | 356.592 |

| **Load bar** | |
|---|---|
| Length of bar, m | 1.060 |
| Operation time per part, s | 190.90 |

| **Rough face** | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 210.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Total depth to be removed (wm), mm | 2.000 |
| **Machining data** | |
| Cutting speed, m/min | 187.508 |
| Feed per revolution, mm | 0.258 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 2.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 6.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 57.0000 |

| | |
|---|---|
| Total volume removed, cm³ | 69.272 |

| Single centerdrill | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Centerdrill diameter, dh, mm | 6.000 |
| Operation time, s | 8.4257 |
| Total volume removed, cm³ | 0.028 |

| Rough cylindrical turn | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 210.000 |
| Diameter of machined surface (dm), mm | 193.000 |
| Length of machined surface (lm), mm | 569.830 |
| **Machining data** | |
| Cutting speed, m/min | 147.523 |
| Feed per revolution, mm | 0.376 |
| Number of passes | 2.000 |
| Depth of cut per pass, mm | 4.250 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 16.78 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 239 |
| **Results** | |
| Operation time, s | 802.0000 |
| Total volume removed, cm³ | 3066.134 |

| Rough cylindrical turn |
|---|

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 193.000 |
| Diameter of machined surface (dm), mm | 183.000 |
| Length of machined surface (lm), mm | 480.730 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 139.903 |
| Feed per revolution, mm | 0.407 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.30 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 237 |

| **Results** | |
|---|---|
| Operation time, s | 306.0000 |
| Total volume removed, $cm^3$ | 1419.649 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 183.000 |
| Diameter of machined surface (dm), mm | 173.000 |
| Length of machined surface (lm), mm | 362.630 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 139.903 |
| Feed per revolution, mm | 0.407 |

| | |
|---|---|
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.30 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 251 |

| **Results** | |
|---|---|
| Operation time, s | 220.0000 |
| Total volume removed, $cm^3$ | 1013.924 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 173.000 |
| Diameter of machined surface (dm), mm | 163.000 |
| Length of machined surface (lm), mm | 310.930 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 139.903 |
| Feed per revolution, mm | 0.407 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.30 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 266 |

| Results | |
|---|---|
| Operation time, s | 180.0000 |
| Total volume removed, cm³ | 820.529 |

| Rough cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 163.000 |
| Diameter of machined surface (dm), mm | 162.000 |
| Length of machined surface (lm), mm | 165.470 |
| **Machining data** | |
| Cutting speed, m/min | 292.303 |
| Feed per revolution, mm | 0.129 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 0.500 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 1.34 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 573 |
| **Results** | |
| Operation time, s | 142.0000 |
| Total volume removed, cm³ | 42.237 |

| Rough cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |

| | |
|---|---|
| Diameter of work surface (dw), mm | 162.000 |
| Diameter of machined surface (dm), mm | 153.000 |
| Length of machined surface (lm), mm | 160.150 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 144.780 |
| Feed per revolution, mm | 0.386 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 4.500 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 17.93 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 293 |

| **Results** | |
|---|---|
| Operation time, s | 92.0000 |
| Total volume removed, $cm^3$ | 356.592 |

## Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 159.000 |
| Length of machined surface (lm), mm | 154.000 |
| Surface roughness | 32 µin. 0.8 µm |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** |
|---|

| | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 639 |

| **Results** | |
|---|---|
| Operation time, s | 219.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 150.000 |
| Length of machined surface (lm), mm | 148.000 |
| Surface roughness | 32 µin. 0.8 µm |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 677 |

| **Results** | |
|---|---|
| Operation time, s | 200.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 160.000 |
| Length of machined surface (lm), mm | 53.240 |
| Surface roughness | 32 µin. 0.8 µm |

| **Machining data** | |
|---|---|

| | |
|---|---|
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 635 |
| **Results** | |
| Operation time, s | 81.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 170.000 |
| Length of machined surface (lm), mm | 120.100 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 597 |
| **Results** | |
| Operation time, s | 184.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |

| | |
|---|---|
| Diameter of machined surface (dm), mm | 180.000 |
| Length of machined surface (lm), mm | 91.660 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 564 |
| **Results** | |
| Operation time, s | 150.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 202.000 |
| Length of machined surface (lm), mm | 8.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 503 |
| **Results** | |
| Operation time, s | 21.0000 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 170.000 |
| Length of machined surface (lm), mm | 126.020 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 597 |
| **Results** | |
| Operation time, s | 193.0000 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 160.000 |
| Length of machined surface (lm), mm | 49.250 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |

| | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 635 |
| **Results** | |
| Operation time, s | 75.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 159.000 |
| Length of machined surface (lm), mm | 153.880 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 639 |
| **Results** | |
| Operation time, s | 219.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 150.000 |
| Length of machined surface (lm), mm | 148.120 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |

| | |
|---|---|
| Cutting speed, m/min | 318.821 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 677 |
| **Results** | |
| Operation time, s | 200.0000 |

| **Measure with micrometer (tolerance >/= 0.001 in. (0.025 mm)** | |
|---|---|
| Acquire and replace micrometer, s | 3.000 |
| Measuring time, s | 60.000 |
| Operation time, s | 63.00 |

| **Finish multiple pocket end mill (live tool)** | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Area of pocket (ap), mm² | 4068.319 |
| Depth of pocket (dt), mm | 10.330 |
| Number of features milled | 2.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Tool diameter, mm | 10.330 |
| Number of teeth | 4.000 |
| Cutting speed, m/min | 97.371 |
| Feed per tooth, mm | 0.043 |
| Feed speed, mm/s | 8.692 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3000 |

| | |
|---|---|
| Spindle speed required, rpm | 3000 |
| **Results** | |
| Operation time, s | 100.0000 |

| **Rough and finish single pocket end mill (live tool)** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Area of pocket (ap), mm² | 3345.431 |
| Total depth of material removed (dt), mm | 12.140 |
| Finish cut allowance, mm | 0.381 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Tool diameter, mm | 12.140 |
| Number of teeth | 4.000 |
| Cutting speed during rough cuts, m/min | 59.505 |
| Feed per tooth during rough cuts, mm | 0.116 |
| Feed speed during rough cuts, mm/s | 12.113 |
| Number of rough cut passes | 3.000 |
| Depth of rough cut per pass, mm | 3.920 |
| Cutting speed during finish cut, m/min | 103.778 |
| Feed per tooth during finish cut, mm | 0.047 |
| Feed speed during finish cut, mm/s | 8.546 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 2.61 |
| Power required, kW | 2.64 |
| Spindle speed available, rpm | 3000 |
| Spindle speed required, rpm | 2721 |
| **Results** | |
| Operation time, s | 109.0000 |

| | |
|---|---|
| Total volume removed, cm³ | 40.613 |

| Measure with vernier caliper | |
|---|---|
| Acquire and replace caliper, s | 3.000 |
| Measuring time, s | 60.000 |
| Operation time, s | 63.00 |

| Load bar | |
|---|---|
| Length of bar, m | 1.050 |
| Operation time per part, s | 60.00 |

| Finish face | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 150.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 318.752 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 65.0000 |

| Drill single hole | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |

| | |
|---|---|
| Diameter of drilled hole (dh), mm | 21.000 |
| Length of drilled hole (lh), mm | 57.000 |
| **Machining data** | |
| Cutting speed, m/min | 73.578 |
| Feed per revolution, mm | 0.320 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 8.16 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 1115 |
| **Results** | |
| Operation time, s | 22.0000 |
| Total volume removed, cm³ | 19.743 |

| **Tap single hole (Metric, coarse)** | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of hole to be tapped (dh), mm | 24.000 |
| Length to be tapped (lt), mm | 48.000 |
| **Machining data** | |
| Thread pitch, mm | 3.000 |
| Cutting speed, m/min | 7.452 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 2510 |
| **Results** | |
| Operation time, s | 9.0000 |

| Load bar | |
|---|---|
| Length of bar, m | 1.050 |
| Operation time per part, s | 191.00 |

| Finish face | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 150.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 318.752 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 65.0000 |

| Drill single hole | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Diameter of drilled hole (dh), mm | 21.000 |
| Length of drilled hole (lh), mm | 57.000 |
| **Machining data** | |
| Cutting speed, m/min | 73.578 |
| Feed per revolution, mm | 0.320 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 8.16 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 1115 |

| Results | |
|---|---|
| Operation time, s | 22.0000 |
| Total volume removed, cm³ | 19.743 |

## Tap single hole (Metric, coarse)

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of hole to be tapped (dh), mm | 24.000 |
| Length to be tapped (lt), mm | 48.000 |

| Machining data | |
|---|---|
| Thread pitch, mm | 3.000 |
| Cutting speed, m/min | 7.452 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 2510 |

| Results | |
|---|---|
| Operation time, s | 9.0000 |

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing

## Cost Breakdown

Friday, 14 October 2022

Drive Shaft.dfmx

Analysis Name: 16 17 DRIVE SHAFT
Part name: Shaft Stock
Part number: 1
Part weight: 287.596 kg

Material name: Generic medium carbon steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

| Cost per part, $ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process Chart** | **Batch size** | **Material** | **Setup** | **Process** | **Rejects** | **Piece part** | **Tooling** | **Total** | **Operation time per part, s** | **Initial tooling investment** |
| **Generic medium carbon steel machined/cut from stock part** | | **456.0178** | **0.3151** | **49.0944** | **2.4455** | **507.8728** | | **507.8728** | **7202.76** | |
| **Stock process** | **187** | **456.0178** | **0.0042** | **0.4333** | | **456.4552** | | **456.4552** | **424.26** | |
| Workpiece | | 456.0178 | | | | 456.0178 | | 456.0178 | | |
| Horizontal bandsaw cutoff | | | 0.0042 | 0.4333 | | 0.4374 | | 0.4374 | 424.26 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.3109** | **48.6612** | **2.4455** | **51.4176** | | **51.4176** | **6778.50** | |
| Setup/load/unload | | | 0.3109 | 2.2251 | | 2.5360 | | 2.5360 | 380.75 | |
| Rough face | | | | 0.3640 | | 0.3640 | | 0.3640 | 50.00 | |
| Single centerdrill | | | | 0.0494 | | 0.0494 | | 0.0494 | 8.43 | |
| Rough cylindrical turn | | | | 2.9103 | | 2.9103 | | 2.9103 | 391.00 | |
| Rough cylindrical turn | | | | 7.4557 | | 7.4557 | | 7.4557 | 998.00 | |
| Rough cylindrical turn | | | | 1.6241 | | 1.6241 | | 1.6241 | 218.00 | |
| Rough cylindrical turn | | | | 1.3384 | | 1.3384 | | 1.3384 | 180.00 | |
| Rough cylindrical turn | | | | 1.0532 | | 1.0532 | | 1.0532 | 142.00 | |
| Rough cylindrical turn | | | | 0.6788 | | 0.6788 | | 0.6788 | 92.00 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Load bar | | | | 1.1156 | | 1.1156 | | 1.1156 | 190.90 | |
| Rough face | | | | 0.4049 | | 0.4049 | | 0.4049 | 57.00 | |
| Single centerdrill | | | | 0.0494 | | 0.0494 | | 0.0494 | 8.43 | |
| Rough cylindrical turn | | | | 5.9876 | | 5.9876 | | 5.9876 | 802.00 | |
| Rough cylindrical turn | | | | 2.2839 | | 2.2839 | | 2.2839 | 306.00 | |
| Rough cylindrical turn | | | | 1.6396 | | 1.6396 | | 1.6396 | 220.00 | |
| Rough cylindrical turn | | | | 1.3384 | | 1.3384 | | 1.3384 | 180.00 | |
| Rough cylindrical turn | | | | 1.0530 | | 1.0530 | | 1.0530 | 142.00 | |
| Rough cylindrical turn | | | | 0.6788 | | 0.6788 | | 0.6788 | 92.00 | |
| Finish cylindrical turn | | | | 1.6319 | | 1.6319 | | 1.6319 | 219.00 | |
| Finish cylindrical turn | | | | 1.4880 | | 1.4880 | | 1.4880 | 200.00 | |
| Finish cylindrical turn | | | | 0.5958 | | 0.5958 | | 0.5958 | 81.00 | |
| Finish cylindrical turn | | | | 1.3688 | | 1.3688 | | 1.3688 | 184.00 | |
| Finish cylindrical turn | | | | 1.1138 | | 1.1138 | | 1.1138 | 150.00 | |
| Finish cylindrical turn | | | | 0.1460 | | 0.1460 | | 0.1460 | 21.00 | |
| Finish cylindrical turn | | | | 1.4359 | | 1.4359 | | 1.4359 | 193.00 | |
| Finish cylindrical turn | | | | 0.5516 | | 0.5516 | | 0.5516 | 75.00 | |
| Finish cylindrical turn | | | | 1.6316 | | 1.6316 | | 1.6316 | 219.00 | |
| Finish cylindrical turn | | | | 1.4882 | | 1.4882 | | 1.4882 | 200.00 | |
| Measure with micrometer (tolerance >/= 0.001 in. (0.025 mm) | | | | 0.3682 | | 0.3682 | | 0.3682 | 63.00 | |
| Finish multiple pocket end mill (live tool) | | | | 0.7007 | | 0.7007 | | 0.7007 | 100.00 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rough and finish single pocket end mill (live tool) | | | | 0.7326 | | 0.7326 | | 0.7326 | 109.00 | |
| Measure with vernier caliper | | | | 0.3682 | | 0.3682 | | 0.3682 | 63.00 | |
| Load bar | | | | 0.3506 | | 0.3506 | | 0.3506 | 60.00 | |
| Finish face | | | | 0.4641 | | 0.4641 | | 0.4641 | 65.00 | |
| Drill single hole | | | | 0.1445 | | 0.1445 | | 0.1445 | 22.00 | |
| Tap single hole (Metric, coarse) | | | | 0.0529 | | 0.0529 | | 0.0529 | 9.00 | |
| Load bar | | | | 1.1162 | | 1.1162 | | 1.1162 | 191.00 | |
| Finish face | | | | 0.4641 | | 0.4641 | | 0.4641 | 65.00 | |
| Drill single hole | | | | 0.1445 | | 0.1445 | | 0.1445 | 22.00 | |
| Tap single hole (Metric, coarse) | | | | 0.0529 | | 0.0529 | | 0.0529 | 9.00 | |

# DFM Concurrent Costing

## Totals

Friday, 14 October 2022

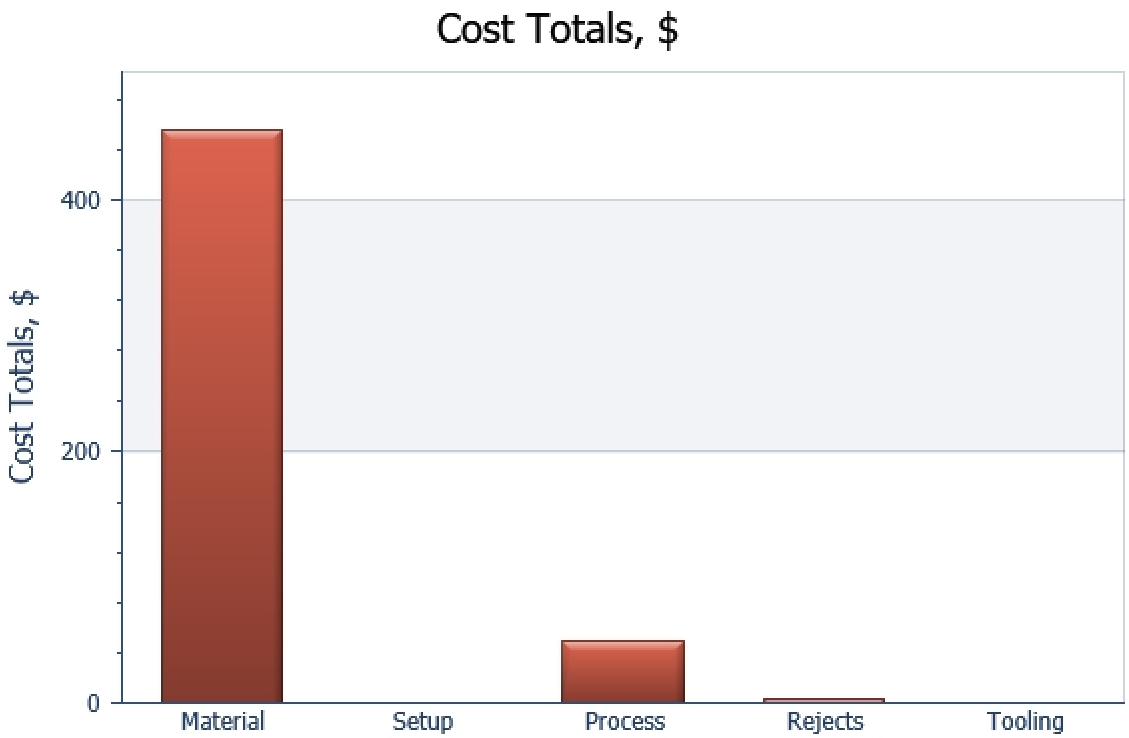
Drive Shaft.dfmx

| Analysis Name | 16 17 DRIVE SHAFT |
|---|---|
| Part name | Shaft Stock |
| Part number | 1 |
| Material | Generic medium carbon steel |
| Manufacturing process | Machined/cut from stock |
| Manufacturing profile | 20A BDI China |

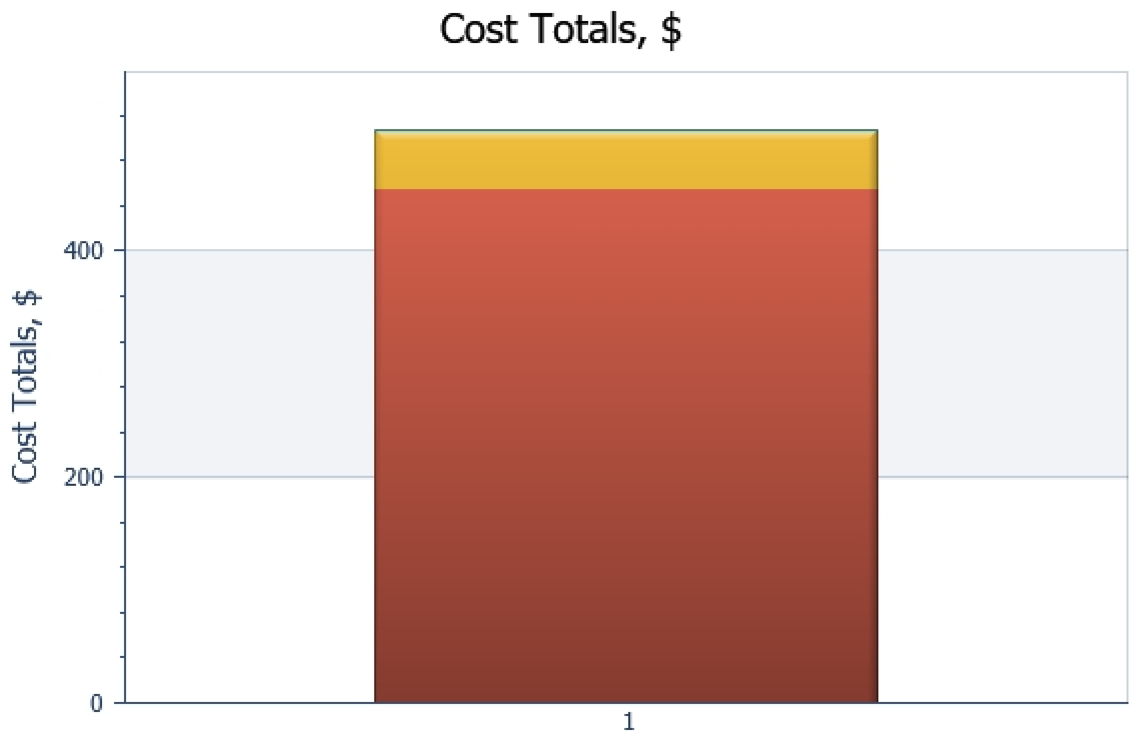
| Cost per part, $ | Value |
|---|---|
| Material | 456.0178 |
| Setup | 0.3151 |
| Process | 49.0944 |
| Rejects | 2.4455 |
| Piece part | 507.8728 |
| Tooling | 0.0000 |
| Total | 507.8728 |
| Initial tooling investment | 0.0000 |

| | |
|---|---|
| Life volume | 1,500 |
| Batch size | 187 |
| Part weight | 287.596 |

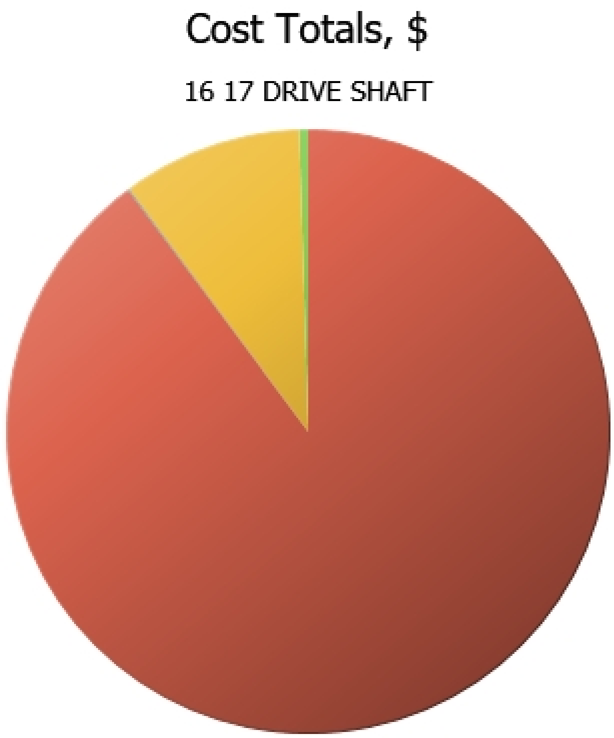

| Cost per part, $ | 16 17 DRIVE SHAFT<br>Machined/cut from stock<br>Generic medium carbon steel |
|---|---|
| Life volume | 1,500 |
| Material | 456.0178 |
| Setup | 0.3151 |
| Process | 49.0944 |
| Rejects | 2.4455 |
| Piece part | 507.8728 |
| Tooling | 0.0000 |
| Total | 507.8728 |
| Initial tooling investment | 0.0000 |




| Cost per part, $ | 16 17 DRIVE SHAFT<br>Machined/cut from stock<br>Generic medium carbon steel |
|---|---|
| Life volume | 1,500 |
| Material | 456.0178 |
| Setup | 0.3151 |
| Process | 49.0944 |
| Rejects | 2.4455 |
| Piece part | 507.8728 |
| Tooling | 0.0000 |
| Total | 507.8728 |
| Initial tooling investment | 0.0000 |




| | Cost per part, $ | 1 16 17 DRIVE SHAFT<br>Machined/cut from stock<br>Generic medium carbon steel |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 456.0178 |
| | Setup | 0.3151 |
| | Process | 49.0944 |
| | Rejects | 2.4455 |
| | Piece part | 507.8728 |
| | Tooling | 0.0000 |
| | Total | 507.8728 |
| | Initial tooling investment | 0.0000 |




| | Cost per part, $ | 1 16 17 DRIVE SHAFT<br>Machined/cut from stock<br>Generic medium carbon steel |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 456.0178 |
| | Setup | 0.3134 |
| | Process | 49.0944 |
| | Rejects | 2.4455 |
| | Piece part | 507.8711 |
| | Tooling | 0.0000 |
| | Total | 507.8711 |
| | Initial tooling investment | 0.0000 |

# DFM Concurrent Costing
## Guide to Cost Reduction

Friday, 14 October 2022

Drive Shaft.dfmx

Analysis Name: 16 17 DRIVE SHAFT

Material name: Generic medium carbon steel

Part name: Shaft Stock

Manufacturing process: Machined/cut from stock

Part number: 1

Manufacturing profile: 20A BDI China

For the product life volume of 1500 and the batch size of 187 you have specified, the tooling costs form 0.00% of the total cost of 507.87. The chart shows how improved equipment might reduce the machining cost in either of two ways: 1. If the machining operations could be carried out on one setup where appropriate. 2. If the various machines imposed no limitations on power or spindle speed.


| Category | Savings, $ |
|---|---|
| Machine limitations | 0.0805 |
| Rejects | 2.4455 |

# Appendix Y.4

**DFM Concurrent Costing Analysis Report of Part No. 4 Idler Shaft of Best Concept Design**

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing

# Executive Summary

Friday, 14 October 2022

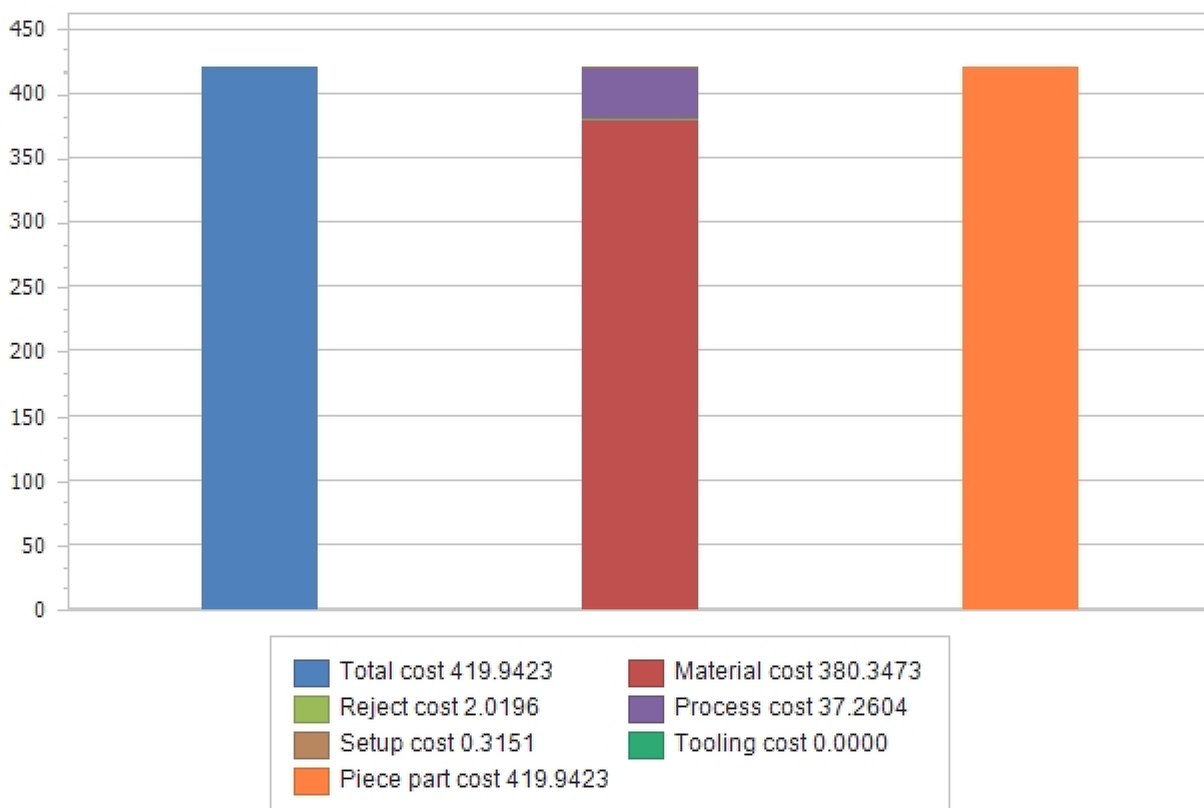
Idler Shaft.dfmx

Analysis Name: 4 IDLER SHAFT
Part name: Idler Shaft
Part number:

Material name: Medium carbon alloy steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

| | |
|---|---|
| Product life volume | 1,500 |
| Batch size | 187 |
| Total cost, $ | 419.9423 |
| Piece part cost, $ | 419.9423 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFM Concurrent Costing
# Notes

Friday, 14 October 2022

Idler Shaft.dfmx

Analysis Name: 4 IDLER SHAFT

Part name: Idler Shaft

Part number:

Material name: Medium carbon alloy steel

Manufacturing process: Machined/cut from stock

Manufacturing profile: 20A BDI China

## Load bar

Swapping bar around to rough the other half and setup for machining between centres.

## Finish multiple pocket end mill (live tool)

Eccentric mass keyways.

## Rough and finish single pocket end mill (live tool)

Pocket mill keyway for gear.

## Load bar

Preparing to tap M24 holes at one end. (Removing tail stock and putting bar on guides).

## Finish face

Finishing end face.

## Load bar

Rotating bar to drill M24 holes in opposite end of shaft.

## Finish face

Finishing end face.

# DFM Concurrent Costing

## Responses

Friday, 14 October 2022

Idler Shaft.dfmx

Analysis Name: 4 IDLER SHAFT
Part name: Idler Shaft
Part number:

Material name: Medium carbon alloy steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

## Medium carbon alloy steel machined/cut from stock part

| Part | |
|---|---|
| Part name | Idler Shaft |
| Part number | |
| Life volume | 1500 |
| Envelope shape | Solid cylinder |
| Part length, mm | 740.000 |
| Part width, mm | 201.818 |
| Part height, mm | 202.000 |
| Average thickness, mm | 35.339 |
| Forming direction | Z |

## Stock process

| Part basic data | |
|---|---|
| Batch size | 187 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Round bar or rod |
| Material hardness, Bhn | 300 |
| Material cost, $/kg | 1.896 |
| Material scrap value, $/kg | 0.132 |
| Cutoff method | Horizontal bandsaw |

| Part geometry | |
|---|---|
| Volume, cm³ | 15227.880 |
| Weight, kg | 118.780 |

## Workpiece

| Bar dimensions | |
|---|---|
| Bar stock length, m | 3.048 |

| Workpiece geometry | |
|---|---|
| Length, mm | 750.000 |
| Diameter, mm | 210.000 |

## Horizontal bandsaw cutoff

| Basic process data | |
|---|---|
| Process rate, $/hr | 3.13 |
| Setup rate, $/hr | 3.13 |
| Setup time, hr | 0.25 |

| Bar loading data | |
|---|---|
| Bar loading time, s | 33.00 |

| Bandsaw cutting data | |
|---|---|
| Cutting rate, cm²/min | 27.030 |
| Kerf, mm | 1.067 |

| Operation time | |
|---|---|
| Process time per part, s | 777.09 |

## Cincinnati Falcon TC-300/1000 turning center

| Basic data | |
|---|---|
| Batch size | 187 |
| Material hardness, Bhn | 300 |
| Rejects, % | 0.50 |

| Machine tool data | |
|---|---|
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 16.32 |
| Operator rate, $/hr | 3.13 |

| | |
|---|---|
| Process rate, $/hr | 17.88 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |

| **Live tool data** | |
|---|---|
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |

| **Result** | |
|---|---|
| Cycle time per part, s | 4928.73 |
| Total setup time, hr | 2.99 |

## Setup/load/unload

| **Work handling** | |
|---|---|
| Workholding device | Face plate (3 clamps) |
| Number of reversals | 1 |
| Load/unload time, s | 147.10 |
| Reversal time, s | 120.53 |

| **Machine setup** | |
|---|---|
| Machine rate during setup, $/hr | 16.32 |
| Setup operator rate, $/hr | 3.13 |
| Setup rate, $/hr | 19.45 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |

| **Other costs** | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

## Rough face

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 210.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Total depth to be removed (wm), mm | 2.000 |
| **Machining data** | |
| Cutting speed, m/min | 159.076 |
| Feed per revolution, mm | 0.276 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 2.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 6.59 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 54.0000 |
| Total volume removed, $cm^3$ | 69.272 |

## Single centerdrill

| | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Centerdrill diameter, dh, mm | 6.000 |
| Operation time, s | 8.0000 |
| Total volume removed, $cm^3$ | 0.028 |

## Rough cylindrical turn

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 210.000 |

| | |
|---|---|
| Diameter of machined surface (dm), mm | 205.000 |
| Length of machined surface (lm), mm | 329.000 |
| **Machining data** | |
| Cutting speed, m/min | 151.181 |
| Feed per revolution, mm | 0.309 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 2.500 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 8.76 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 232 |
| **Results** | |
| Operation time, s | 290.0000 |
| Total volume removed, $cm^3$ | 536.174 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 205.000 |
| Diameter of machined surface (dm), mm | 173.000 |
| Length of machined surface (lm), mm | 328.440 |
| **Machining data** | |
| Cutting speed, m/min | 139.000 |
| Feed per revolution, mm | 0.500 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 16.000 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 83.50 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 235 |

| Results | |
|---|---|
| Operation time, s | 175.0000 |
| Total volume removed, cm³ | 3120.252 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 173.000 |
| Diameter of machined surface (dm), mm | 163.000 |
| Length of machined surface (lm), mm | 195.260 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 139.000 |
| Feed per revolution, mm | 0.500 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 26.09 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 264 |

| Results | |
|---|---|
| Operation time, s | 96.0000 |
| Total volume removed, cm³ | 515.281 |

| Rough cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 163.000 |
| Diameter of machined surface (dm), mm | 153.000 |
| Length of machined surface (lm), mm | 165.030 |
| **Machining data** | |
| Cutting speed, m/min | 127.711 |
| Feed per revolution, mm | 0.435 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 258 |
| **Results** | |
| Operation time, s | 95.0000 |
| Total volume removed, cm³ | 409.583 |

| Load bar | |
|---|---|
| Length of bar, m | 0.750 |
| Operation time per part, s | 190.00 |

| Rough face | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 210.000 |

| | |
|---|---|
| Inner diameter of faced surface (d2), mm | 0.000 |
| Total depth to be removed (wm), mm | 2.000 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 159.076 |
| Feed per revolution, mm | 0.276 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 2.000 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 6.59 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |

| **Results** | |
|---|---|
| Operation time, s | 61.0000 |
| Total volume removed, cm³ | 69.272 |

## Single centerdrill

| | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Centerdrill diameter, dh, mm | 6.000 |
| Operation time, s | 8.9028 |
| Total volume removed, cm³ | 0.028 |

## Rough cylindrical turn

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 210.000 |
| Diameter of machined surface (dm), mm | 193.000 |
| Length of machined surface (lm), mm | 410.820 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 133.807 |
| Feed per revolution, mm | 0.402 |
| Number of passes | 2.000 |
| Depth of cut per pass, mm | 4.250 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 17.19 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 216 |

| Results | |
|---|---|
| Operation time, s | 600.0000 |
| Total volume removed, $cm^3$ | 2210.535 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 193.000 |
| Diameter of machined surface (dm), mm | 183.000 |
| Length of machined surface (lm), mm | 411.700 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 127.711 |
| Feed per revolution, mm | 0.435 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |

| | |
|---|---|
| Maximum power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 217 |
| **Results** | |
| Operation time, s | 269.0000 |
| Total volume removed, cm³ | 1215.796 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 183.000 |
| Diameter of machined surface (dm), mm | 173.000 |
| Length of machined surface (lm), mm | 328.440 |
| **Machining data** | |
| Cutting speed, m/min | 127.711 |
| Feed per revolution, mm | 0.435 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 229 |
| **Results** | |
| Operation time, s | 205.0000 |
| Total volume removed, cm³ | 918.328 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 173.000 |
| Diameter of machined surface (dm), mm | 163.000 |
| Length of machined surface (lm), mm | 212.190 |
| **Machining data** | |
| Cutting speed, m/min | 127.711 |
| Feed per revolution, mm | 0.435 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 242 |
| **Results** | |
| Operation time, s | 128.0000 |
| Total volume removed, cm³ | 559.959 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 163.000 |
| Diameter of machined surface (dm), mm | 153.000 |
| Length of machined surface (lm), mm | 165.470 |
| **Machining data** | |
| Cutting speed, m/min | 127.711 |
| Feed per revolution, mm | 0.435 |

| | |
|---|---|
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 258 |
| **Results** | |
| Operation time, s | 96.0000 |
| Total volume removed, cm³ | 410.675 |

### Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 150.000 |
| Length of machined surface (lm), mm | 165.470 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 495 |
| **Results** | |
| Operation time, s | 301.0000 |

### Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 160.000 |
| Length of machined surface (lm), mm | 52.240 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 464 |
| **Results** | |
| Operation time, s | 106.0000 |

## Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 170.000 |
| Length of machined surface (lm), mm | 120.100 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 437 |

| Results | |
|---|---|
| Operation time, s | 249.0000 |

## Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 180.000 |
| Length of machined surface (lm), mm | 90.140 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.096 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 413 |
| **Results** | |
| Operation time, s | 144.0000 |

## Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 202.000 |
| Length of machined surface (lm), mm | 10.000 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.096 |

| | |
|---|---|
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 368 |
| **Results** | |
| Operation time, s | 24.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 170.000 |
| Length of machined surface (lm), mm | 124.040 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 437 |
| **Results** | |
| Operation time, s | 257.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 160.000 |
| Length of machined surface (lm), mm | 48.260 |

| | |
|---|---|
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 464 |
| **Results** | |
| Operation time, s | 98.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 150.000 |
| Length of machined surface (lm), mm | 147.090 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 495 |
| **Results** | |
| Operation time, s | 269.0000 |

| **Finish multiple pocket end mill (live tool)** | |
|---|---|
| Tool material | Indexable carbide |

| | |
|---|---|
| Include tool replacement cost? | Yes |
| Area of pocket (ap), mm² | 4068.319 |
| Depth of pocket (dt), mm | 10.330 |
| Number of features milled | 2.000 |
| Surface roughness | 32 µin. 0.8 µm |

| **Machining data** | |
|---|---|
| Tool diameter, mm | 10.330 |
| Number of teeth | 4.000 |
| Cutting speed, m/min | 97.317 |
| Feed per tooth, mm | 0.043 |
| Feed speed, mm/s | 8.687 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Spindle speed available, rpm | 3000 |
| Spindle speed required, rpm | 2998 |

| **Results** | |
|---|---|
| Operation time, s | 100.0000 |

## Rough and finish single pocket end mill (live tool)

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Area of pocket (ap), mm² | 3345.431 |
| Total depth of material removed (dt), mm | 12.140 |
| Finish cut allowance, mm | 0.381 |
| Surface roughness | 32 µin. 0.8 µm |

| **Machining data** | |
|---|---|
| Tool diameter, mm | 12.140 |
| Number of teeth | 4.000 |
| Cutting speed during rough cuts, m/min | 63.094 |
| Feed per tooth during rough cuts, mm | 0.067 |

| | |
|---|---|
| Feed speed during rough cuts, mm/s | 7.339 |
| Number of rough cut passes | 3.000 |
| Depth of rough cut per pass, mm | 3.920 |
| Cutting speed during finish cut, m/min | 83.914 |
| Feed per tooth during finish cut, mm | 0.047 |
| Feed speed during finish cut, mm/s | 6.910 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 2.61 |
| Power required, kW | 1.63 |
| Spindle speed available, rpm | 3000 |
| Spindle speed required, rpm | 2200 |
| **Results** | |
| Operation time, s | 164.0000 |
| Total volume removed, cm³ | 40.613 |

## Load bar

| | |
|---|---|
| Length of bar, m | 3.048 |
| Operation time per part, s | 143.20 |

## Finish face

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 150.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 320.000 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |

| Results | |
|---|---|
| Operation time, s | 65.0000 |

## Drill single hole

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled hole (dh), mm | 21.000 |
| Length of drilled hole (lh), mm | 57.000 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 11.861 |
| Feed per revolution, mm | 0.180 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 0.75 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 180 |

| Results | |
|---|---|
| Operation time, s | 153.0000 |
| Total volume removed, $cm^3$ | 19.743 |

## Tap single hole (Metric, coarse)

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of hole to be tapped (dh), mm | 24.000 |
| Length to be tapped (lt), mm | 48.000 |

**Machining data**

| | |
|---|---|
| Thread pitch, mm | 3.000 |
| Cutting speed, m/min | 3.670 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 1236 |
| **Results** | |
| Operation time, s | 10.0000 |

## Load bar

| | |
|---|---|
| Length of bar, m | 0.750 |
| Operation time per part, s | 180.00 |

## Finish face

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 150.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Surface roughness | 32 μin. 0.8 μm |
| **Machining data** | |
| Cutting speed, m/min | 320.000 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 65.0000 |

## Drill single hole

| | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Diameter of drilled hole (dh), mm | 21.000 |
| Length of drilled hole (lh), mm | 57.000 |
| **Machining data** | |
| Cutting speed, m/min | 28.994 |
| Feed per revolution, mm | 0.280 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 2.85 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 439 |
| **Results** | |
| Operation time, s | 47.0000 |
| Total volume removed, $cm^3$ | 19.743 |

## Tap single hole (Metric, coarse)

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of hole to be tapped (dh), mm | 24.000 |
| Length to be tapped (lt), mm | 48.000 |
| **Machining data** | |
| Thread pitch, mm | 3.000 |
| Cutting speed, m/min | 3.670 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 1236 |
| **Results** | |

| | |
|---|---|
| Operation time, s | 10.0000 |

# DFMA® - Boothroyd Dewhurst, Inc.
## DFM Concurrent Costing
## Cost Breakdown

Friday, 14 October 2022

Idler Shaft.dfmx

Analysis Name: 4 IDLER SHAFT
Part name: Idler Shaft
Part number:
Part weight: 203.488 kg

Material name: Medium carbon alloy steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

| Cost per part, $ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process Chart** | **Batch size** | **Material** | **Setup** | **Process** | **Rejects** | **Piece part** | **Tooling** | **Total** | **Operation time per part, s** | **Initial tooling investment** |
| **Medium carbon alloy steel machined/cut from stock part** | | **380.3473** | **0.3151** | **37.2604** | **2.0196** | **419.9423** | | **419.9423** | **5705.82** | |
| **Stock process** | **187** | **380.3473** | **0.0042** | **0.7936** | | **381.1451** | | **381.1451** | **777.09** | |
| Workpiece | | 380.3473 | | | | 380.3473 | | 380.3473 | | |
| Horizontal bandsaw cutoff | | | 0.0042 | 0.7936 | | 0.7978 | | 0.7978 | 777.09 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.3109** | **36.4668** | **2.0196** | **38.7973** | | **38.7973** | **4928.73** | |
| Setup/load/unload | | | 0.3109 | 1.5640 | | 1.8749 | | 1.8749 | 267.63 | |
| Rough face | | | | 0.3944 | | 0.3944 | | 0.3944 | 54.00 | |
| Single centerdrill | | | | 0.0482 | | 0.0482 | | 0.0482 | 8.00 | |
| Rough cylindrical turn | | | | 2.1522 | | 2.1522 | | 2.1522 | 290.00 | |
| Rough cylindrical turn | | | | 2.1235 | | 2.1235 | | 2.1235 | 175.00 | |
| Rough cylindrical turn | | | | 0.7605 | | 0.7605 | | 0.7605 | 96.00 | |
| Rough cylindrical turn | | | | 0.6964 | | 0.6964 | | 0.6964 | 95.00 | |
| Load bar | | | | 1.1104 | | 1.1104 | | 1.1104 | 190.00 | |
| Rough face | | | | 0.4353 | | 0.4353 | | 0.4353 | 61.00 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Single centerdrill | | | | 0.0535 | | 0.0535 | | 0.0535 | 8.90 | |
| Rough cylindrical turn | | | | 4.4675 | | 4.4675 | | 4.4675 | 600.00 | |
| Rough cylindrical turn | | | | 1.9912 | | 1.9912 | | 1.9912 | 269.00 | |
| Rough cylindrical turn | | | | 1.5147 | | 1.5147 | | 1.5147 | 205.00 | |
| Rough cylindrical turn | | | | 0.9411 | | 0.9411 | | 0.9411 | 128.00 | |
| Rough cylindrical turn | | | | 0.7026 | | 0.7026 | | 0.7026 | 96.00 | |
| Finish cylindrical turn | | | | 2.2486 | | 2.2486 | | 2.2486 | 301.00 | |
| Finish cylindrical turn | | | | 0.7843 | | 0.7843 | | 0.7843 | 106.00 | |
| Finish cylindrical turn | | | | 1.8578 | | 1.8578 | | 1.8578 | 249.00 | |
| Finish cylindrical turn | | | | 1.0696 | | 1.0696 | | 1.0696 | 144.00 | |
| Finish cylindrical turn | | | | 0.1686 | | 0.1686 | | 0.1686 | 24.00 | |
| Finish cylindrical turn | | | | 1.9178 | | 1.9178 | | 1.9178 | 257.00 | |
| Finish cylindrical turn | | | | 0.7250 | | 0.7250 | | 0.7250 | 98.00 | |
| Finish cylindrical turn | | | | 2.0072 | | 2.0072 | | 2.0072 | 269.00 | |
| Finish multiple pocket end mill (live tool) | | | | 0.8559 | | 0.8559 | | 0.8559 | 100.00 | |
| Rough and finish single pocket end mill (live tool) | | | | 1.2221 | | 1.2221 | | 1.2221 | 164.00 | |
| Load bar | | | | 0.8369 | | 0.8369 | | 0.8369 | 143.20 | |
| Finish face | | | | 0.6787 | | 0.6787 | | 0.6787 | 65.00 | |
| Drill single hole | | | | 0.9692 | | 0.9692 | | 0.9692 | 153.00 | |
| Tap single hole (Metric, coarse) | | | | 0.0590 | | 0.0590 | | 0.0590 | 10.00 | |
| Load bar | | | | 1.0519 | | 1.0519 | | 1.0519 | 180.00 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Finish face | | | | 0.6787 | | 0.6787 | | 0.6787 | 65.00 | |
| Drill single hole | | | | 0.3208 | | 0.3208 | | 0.3208 | 47.00 | |
| Tap single hole (Metric, coarse) | | | | 0.0590 | | 0.0590 | | 0.0590 | 10.00 | |

# DFM Concurrent Costing
## Totals

Friday, 14 October 2022

Idler Shaft.dfmx

| Analysis Name | 4 IDLER SHAFT |
|---|---|
| Part name | Idler Shaft |
| Part number | |
| Material | Medium carbon alloy steel |
| Manufacturing process | Machined/cut from stock |
| Manufacturing profile | 20A BDI China |

| Cost per part, $ | Value |
|---|---|
| Material | 380.3473 |
| Setup | 0.3151 |
| Process | 37.2604 |
| Rejects | 2.0196 |
| Piece part | 419.9423 |
| Tooling | 0.0000 |
| Total | 419.9423 |
| Initial tooling investment | 0.0000 |

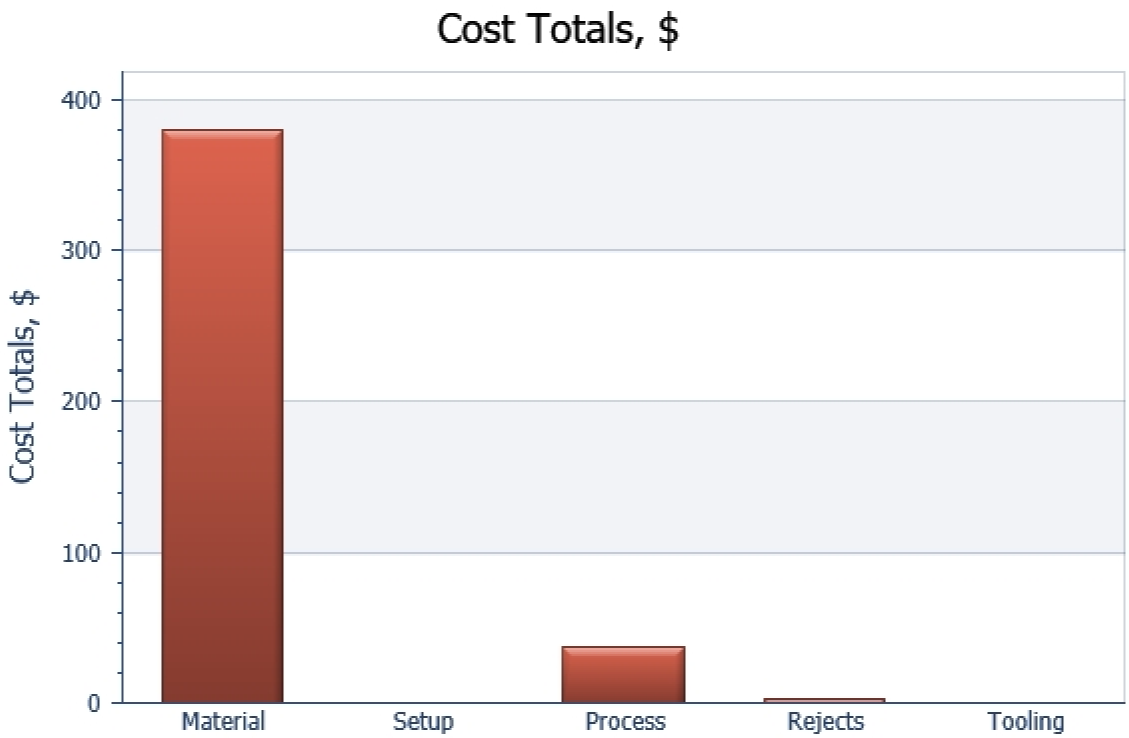
| | |
|---|---|
| Life volume | 1,500 |
| Batch size | 187 |
| Part weight | 203.488 |

# DFM Concurrent Costing
## Cost vs. Life Volume

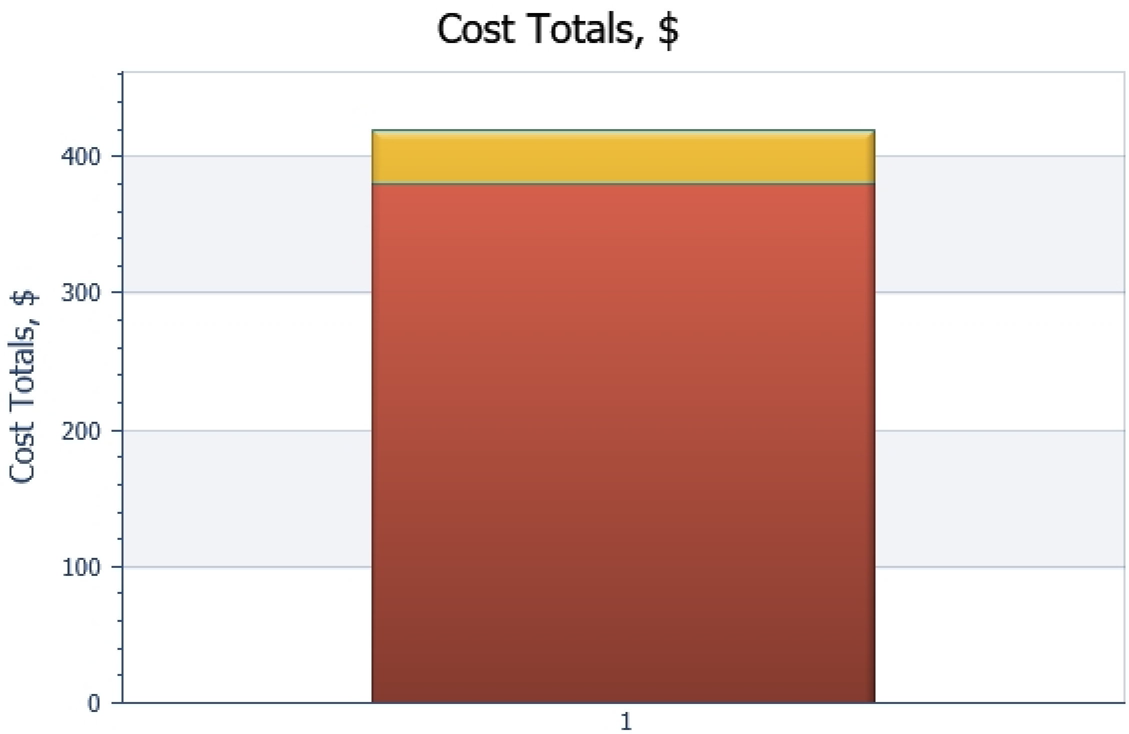
Friday, 14 October 2022

Idler Shaft.dfmx

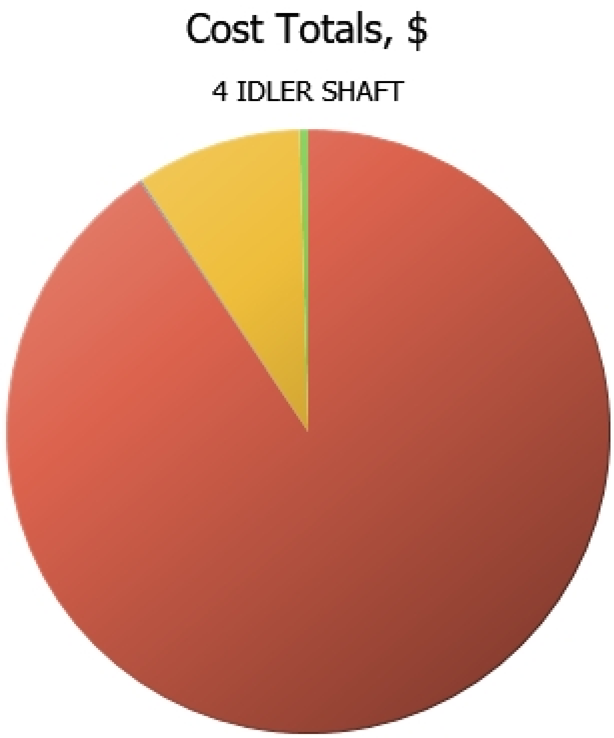

| Cost per part, $ | 4 IDLER SHAFT Machined/cut from stock Medium carbon alloy steel |
|---|---|
| Life volume | 1,500 |
| Material | 380.3473 |
| Setup | 0.3151 |
| Process | 37.2604 |
| Rejects | 2.0196 |
| Piece part | 419.9423 |
| Tooling | 0.0000 |
| Total | 419.9423 |
| Initial tooling investment | 0.0000 |




| Cost per part, $ | 4 IDLER SHAFT<br>Machined/cut from stock<br>Medium carbon alloy steel |
|---|---|
| Life volume | 1,500 |
| Material | 380.3473 |
| Setup | 0.3151 |
| Process | 37.2604 |
| Rejects | 2.0196 |
| Piece part | 419.9423 |
| Tooling | 0.0000 |
| Total | 419.9423 |
| Initial tooling investment | 0.0000 |




| | Cost per part, $ | 1 4 IDLER SHAFT<br>Machined/cut from stock<br>Medium carbon alloy steel |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 380.3473 |
| | Setup | 0.3151 |
| | Process | 37.2604 |
| | Rejects | 2.0196 |
| | Piece part | 419.9423 |
| | Tooling | 0.0000 |
| | Total | 419.9423 |
| | Initial tooling investment | 0.0000 |




| | Cost per part, $ | 1 4 IDLER SHAFT<br>Machined/cut from stock<br>Medium carbon alloy steel |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 380.3473 |
| | Setup | 0.3134 |
| | Process | 37.2604 |
| | Rejects | 2.0196 |
| | Piece part | 419.9406 |
| | Tooling | 0.0000 |
| | Total | 419.9406 |
| | Initial tooling investment | 0.0000 |

# DFMA® - Boothroyd Dewhurst, Inc.
DFM Concurrent Costing
Guide to Cost Reduction

Friday, 14 October 2022 | Idler Shaft.dfmx

Analysis Name: 4 IDLER SHAFT | Material name: Medium carbon alloy steel

Part name: Idler Shaft | Manufacturing process: Machined/cut from stock

Part number: | Manufacturing profile: 20A BDI China

For the product life volume of 1500 and the batch size of 187 you have specified, the tooling costs form 0.00% of the total cost of 419.94. The chart shows how improved equipment might reduce the machining cost in either of two ways: 1. If the machining operations could be carried out on one setup where appropriate. 2. If the various machines imposed no limitations on power or spindle speed.


| Category | Savings, $ |
|---|---|
| Machine limitations | 0.0751 |
| Rejects | 2.0196 |

# Appendix Y.5

**DFM Concurrent Costing Analysis Report of Part No. 5/6 Drive and Idler Gears of Best Concept Design**

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing
# Executive Summary

Friday, 14 October 2022

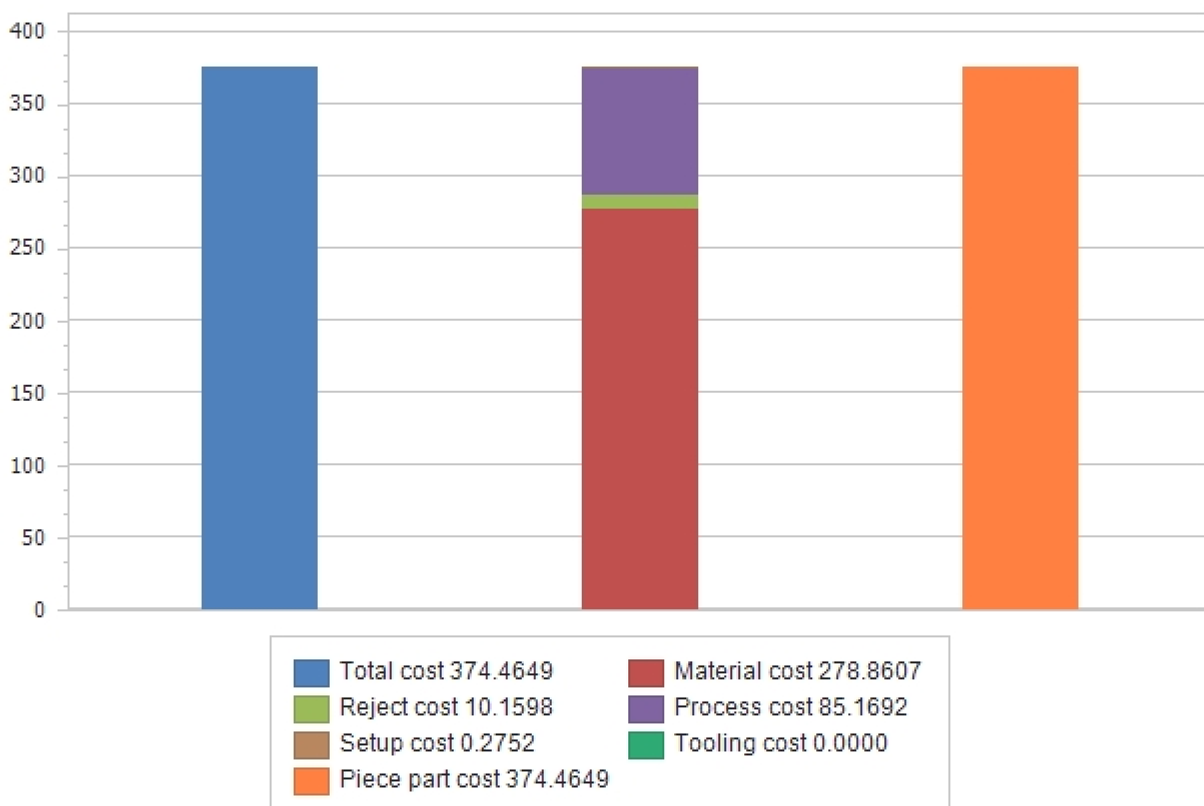
Idler Gear.dfmx

Analysis Name: 6 IDLER GEAR
Part name: Idler Gear
Part number:

Material name: Medium carbon alloy steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

| | |
|---|---|
| Product life volume | 1,500 |
| Batch size | 187 |
| Total cost, $ | 374.4649 |
| Piece part cost, $ | 374.4649 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFM Concurrent Costing
# Notes

Friday, 14 October 2022 | Idler Gear.dfmx

Analysis Name: 6 IDLER GEAR
Part name: Idler Gear
Part number:

Material name: Medium carbon alloy steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

## Workpiece

Length changed from default DFM value of 95mm to 105mm to account for additional stock to be removed from each end for finishing face.

## Rough face

Face intial side of gear stock.

## Rough cylindrical turn

Length is 100mm due to 5mm being removed for rough facing operation.

## Load bar

Rotate gear 180° to to complete operations on other face.

## Rough face

Takes bar length down to 96mm. Finishing operation follows to obtain finsihed width of gear.

## Load bar

Load bar into cylindrical borer.

## Rough cylindrical bore

Cutting bore for gear.

## Load bar

Load machined stock into mill for keyway slotting

## Finish single slot end mill (live tool)

Cut keyway for gear

## Measure with vernier caliper

Measure OD of gear.

## Measure with vernier caliper

Measure ID of gear bore.

Friday, 14 October 2022

Idler Gear.dfmx

### Measure with vernier caliper

Measure keyway dimensions.

### Setup/load/unload

Load gear into hobbing machine for gear cutting

### Gear hobbing

Option for simultaneous gearing selected, i.e., can machine both drive and driven gears.

# DFM Concurrent Costing
## Responses

Friday, 14 October 2022

Idler Gear.dfmx

Analysis Name: 6 IDLER GEAR
Part name: Idler Gear
Part number:

Material name: Medium carbon alloy steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

## Medium carbon alloy steel machined/cut from stock part

| Part | |
|---|---|
| Part name | Idler Gear |
| Part number | |
| Life volume | 1500 |
| Envelope shape | Solid cylinder |
| Part length, mm | 467.991 |
| Part width, mm | 95.000 |
| Part height, mm | 468.000 |
| Average thickness, mm | 50.361 |
| Forming direction | Z |

## Stock process

| Part basic data | |
|---|---|
| Batch size | 187 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Round bar or rod |
| Material hardness, Bhn | 300 |
| Material cost, $/kg | 1.896 |
| Material scrap value, $/kg | 0.132 |
| Cutoff method | Horizontal bandsaw |

| Part geometry | |
|---|---|
| Volume, cm³ | 8662.800 |
| Weight, kg | 67.859 |

## Workpiece

| Bar dimensions | |
|---|---|
| Bar stock length, m | 3.048 |

| Workpiece geometry | |
|---|---|
| Length, mm | 105.000 |
| Diameter, mm | 478.000 |

## Horizontal bandsaw cutoff

| Basic process data | |
|---|---|
| Process rate, $/hr | 3.13 |
| Setup rate, $/hr | 3.13 |
| Setup time, hr | 0.25 |

| Bar loading data | |
|---|---|
| Bar loading time, s | 33.00 |

| Bandsaw cutting data | |
|---|---|
| Cutting rate, cm²/min | 23.392 |
| Kerf, mm | 1.067 |

| Operation time | |
|---|---|
| Process time per part, s | 4604.02 |

## Cincinnati Falcon TC-300/1000 turning center

| Basic data | |
|---|---|
| Batch size | 187 |
| Material hardness, Bhn | 300 |
| Rejects, % | 0.50 |

| Machine tool data | |
|---|---|
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 16.32 |
| Operator rate, $/hr | 3.13 |

| | |
|---|---|
| Process rate, $/hr | 17.88 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |

| **Live tool data** | |
|---|---|
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |

| **Result** | |
|---|---|
| Cycle time per part, s | 6802.13 |
| Total setup time, hr | 1.39 |

## Setup/load/unload

| **Work handling** | |
|---|---|
| Workholding device | Collet |
| Number of reversals | 1 |
| Load/unload time, s | 44.10 |
| Reversal time, s | 82.33 |

| **Machine setup** | |
|---|---|
| Machine rate during setup, $/hr | 16.32 |
| Setup operator rate, $/hr | 3.13 |
| Setup rate, $/hr | 19.45 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |

| **Other costs** | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

## Rough face

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 478.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Total depth to be removed (wm), mm | 5.000 |
| **Machining data** | |
| Cutting speed, m/min | 127.426 |
| Feed per revolution, mm | 0.436 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 201.0000 |
| Total volume removed, $cm^3$ | 897.259 |

## Finish face

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 478.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 232.931 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |

| Results | |
|---|---|
| Operation time, s | 687.0000 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 478.000 |
| Diameter of machined surface (dm), mm | 471.000 |
| Length of machined surface (lm), mm | 100.000 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 139.903 |
| Feed per revolution, mm | 0.365 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 3.500 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 13.43 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 94 |

| Results | |
|---|---|
| Operation time, s | 182.0000 |
| Total volume removed, $cm^3$ | 521.742 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 413.550 |
| Diameter of machined surface (dm), mm | 367.360 |
| Length of machined surface (lm), mm | 30.550 |
| **Machining data** | |
| Cutting speed, m/min | 131.369 |
| Feed per revolution, mm | 0.420 |
| Number of passes | 5.000 |
| Depth of cut per pass, mm | 4.619 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 19.12 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 113 |
| **Results** | |
| Operation time, s | 236.0000 |
| Total volume removed, $cm^3$ | 865.470 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 367.360 |
| Diameter of machined surface (dm), mm | 283.140 |
| Length of machined surface (lm), mm | 42.210 |
| **Machining data** | |
| Cutting speed, m/min | 131.064 |
| Feed per revolution, mm | 0.422 |
| Number of passes | 9.000 |

| | |
|---|---|
| Depth of cut per pass, mm | 4.679 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 19.45 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 145 |
| **Results** | |
| Operation time, s | 479.0000 |
| Total volume removed, cm³ | 1816.225 |

| Rough cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 283.140 |
| Diameter of machined surface (dm), mm | 210.720 |
| Length of machined surface (lm), mm | 51.370 |
| **Machining data** | |
| Cutting speed, m/min | 131.978 |
| Feed per revolution, mm | 0.415 |
| Number of passes | 8.000 |
| Depth of cut per pass, mm | 4.526 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 18.63 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 196 |
| **Results** | |

| | |
|---|---|
| Operation time, s | 401.0000 |
| Total volume removed, cm³ | 1442.992 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 468.000 |
| Length of machined surface (lm), mm | 100.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 159 |
| **Results** | |
| Operation time, s | 562.0000 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 364.360 |
| Length of machined surface (lm), mm | 30.550 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |

| | |
|---|---|
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 204 |
| **Results** | |
| Operation time, s | 139.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 280.140 |
| Length of machined surface (lm), mm | 42.210 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 265 |
| **Results** | |
| Operation time, s | 147.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 207.720 |
| Length of machined surface (lm), mm | 48.370 |

| | |
|---|---|
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 358 |
| **Results** | |
| Operation time, s | 126.0000 |

| **Load bar** | |
|---|---|
| Length of bar, m | 3.048 |
| Operation time per part, s | 82.90 |

| **Rough face** | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 468.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Total depth to be removed (wm), mm | 4.000 |
| **Machining data** | |
| Cutting speed, m/min | 135.633 |
| Feed per revolution, mm | 0.390 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 4.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 15.90 |

| | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 209.0000 |
| Total volume removed, cm³ | 688.087 |

| **Finish face** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 468.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 232.931 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 659.0000 |

| **Rough cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 402.000 |
| Diameter of machined surface (dm), mm | 367.360 |
| Length of machined surface (lm), mm | 26.460 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 133.198 |
| Feed per revolution, mm | 0.406 |
| Number of passes | 4.000 |
| Depth of cut per pass, mm | 4.330 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 17.59 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 115 |

| Results | |
|---|---|
| Operation time, s | 168.0000 |
| Total volume removed, cm³ | 553.846 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 367.360 |
| Diameter of machined surface (dm), mm | 253.140 |
| Length of machined surface (lm), mm | 57.180 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 130.454 |
| Feed per revolution, mm | 0.426 |
| Number of passes | 12.000 |
| Depth of cut per pass, mm | 4.759 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |

| | |
|---|---|
| Maximum power required, kW | 19.85 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 161 |
| **Results** | |
| Operation time, s | 800.0000 |
| Total volume removed, cm³ | 3182.878 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 253.140 |
| Diameter of machined surface (dm), mm | 210.720 |
| Length of machined surface (lm), mm | 27.230 |
| **Machining data** | |
| Cutting speed, m/min | 134.112 |
| Feed per revolution, mm | 0.402 |
| Number of passes | 5.000 |
| Depth of cut per pass, mm | 4.242 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 17.17 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 199 |
| **Results** | |
| Operation time, s | 143.0000 |
| Total volume removed, cm³ | 420.821 |

## Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 364.360 |
| Length of machined surface (lm), mm | 26.460 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 204 |
| **Results** | |
| Operation time, s | 121.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 250.140 |
| Length of machined surface (lm), mm | 57.180 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 297 |

| Results | |
|---|---|
| Operation time, s | 177.0000 |

## Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 207.720 |
| Length of machined surface (lm), mm | 27.230 |
| Surface roughness | 32 µin. 0.8 µm |

| Machining data | |
|---|---|
| Cutting speed, m/min | 233.172 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 358 |

| Results | |
|---|---|
| Operation time, s | 74.0000 |

## Rough cylindrical bore

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 0.000 |
| Diameter of machined surface (dm), mm | 0.000 |
| Length of machined surface (lm), mm | 0.000 |
| WARNING | enter dimensions |

## Load bar

| | |
|---|---|
| Length of bar, m | 3.048 |

| | |
|---|---|
| Operation time per part, s | 82.90 |

| Rough cylindrical bore | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 0.000 |
| Diameter of machined surface (dm), mm | 180.000 |
| Length of machined surface (lm), mm | 95.000 |
| **Machining data** | |
| Cutting speed, m/min | 80.510 |
| Feed per revolution, mm | 0.428 |
| Number of passes | 18.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 12.93 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 868.0000 |
| Total volume removed, cm³ | 2417.467 |

| Load bar | |
|---|---|
| Length of bar, m | 3.048 |
| Operation time per part, s | 82.90 |

| Finish single slot end mill (live tool) | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 45.000 |

| | |
|---|---|
| Length of surface to be milled (lc), mm | 95.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Tool diameter, mm | 45.000 |
| Number of teeth | 4.000 |
| Cutting speed, m/min | 83.914 |
| Feed per tooth, mm | 0.091 |
| Feed speed, mm/s | 3.589 |
| Number of passes | 1.000 |
| Width per pass, mm | 45.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3000 |
| Spindle speed required, rpm | 593 |
| **Results** | |
| Operation time, s | 48.0000 |

| **Measure with vernier caliper** | |
|---|---|
| Rejects, % | 0.500 |
| Operator rate, $/hr | 3.125 |
| Part handling time, s | 20.100 |
| Number of checks | 1.000 |
| Gaging frequency | 1.000 |
| Time for one measurement, s | 7.800 |
| Operation time per part, s | 27.9000 |

| **Measure with vernier caliper** | |
|---|---|
| Rejects, % | 0.500 |
| Operator rate, $/hr | 3.125 |
| Part handling time, s | 20.100 |
| Number of checks | 1.000 |

| | |
|---|---|
| Gaging frequency | 1.000 |
| Time for one measurement, s | 7.800 |
| Operation time per part, s | 27.9000 |

## Measure with vernier caliper

| | |
|---|---|
| Rejects, % | 0.500 |
| Operator rate, $/hr | 3.125 |
| Part handling time, s | 20.100 |
| Number of checks | 1.000 |
| Gaging frequency | 1.000 |
| Time for one measurement, s | 7.800 |
| Operation time per part, s | 27.9000 |

## Generic gear hobbing machine

| **Basic data** | |
|---|---|
| Batch size | 187 |
| Material hardness, Bhn | 300 |
| Rejects, % | 0.50 |

| **Machine tool data** | |
|---|---|
| Number of machines per operator | 3.00 |
| Machine rate, $/hr | 20.00 |
| Operator rate, $/hr | 3.13 |
| Process rate, $/hr | 21.04 |
| Tool positioning or index time, s | 0.00 |

| **Result** | |
|---|---|
| Cycle time per part, s | 5066.10 |
| Total setup time, hr | 1.00 |

## Setup/load/unload

**Work handling**

| | |
|---|---|
| Workholding device | Rotary table or index plate |
| Number of reversals | 0 |
| Load/unload time, s | 210.10 |
| **Machine setup** | |
| Machine rate during setup, $/hr | 20.00 |
| Setup operator rate, $/hr | 3.13 |
| Setup rate, $/hr | 23.13 |
| Basic setup time, hr | 1.00 |
| Setup time per tool, hr | 0.00 |
| **Other costs** | |
| Tool, fixture or program cost, $ | 0 |

## Gear hobbing

| | |
|---|---|
| Include tool replacement cost? | Yes |
| Pitch diameter (pd), mm | 468.000 |
| Face width (wf), mm | 80.000 |
| Number of gear teeth | 115.000 |
| Helix angle, deg | 20.000 |
| Gears machined simultaneously | 2.000 |
| **Machining data** | |
| Diametral pitch, 1/mm | 0.246 |
| Hob diameter, mm | 134.424 |
| Hob starts | three |
| Cutting speed, m/min | 32.120 |
| Feed per work rev, mm | 1.233 |
| Special tooling cost, $ | 0.000 |
| **Results** | |
| Operation time, s | 4856.0000 |

## Induction hardening

| | |
|---|---|
| Rejects, % | 0.500 |
| Process rate, $/hr | 3.13 |
| Setup rate, $/hr | 3.125 |
| Setup time, hr | 0.167 |
| Handling time, s | 20.100 |
| Clamp and unclamp time, s | 10.000 |
| Number of hardened areas | 330.000 |
| Hardening time per area, s | 30.000 |
| Total repositioning time, s | 329.000 |
| Operation time, s | 10259.10 |

# DFMA® - Boothroyd Dewhurst, Inc.
## DFM Concurrent Costing
## Cost Breakdown

Friday, 14 October 2022

Idler Gear.dfmx

Analysis Name: 6 IDLER GEAR
Part name: Idler Gear
Part number:
Part weight: 147.599 kg

Material name: Medium carbon alloy steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI China

| Cost per part, $ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process Chart** | **Batch size** | **Material** | **Setup** | **Process** | **Rejects** | **Piece part** | **Tooling** | **Total** | **Operation time per part, s** | **Initial tooling investment** |
| **Medium carbon alloy steel machined/cut from stock part** | | **278.8607** | **0.2752** | **85.1692** | **10.1598** | **374.4649** | | **374.4649** | **26815.05** | |
| **Stock process** | **187** | **278.8607** | **0.0042** | **4.7018** | | **283.5667** | | **283.5667** | **4604.02** | |
| Workpiece | | 278.8607 | | | | 278.8607 | | 278.8607 | | |
| Horizontal bandsaw cutoff | | | 0.0042 | 4.7018 | | 4.7060 | | 4.7060 | 4604.02 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.1445** | **49.7371** | **1.6298** | **51.5114** | | **51.5114** | **6802.13** | |
| Setup/load/unload | | | 0.1445 | 0.7389 | | 0.8834 | | 0.8834 | 126.43 | |
| Rough face | | | | 1.4815 | | 1.4815 | | 1.4815 | 201.00 | |
| Finish face | | | | 5.1403 | | 5.1403 | | 5.1403 | 687.00 | |
| Rough cylindrical turn | | | | 1.3538 | | 1.3538 | | 1.3538 | 182.00 | |
| Rough cylindrical turn | | | | 1.7185 | | 1.7185 | | 1.7185 | 236.00 | |
| Rough cylindrical turn | | | | 3.5011 | | 3.5011 | | 3.5011 | 479.00 | |
| Rough cylindrical turn | | | | 2.9239 | | 2.9239 | | 2.9239 | 401.00 | |
| Finish cylindrical turn | | | | 4.2074 | | 4.2074 | | 4.2074 | 562.00 | |
| Finish cylindrical turn | | | | 1.0319 | | 1.0319 | | 1.0319 | 139.00 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Finish cylindrical turn | | | | 1.0923 | | 1.0923 | | 1.0923 | 147.00 | |
| Finish cylindrical turn | | | | 0.9345 | | 0.9345 | | 0.9345 | 126.00 | |
| Load bar | | | | 0.4845 | | 0.4845 | | 0.4845 | 82.90 | |
| Rough face | | | | 1.5444 | | 1.5444 | | 1.5444 | 209.00 | |
| Finish face | | | | 4.9301 | | 4.9301 | | 4.9301 | 659.00 | |
| Rough cylindrical turn | | | | 1.2168 | | 1.2168 | | 1.2168 | 168.00 | |
| Rough cylindrical turn | | | | 5.8762 | | 5.8762 | | 5.8762 | 800.00 | |
| Rough cylindrical turn | | | | 1.0201 | | 1.0201 | | 1.0201 | 143.00 | |
| Finish cylindrical turn | | | | 0.8973 | | 0.8973 | | 0.8973 | 121.00 | |
| Finish cylindrical turn | | | | 1.3165 | | 1.3165 | | 1.3165 | 177.00 | |
| Finish cylindrical turn | | | | 0.5440 | | 0.5440 | | 0.5440 | 74.00 | |
| Rough cylindrical bore | | | | | | | | | | |
| Load bar | | | | 0.4845 | | 0.4845 | | 0.4845 | 82.90 | |
| Rough cylindrical bore | | | | 6.4682 | | 6.4682 | | 6.4682 | 868.00 | |
| Load bar | | | | 0.4845 | | 0.4845 | | 0.4845 | 82.90 | |
| Finish single slot end mill (live tool) | | | | 0.3461 | | 0.3461 | | 0.3461 | 48.00 | |
| **Measure with vernier caliper** | | | | **0.0285** | **1.6381** | **1.6666** | | **1.6666** | **27.90** | |
| **Measure with vernier caliper** | | | | **0.0285** | **1.6465** | **1.6750** | | **1.6750** | **27.90** | |
| **Measure with vernier caliper** | | | | **0.0285** | **1.6549** | **1.6834** | | **1.6834** | **27.90** | |
| **Generic gear hobbing machine** | | | **0.1237** | **20.1678** | **1.7646** | **22.0560** | | **22.0560** | **5066.10** | |
| Setup/load/unload | | | 0.1237 | 1.4447 | | 1.5684 | | 1.5684 | 210.10 | |
| Gear hobbing | | | | 18.7230 | | 18.7230 | | 18.7230 | 4856.00 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Induction hardening** | | | **0.0028** | **10.4770** | **1.8261** | **12.3059** | | **12.3059** | **10259.10** | |

# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Totals

Friday, 14 October 2022

Idler Gear.dfmx

| Analysis Name | 6 IDLER GEAR |
|---|---|
| Part name | Idler Gear |
| Part number | |
| Material | Medium carbon alloy steel |
| Manufacturing process | Machined/cut from stock |
| Manufacturing profile | 20A BDI China |

| Cost per part, $ | Value |
|---|---|
| Material | 278.8607 |
| Setup | 0.2752 |
| Process | 85.1692 |
| Rejects | 10.1598 |
| Piece part | 374.4649 |
| Tooling | 0.0000 |
| Total | 374.4649 |
| Initial tooling investment | 0.0000 |

| | |
|---|---|
| Life volume | 1,500 |
| Batch size | 187 |
| Part weight | 147.599 |

# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Cost vs. Life Volume

Friday, 14 October 2022

Idler Gear.dfmx


| Cost per part, $ | 6 IDLER GEAR<br>Machined/cut from stock<br>Medium carbon alloy steel |
|---|---|
| Life volume | 1,500 |
| Material | 278.8607 |
| Setup | 0.2752 |
| Process | 85.1692 |
| Rejects | 10.1598 |
| Piece part | 374.4649 |
| Tooling | 0.0000 |
| Total | 374.4649 |
| Initial tooling investment | 0.0000 |

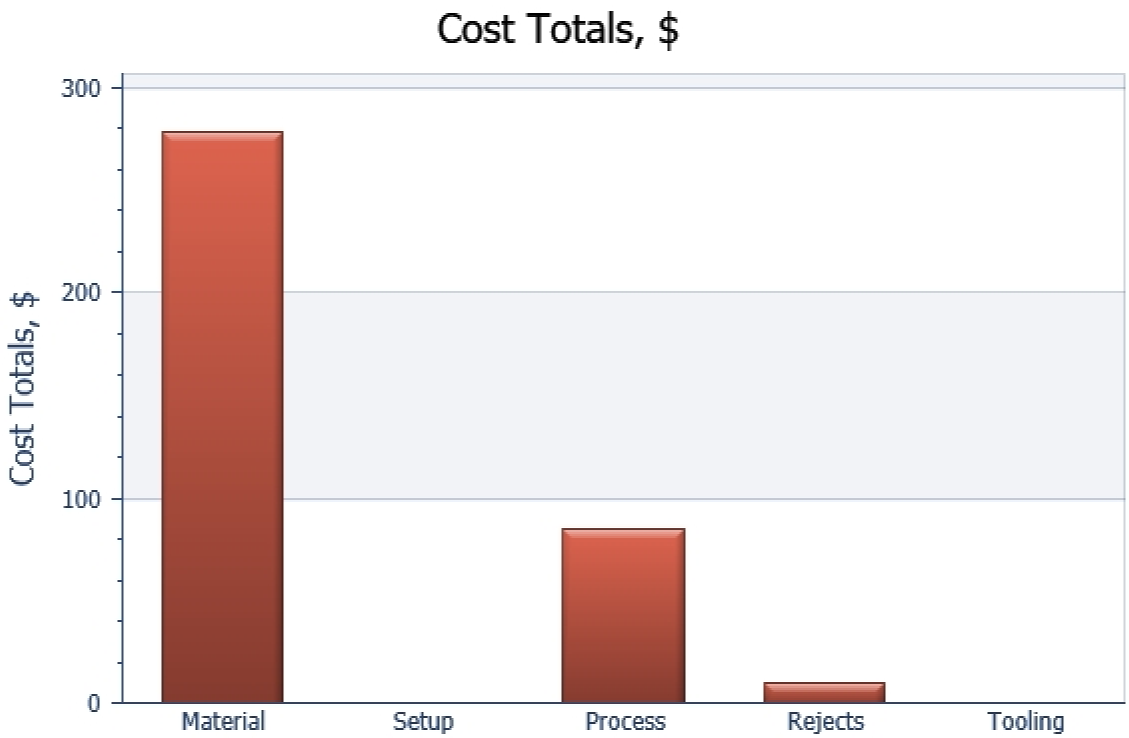
# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Cost Totals

Friday, 14 October 2022

Idler Gear.dfmx




| Cost per part, $ | 6 IDLER GEAR<br>Machined/cut from stock<br>Medium carbon alloy steel |
|---|---|
| Life volume | 1,500 |
| Material | 278.8607 |
| Setup | 0.2752 |
| Process | 85.1692 |
| Rejects | 10.1598 |
| Piece part | 374.4649 |
| Tooling | 0.0000 |
| Total | 374.4649 |
| Initial tooling investment | 0.0000 |

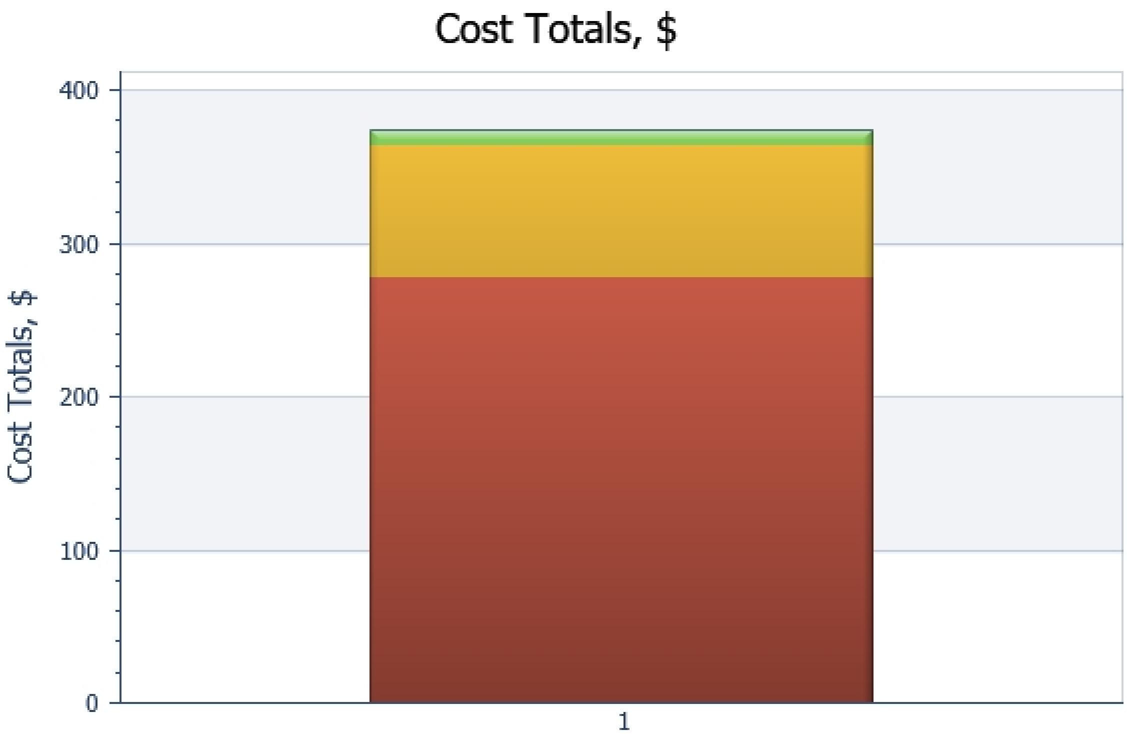
# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Cost Totals

Friday, 14 October 2022

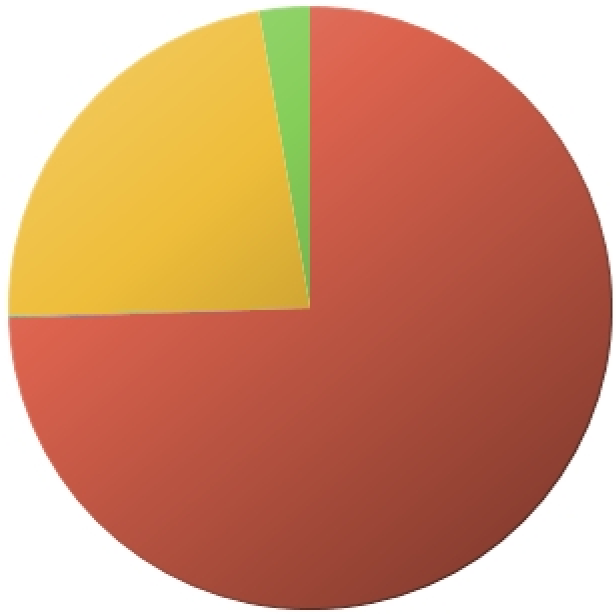
Idler Gear.dfmx




| | Cost per part, $ | 1 6 IDLER GEAR<br>Machined/cut from stock<br>Medium carbon alloy steel |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 278.8607 |
| | Setup | 0.2752 |
| | Process | 85.1692 |
| | Rejects | 10.1598 |
| | Piece part | 374.4649 |
| | Tooling | 0.0000 |
| | Total | 374.4649 |
| | Initial tooling investment | 0.0000 |

## Cost Totals, $

6 IDLER GEAR



| | Cost per part, $ | 1 6 IDLER GEAR<br>Machined/cut from stock<br>Medium carbon alloy steel |
|---|---|---|
| | Life volume | 1,500 |
| | Material | 278.8607 |
| | Setup | 0.2737 |
| | Process | 85.1692 |
| | Rejects | 10.1598 |
| | Piece part | 374.4634 |
| | Tooling | 0.0000 |
| | Total | 374.4634 |
| | Initial tooling investment | 0.0000 |

# DFMA® - Boothroyd Dewhurst, Inc.

## DFM Concurrent Costing

## Guide to Cost Reduction

Friday, 14 October 2022

Idler Gear.dfmx

Analysis Name: 6 IDLER GEAR

Material name: Medium carbon alloy steel

Part name: Idler Gear

Manufacturing process: Machined/cut from stock

Part number:

Manufacturing profile: 20A BDI China

For the product life volume of 1500 and the batch size of 187 you have specified, the tooling costs form 0.00% of the total cost of 374.46. The chart shows how improved equipment might reduce the machining cost in either of two ways: 1. If the machining operations could be carried out on one setup where appropriate. 2. If the various machines imposed no limitations on power or spindle speed.


| Category | Savings, $ |
|---|---|
| Avoidable setups | 1.5684 |
| Machine limitations | 0.0376 |
| Additional operations | 17.3308 |
| Rejects | 10.1598 |

# Appendix Y.7

**DFM Concurrent Costing Analysis Report of Part No. 9 Bearing Retainer of Best Concept Design**

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing
# Executive Summary

Friday, 14 October 2022

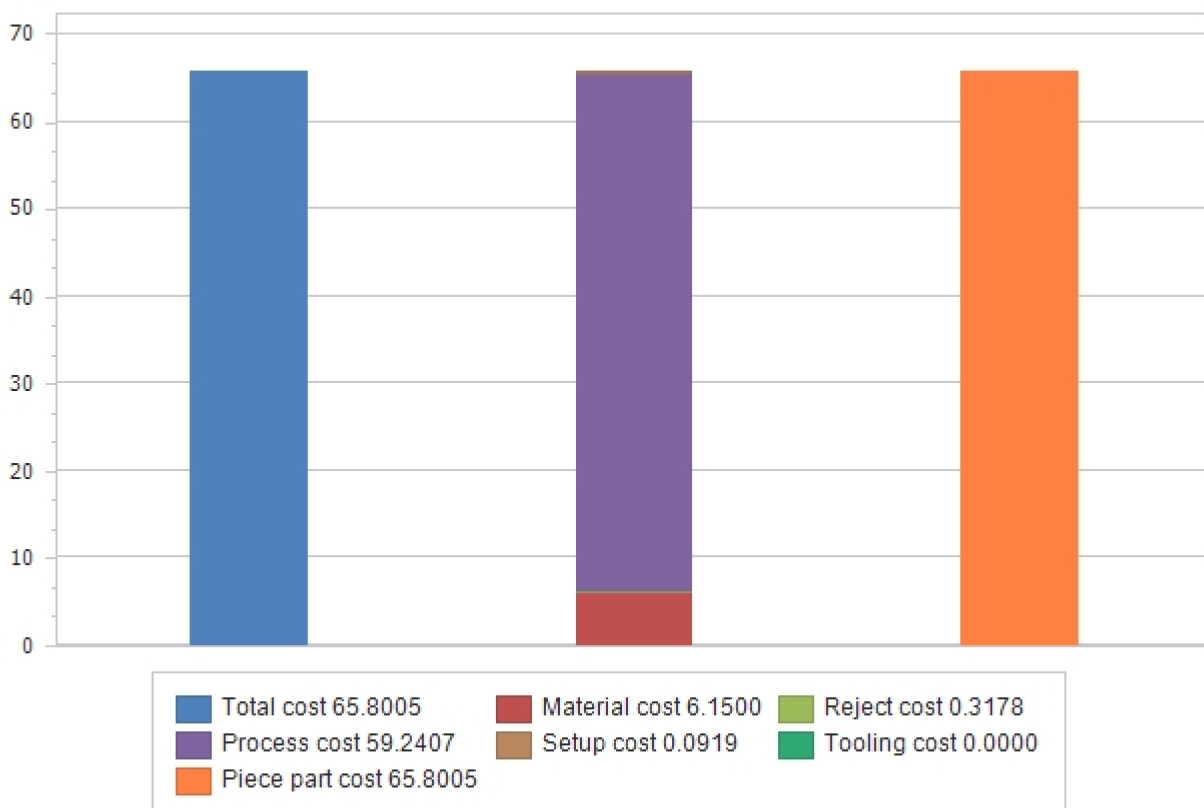
Bearing Retainer.bck.dfmx

Analysis Name: 7 BEARING RETAINER
Part name: 7 BEARING RETAINER
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| | |
|---|---|
| Product life volume | 6,000 |
| Batch size | 750 |
| Total cost, $ | 65.8005 |
| Piece part cost, $ | 65.8005 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFM Concurrent Costing
# Notes

Friday, 14 October 2022

Bearing Retainer.bck.dfmx

Analysis Name: 7 BEARING RETAINER

Part name: 7 BEARING RETAINER

Part number:

Material name: Low carbon steel, cold rolled, commercial quality

Manufacturing process: Machined/cut from stock

Manufacturing profile: 20A BDI North America

## Rough and finish cylindrical bore

Bore hole for bearing retainer.

## Rough and finish face

Rough and face primary face of retainer.

## Cutoff

Cut off so component can be reversed for further machining on rear side.

## Load bar

Load bar back into chuck to machine other side.

# DFM Concurrent Costing

# Responses

Friday, 14 October 2022

Bearing Retainer.bck.dfmx

Analysis Name: 7 BEARING RETAINER
Part name: 7 BEARING RETAINER
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

## Low carbon steel, cold rolled, commercial quality machined/cut from stock part

| Part | |
|---|---|
| Part name | 7 BEARING RETAINER |
| Part number | |
| Life volume | 6000 |
| Envelope shape | Solid cylinder |
| Part length, mm | 449.851 |
| Part width, mm | 42.000 |
| Part height, mm | 449.702 |
| Average thickness, mm | 15.586 |
| Forming direction | Z |

## Stock process

| Part basic data | |
|---|---|
| Batch size | 750 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Round bar or rod |
| Material hardness, Bhn | 200 |
| Material cost, $/kg | 0.838 |
| Material scrap value, $/kg | 0.110 |
| Cutoff method | Horizontal bandsaw |

| Part geometry | |
|---|---|
| Volume, $cm^3$ | 2477.161 |
| Weight, kg | 19.404 |

## Workpiece

| | |
|---|---|
| **Bar dimensions** | |
| Bar stock length, m | 3.048 |

| | |
|---|---|
| **Workpiece geometry** | |
| Length, mm | 449.702 |
| Diameter, mm | 42.000 |

## Horizontal bandsaw cutoff

| | |
|---|---|
| **Basic process data** | |
| Process rate, $/hr | 15.00 |
| Setup rate, $/hr | 15.00 |
| Setup time, hr | 0.25 |

| | |
|---|---|
| **Bar loading data** | |
| Bar loading time, s | 33.00 |

| | |
|---|---|
| **Bandsaw cutting data** | |
| Cutting rate, cm²/min | 71.418 |
| Kerf, mm | 1.067 |

| | |
|---|---|
| **Operation time** | |
| Process time per part, s | 17.14 |

## Cincinnati Falcon TC-300/1000 turning center

| | |
|---|---|
| **Basic data** | |
| Batch size | 750 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |

| | |
|---|---|
| **Machine tool data** | |
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 20.40 |
| Operator rate, $/hr | 25.00 |

| | |
|---|---|
| Process rate, $/hr | 32.90 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |

| **Live tool data** | |
|---|---|
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |

| **Result** | |
|---|---|
| Cycle time per part, s | 4412.05 |
| Total setup time, hr | 1.39 |

## Setup/load/unload

| **Work handling** | |
|---|---|
| Workholding device | Collet |
| Number of reversals | 0 |
| Load/unload time, s | 17.85 |

| **Machine setup** | |
|---|---|
| Machine rate during setup, $/hr | 16.90 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 46.90 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |

| **Other costs** | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

## Rough and finish cylindrical bore

| | |
|---|---|
| Tool material | Indexable carbide |

| | |
|---|---|
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 202.000 |
| Diameter of machined surface (dm), mm | 450.000 |
| Length of machined surface (lm), mm | 37.000 |
| Finish cut allowance on radius, mm | 0.200 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed during rough cuts, m/min | 101.179 |
| Feed per revolution during rough cuts, mm | 0.319 |
| Number of rough cut passes | 25.000 |
| Depth of rough cut per pass, mm | 4.952 |
| Cutting speed during finish cut, m/min | 229.891 |
| Feed per revolution during finish cut, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 10.17 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 163 |
| **Results** | |
| Operation time, s | 2130.0000 |
| Total volume removed, cm³ | 4698.864 |

| **Rough and finish face** | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 450.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Total depth to be removed (wm), mm | 3.000 |
| Finish cut allowance, mm | 0.200 |
| Surface roughness | 32 µin. 0.8 µm |

| Machining data | |
|---|---|
| Cutting speed during rough cuts, m/min | 179.623 |
| Feed per revolution during rough cuts, mm | 0.305 |
| Number of rough cut passes | 1.000 |
| Depth of rough cut per pass, mm | 2.800 |
| Cutting speed during finish cut, m/min | 340.061 |
| Feed per revolution during finish cut, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 9.77 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |

| Results | |
|---|---|
| Operation time, s | 609.0000 |
| Total volume removed, $cm^3$ | 477.132 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 453.000 |
| Diameter of machined surface (dm), mm | 363.000 |
| Length of machined surface (lm), mm | 15.000 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 149.352 |
| Feed per revolution, mm | 0.407 |
| Number of passes | 9.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 19.38 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 130 |

| **Results** | |
|---|---|
| Operation time, s | 229.0000 |
| Total volume removed, $cm^3$ | 865.199 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 343.000 |
| Diameter of machined surface (dm), mm | 326.900 |
| Length of machined surface (lm), mm | 15.000 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 160.020 |
| Feed per revolution, mm | 0.365 |
| Number of passes | 2.000 |
| Depth of cut per pass, mm | 4.025 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 15.00 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 154 |

| **Results** | |
|---|---|
| Operation time, s | 46.0000 |
| Total volume removed, $cm^3$ | 127.063 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 450.000 |
| Length of machined surface (lm), mm | 5.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 241 |
| **Results** | |
| Operation time, s | 25.0000 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 340.000 |
| Length of machined surface (lm), mm | 19.160 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |

| | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 319 |
| **Results** | |
| Operation time, s | 60.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 305.000 |
| Length of machined surface (lm), mm | 23.050 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.096 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 355 |
| **Results** | |
| Operation time, s | 48.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 0.000 |
| Length of machined surface (lm), mm | 0.000 |
| Surface roughness | 63 µin. 1.6 µm |
| WARNING | enter dimensions |

| Cutoff | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter (d1), mm | 450.000 |
| Inner diameter (d2), mm | 202.000 |
| **Machining data** | |
| Cutoff tool width, mm | 12.570 |
| Cutting speed, m/min | 152.400 |
| Feed per revolution, mm | 0.149 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 18.23 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 240 |
| **Results** | |
| Operation time, s | 349.0000 |
| Total volume removed, $cm^3$ | 1596.344 |

| Load bar | |
|---|---|
| Length of bar, m | 3.048 |
| Operation time per part, s | 31.2000 |

| Rough and finish face | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 460.000 |
| Inner diameter of faced surface (d2), mm | 450.000 |
| Total depth to be removed (wm), mm | 3.000 |
| Finish cut allowance, mm | 0.200 |

| | |
|---|---|
| Surface roughness | 32 µin. 0.8 µm |

| **Machining data** | |
|---|---|
| Cutting speed during rough cuts, m/min | 179.623 |
| Feed per revolution during rough cuts, mm | 0.305 |
| Number of rough cut passes | 1.000 |
| Depth of rough cut per pass, mm | 2.800 |
| Cutting speed during finish cut, m/min | 340.061 |
| Feed per revolution during finish cut, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 9.77 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 241 |

| **Results** | |
|---|---|
| Operation time, s | 47.0000 |
| Total volume removed, $cm^3$ | 21.441 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 460.000 |
| Diameter of machined surface (dm), mm | 453.000 |
| Length of machined surface (lm), mm | 61.320 |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 167.335 |
| Feed per revolution, mm | 0.341 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 3.500 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 12.72 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 117 |

| Results | |
|---|---|
| Operation time, s | 99.0000 |
| Total volume removed, cm³ | 307.796 |

| Rough cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 345.000 |
| Diameter of machined surface (dm), mm | 334.080 |
| Length of machined surface (lm), mm | 15.960 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 181.356 |
| Feed per revolution, mm | 0.301 |
| Number of passes | 2.000 |
| Depth of cut per pass, mm | 2.730 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 9.50 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 172 |

| Results | |
|---|---|
| Operation time, s | 51.0000 |
| Total volume removed, cm³ | 92.954 |

| Rough cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 315.000 |
| Diameter of machined surface (dm), mm | 289.000 |
| Length of machined surface (lm), mm | 15.000 |
| **Machining data** | |
| Cutting speed, m/min | 156.362 |
| Feed per revolution, mm | 0.379 |
| Number of passes | 3.000 |
| Depth of cut per pass, mm | 4.333 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 16.38 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 170 |
| **Results** | |
| Operation time, s | 63.0000 |
| Total volume removed, $cm^3$ | 185.009 |

| Rough cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 272.000 |
| Diameter of machined surface (dm), mm | 248.000 |
| Length of machined surface (lm), mm | 15.000 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 160.325 |
| Feed per revolution, mm | 0.364 |
| Number of passes | 3.000 |
| Depth of cut per pass, mm | 4.000 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 14.89 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 203 |

| Results | |
|---|---|
| Operation time, s | 57.0000 |
| Total volume removed, $cm^3$ | 147.027 |

## Rough cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 233.000 |
| Diameter of machined surface (dm), mm | 205.000 |
| Length of machined surface (lm), mm | 15.000 |

| Machining data | |
|---|---|
| Cutting speed, m/min | 152.705 |
| Feed per revolution, mm | 0.394 |
| Number of passes | 3.000 |
| Depth of cut per pass, mm | 4.667 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |

| | |
|---|---|
| Maximum power required, kW | 17.87 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 232 |
| **Results** | |
| Operation time, s | 51.0000 |
| Total volume removed, $cm^3$ | 144.483 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 450.000 |
| Length of machined surface (lm), mm | 61.320 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 241 |
| **Results** | |
| Operation time, s | 231.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 331.080 |
| Length of machined surface (lm), mm | 15.960 |

| | |
|---|---|
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 327 |
| **Results** | |
| Operation time, s | 50.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 286.000 |
| Length of machined surface (lm), mm | 15.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 379 |
| **Results** | |
| Operation time, s | 42.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 145.000 |
| Length of machined surface (lm), mm | 15.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 747 |
| **Results** | |
| Operation time, s | 25.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 230.000 |
| Length of machined surface (lm), mm | 15.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 471 |
| **Results** | |

| | |
|---|---|
| Operation time, s | 35.0000 |

| Drill multiple holes | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 13.500 |
| Length of drilled holes (lh), mm | 27.000 |
| Number of identical holes drilled | 8 |
| Number of holes drilled simultaneously | 1 |
| **Machining data** | |
| Cutting speed, m/min | 30.480 |
| Feed per revolution, mm | 0.276 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Power required, kW | 1.68 |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 719 |
| **Results** | |
| Operation time, s | 116.0000 |
| Total volume removed, $cm^3$ | 30.918 |

# DFMA® - Boothroyd Dewhurst, Inc.

## DFM Concurrent Costing

## Cost Breakdown

Friday, 14 October 2022

Bearing Retainer.bck.dfmx

Analysis Name: 7 BEARING RETAINER
Part name: 7 BEARING RETAINER
Part number:
Part weight: 4.880 kg

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| Cost per part, $ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Process Chart | Batch size | Material | Setup | Process | Rejects | Piece part | Tooling | Total | Operation time per part, s | Initial tooling investment |
| **Low carbon steel, cold rolled, commercial quality machined/cut from stock part** | | **6.1500** | **0.0919** | **59.2407** | **0.3178** | **65.8005** | | **65.8005** | **4429.19** | |
| **Stock process** | **750** | **6.1500** | **0.0050** | **0.0840** | | **6.2390** | | **6.2390** | **17.14** | |
| Workpiece | | 6.1500 | | | | 6.1500 | | 6.1500 | | |
| Horizontal bandsaw cutoff | | | 0.0050 | 0.0840 | | 0.0890 | | 0.0890 | 17.14 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.0869** | **59.1567** | **0.3178** | **59.5615** | | **59.5615** | **4412.05** | |
| Setup/load/unload | | | 0.0869 | 0.1919 | | 0.2788 | | 0.2788 | 17.85 | |
| Rough and finish cylindrical bore | | | | 28.8806 | | 28.8806 | | 28.8806 | 2130.00 | |
| Rough and finish face | | | | 8.3403 | | 8.3403 | | 8.3403 | 609.00 | |
| Rough cylindrical turn | | | | 2.9840 | | 2.9840 | | 2.9840 | 229.00 | |
| Rough cylindrical turn | | | | 0.5935 | | 0.5935 | | 0.5935 | 46.00 | |
| Finish cylindrical turn | | | | 0.3246 | | 0.3246 | | 0.3246 | 25.00 | |
| Finish cylindrical turn | | | | 0.8067 | | 0.8067 | | 0.8067 | 60.00 | |
| Finish cylindrical turn | | | | 0.6403 | | 0.6403 | | 0.6403 | 48.00 | |
| Finish cylindrical turn | | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cutoff | | | | 4.7717 | | 4.7717 | | 4.7717 | 349.00 | |
| Load bar | | | | 0.3355 | | 0.3355 | | 0.3355 | 31.20 | |
| Rough and finish face | | | | 0.5855 | | 0.5855 | | 0.5855 | 47.00 | |
| Rough cylindrical turn | | | | 1.3469 | | 1.3469 | | 1.3469 | 99.00 | |
| Rough cylindrical turn | | | | 0.6630 | | 0.6630 | | 0.6630 | 51.00 | |
| Rough cylindrical turn | | | | 0.8095 | | 0.8095 | | 0.8095 | 63.00 | |
| Rough cylindrical turn | | | | 0.7281 | | 0.7281 | | 0.7281 | 57.00 | |
| Rough cylindrical turn | | | | 0.6429 | | 0.6429 | | 0.6429 | 51.00 | |
| Finish cylindrical turn | | | | 3.1679 | | 3.1679 | | 3.1679 | 231.00 | |
| Finish cylindrical turn | | | | 0.6686 | | 0.6686 | | 0.6686 | 50.00 | |
| Finish cylindrical turn | | | | 0.5580 | | 0.5580 | | 0.5580 | 42.00 | |
| Finish cylindrical turn | | | | 0.3227 | | 0.3227 | | 0.3227 | 25.00 | |
| Finish cylindrical turn | | | | 0.4619 | | 0.4619 | | 0.4619 | 35.00 | |
| Drill multiple holes | | | | 1.3326 | | 1.3326 | | 1.3326 | 116.00 | |

# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Totals

Friday, 14 October 2022

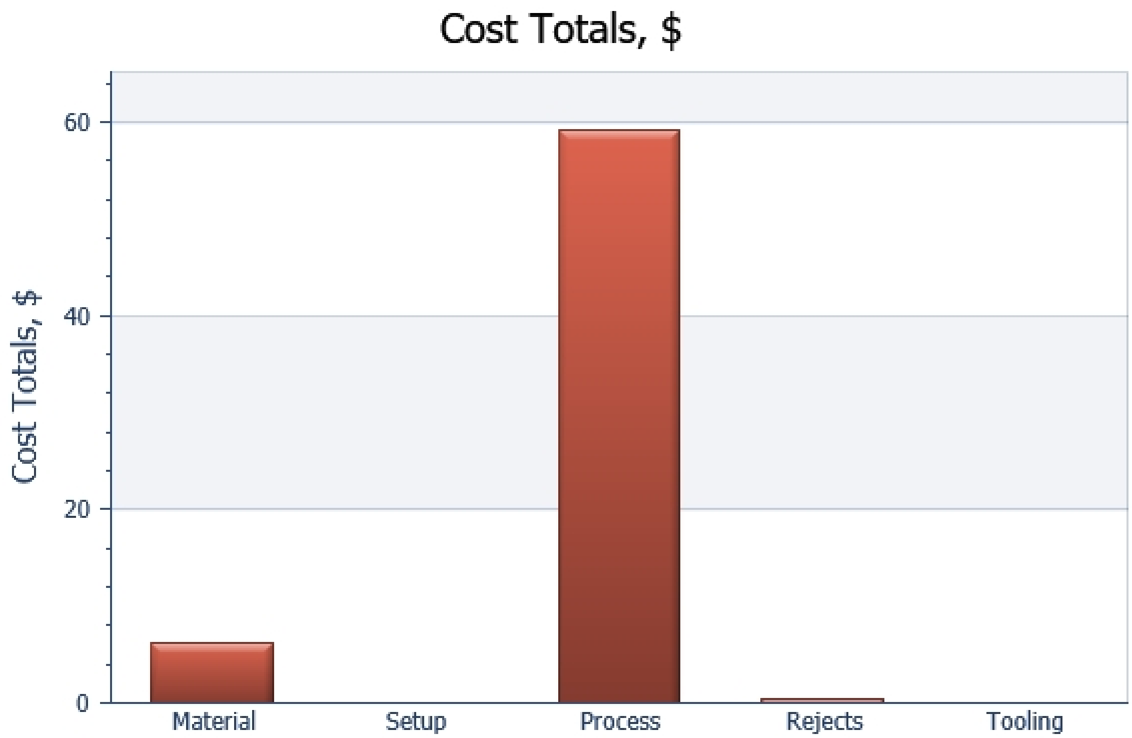
Bearing Retainer.bck.dfmx

| **Analysis Name** | **7 BEARING RETAINER** |
|---|---|
| Part name | 7 BEARING RETAINER |
| Part number | |
| Material | Low carbon steel, cold rolled, commercial quality |
| Manufacturing process | Machined/cut from stock |
| Manufacturing profile | 20A BDI North America |

| Cost per part, $ | Value |
|---|---|
| Material | 6.1500 |
| Setup | 0.0919 |
| Process | 59.2407 |
| Rejects | 0.3178 |
| Piece part | 65.8005 |
| Tooling | 0.0000 |
| Total | 65.8005 |
| Initial tooling investment | 0.0000 |

| | |
|---|---|
| Life volume | 6,000 |
| Batch size | 750 |
| Part weight | 4.880 |


| Cost per part, $ | 7 BEARING RETAINE<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 6,000 |
| Material | 6.1500 |
| Setup | 0.0919 |
| Process | 59.2407 |
| Rejects | 0.3178 |
| Piece part | 65.8005 |
| Tooling | 0.0000 |
| Total | 65.8005 |
| Initial tooling investment | 0.0000 |



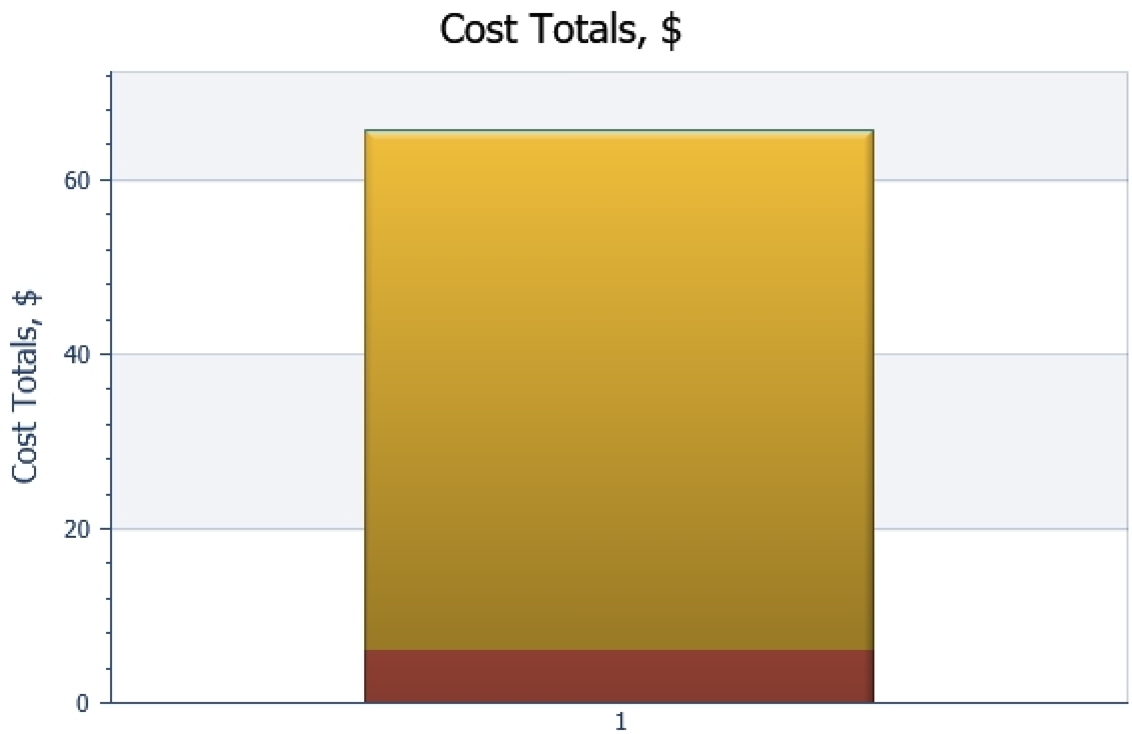

| Cost per part, $ | 7 BEARING RETAINE<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 6,000 |
| Material | 6.1500 |
| Setup | 0.0919 |
| Process | 59.2407 |
| Rejects | 0.3178 |
| Piece part | 65.8005 |
| Tooling | 0.0000 |
| Total | 65.8005 |
| Initial tooling investment | 0.0000 |

# DFM Concurrent Costing

## Cost Totals

Friday, 14 October 2022

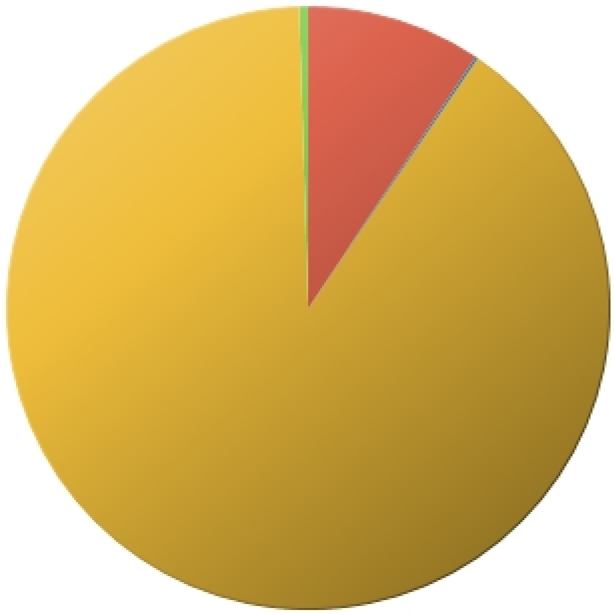
Bearing Retainer.bck.dfmx




| | Cost per part, $ | 1 7 BEARING RETAINER<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|---|
| | Life volume | 6,000 |
| | Material | 6.1500 |
| | Setup | 0.0919 |
| | Process | 59.2407 |
| | Rejects | 0.3178 |
| | Piece part | 65.8005 |
| | Tooling | 0.0000 |
| | Total | 65.8005 |
| | Initial tooling investment | 0.0000 |

Cost Totals, $

7 BEARING RETAINER



| | Cost per part, $ | 1 7 BEARING RETAINER<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|---|
| | Life volume | 6,000 |
| | Material | 6.1500 |
| | Setup | 0.0919 |
| | Process | 59.2407 |
| | Rejects | 0.3178 |
| | Piece part | 65.8005 |
| | Tooling | 0.0000 |
| | Total | 65.8005 |
| | Initial tooling investment | 0.0000 |

# DFMA® - Boothroyd Dewhurst, Inc.

## DFM Concurrent Costing

## Guide to Cost Reduction

Friday, 14 October 2022

Bearing Retainer.bck.dfmx

Analysis Name: 7 BEARING RETAINER

Material name: Low carbon steel, cold rolled, commercial quality

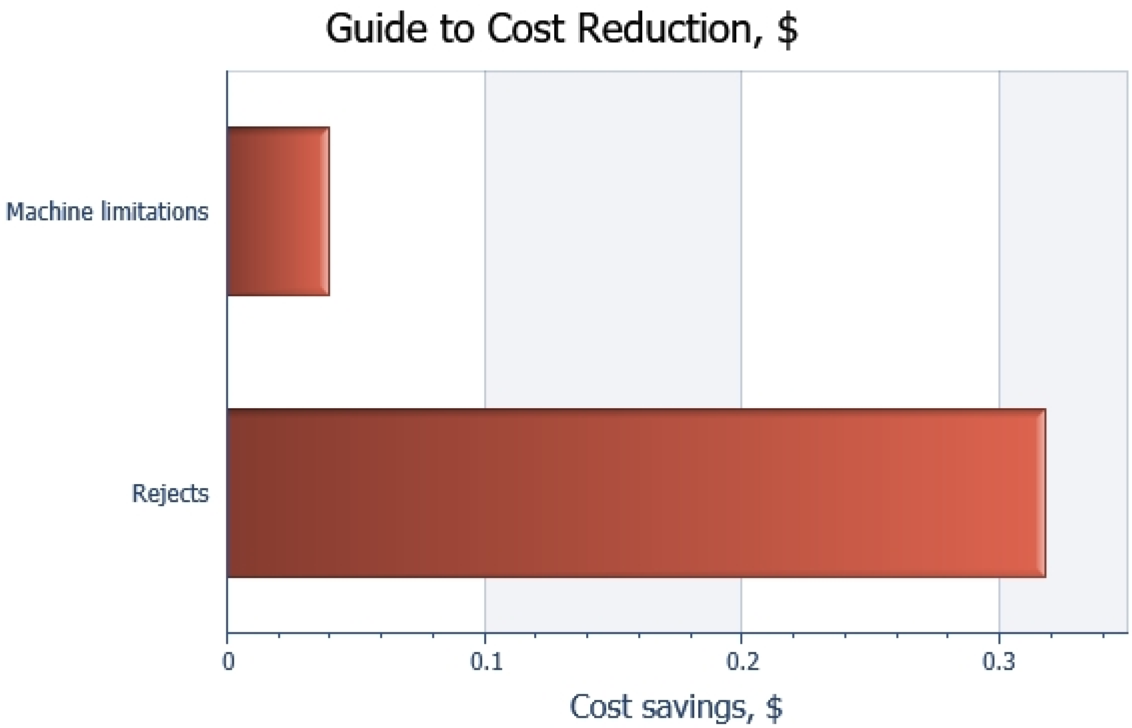
Part name: 7 BEARING RETAINER

Manufacturing process: Machined/cut from stock

Part number:

Manufacturing profile: 20A BDI North America

For the product life volume of 6000 and the batch size of 750 you have specified, the tooling costs form 0.00% of the total cost of 65.80. The chart shows how improved equipment might reduce the machining cost in either of two ways: 1. If the machining operations could be carried out on one setup where appropriate. 2. If the various machines imposed no limitations on power or spindle speed.




| Category | Savings, $ |
|---|---|
| Machine limitations | 0.0399 |
| Rejects | 0.3178 |

# Appendix Y.8

**DFM Concurrent Costing Analysis Report of Part No. 12 Labyrinth Seal of Best Concept Design**

# DFMA® - Boothroyd Dewhurst, Inc.

## DFM Concurrent Costing
## Executive Summary

Friday, 14 October 2022

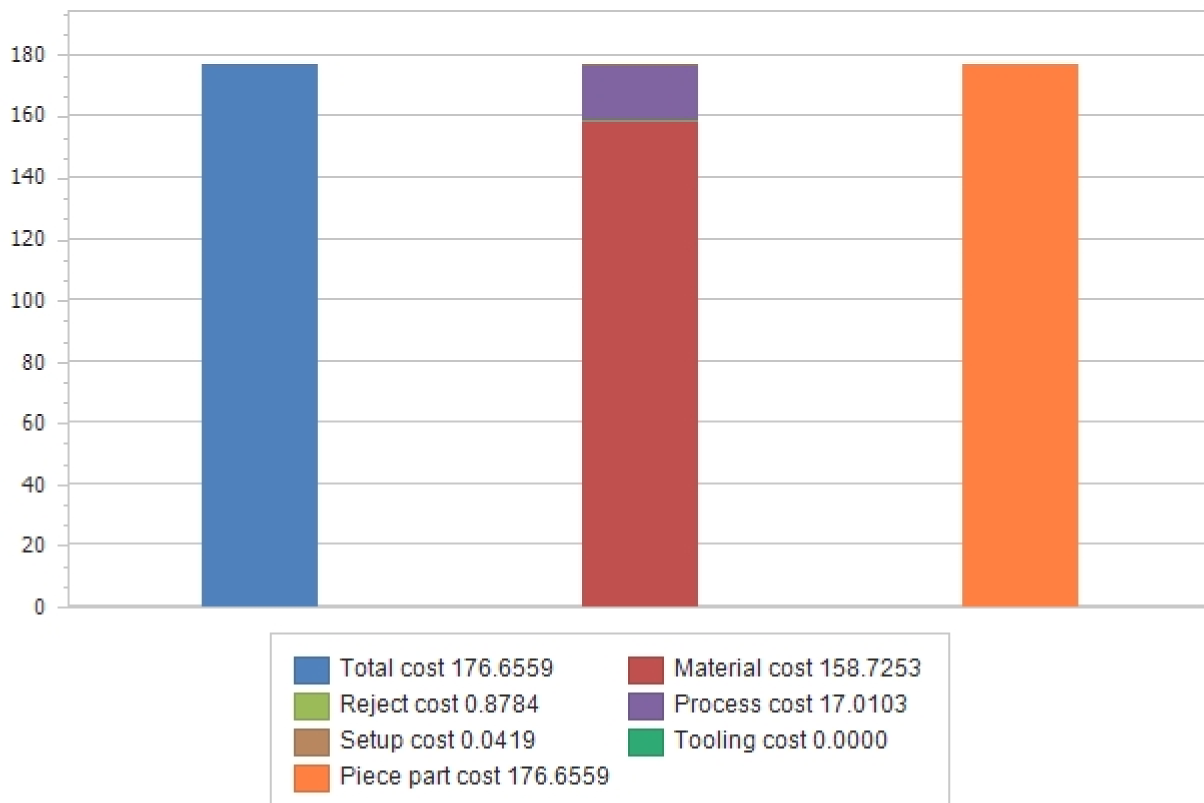
Labyrinth Seal.dfmx

Analysis Name: 6 LABYRINTH SEAL
Part name: 6 LABYRINTH SEAL
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| | |
|---|---|
| Product life volume | 6,000 |
| Batch size | 750 |
| Total cost, $ | 176.6559 |
| Piece part cost, $ | 176.6559 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFMA® - Boothroyd Dewhurst, Inc.
## DFM Concurrent Costing
## Notes

Friday, 14 October 2022 | Labyrinth Seal.dfmx

Analysis Name: 6 LABYRINTH SEAL
Part name: 6 LABYRINTH SEAL
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

### Finish cylindrical turn

Grooving tool to be used for contour.

### Finish cylindrical turn

Grooving tool to be used for contour.

### Finish cylindrical turn

Grooving tool to be used for contour.

### Finish cylindrical turn

Grooving tool to be used for contour.

### Finish cylindrical turn

Inside cutting tool for bore primary face.

### Finish cylindrical turn

Rear inside bore

### Finish cylindrical turn

Grooving tool used for recess in labyrinth

### Finish cylindrical turn

Opposite side of seal to be machined to specified diameter.

### Finish cylindrical turn

Grooving tool to be used for final contour on rear edge of seal.

# DFM Concurrent Costing
# Responses

Friday, 14 October 2022

Labyrinth Seal.dfmx

Analysis Name: 6 LABYRINTH SEAL
Part name: 6 LABYRINTH SEAL
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

## Low carbon steel, cold rolled, commercial quality machined/cut from stock part

| Part | |
|---|---|
| Part name | 6 LABYRINTH SEAL |
| Part number | |
| Life volume | 6000 |
| Envelope shape | Solid block |
| Part length, mm | 319.894 |
| Part width, mm | 42.000 |
| Part height, mm | 320.000 |
| Average thickness, mm | 10.513 |
| Forming direction | Z |

## Stock process

| Part basic data | |
|---|---|
| Batch size | 750 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Round bar or rod |
| Material hardness, Bhn | 200 |
| Material cost, $/kg | 0.838 |
| Material scrap value, $/kg | 0.110 |
| Cutoff method | Horizontal bandsaw |

| Part geometry | |
|---|---|
| Volume, $cm^3$ | 1076.192 |
| Weight, kg | 8.430 |

## Workpiece

| Bar dimensions | |
|---|---|
| Bar stock length, m | 3.048 |

| Workpiece geometry | |
|---|---|
| Length, mm | 320.000 |
| Diameter, mm | 322.639 |

## Horizontal bandsaw cutoff

| Basic process data | |
|---|---|
| Process rate, $/hr | 15.00 |
| Setup rate, $/hr | 15.00 |
| Setup time, hr | 0.25 |

| Bar loading data | |
|---|---|
| Bar loading time, s | 33.00 |

| Bandsaw cutting data | |
|---|---|
| Cutting rate, cm²/min | 83.845 |
| Kerf, mm | 1.067 |

| Operation time | |
|---|---|
| Process time per part, s | 588.72 |

## Cincinnati Falcon TC-300/1000 turning center

| Basic data | |
|---|---|
| Batch size | 750 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |

| Machine tool data | |
|---|---|
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 20.40 |
| Operator rate, $/hr | 25.00 |

| | |
|---|---|
| Process rate, $/hr | 32.90 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |
| **Live tool data** | |
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |
| **Result** | |
| Cycle time per part, s | 1068.10 |
| Total setup time, hr | 0.59 |

## Setup/load/unload

| | |
|---|---|
| **Work handling** | |
| Workholding device | Face plate (3 clamps) |
| Number of reversals | 0 |
| Load/unload time, s | 147.10 |
| **Machine setup** | |
| Machine rate during setup, $/hr | 16.90 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 46.90 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |
| **Other costs** | |
| Tool, fixture or program cost, $ | 0 |

## Finish cylindrical turn

| | |
|---|---|
| Tool material | Indexable carbide |

| | |
|---|---|
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 320.000 |
| Length of machined surface (lm), mm | 197.320 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 339 |
| **Results** | |
| Operation time, s | 520.0000 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 308.000 |
| Length of machined surface (lm), mm | 16.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 352 |
| **Results** | |
| Operation time, s | 47.0000 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 265.000 |
| Length of machined surface (lm), mm | 18.030 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 409 |
| **Results** | |
| Operation time, s | 46.0000 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 249.000 |
| Length of machined surface (lm), mm | 41.130 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |

| | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 435 |
| **Results** | |
| Operation time, s | 90.0000 |

## Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 0.000 |
| Length of machined surface (lm), mm | 24.020 |
| Surface roughness | 32 µin. 0.8 µm |
| WARNING | dm must be greater than zero |

## Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 162.000 |
| Length of machined surface (lm), mm | 18.440 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 669 |
| **Results** | |
| Operation time, s | 31.0000 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 160.000 |
| Length of machined surface (lm), mm | 10.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 677 |
| **Results** | |
| Operation time, s | 20.0000 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 318.000 |
| Length of machined surface (lm), mm | 56.540 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |

| | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 341 |

| **Results** | |
|---|---|
| Operation time, s | 153.0000 |

## Finish cylindrical turn

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 205.000 |
| Length of machined surface (lm), mm | 4.000 |
| Surface roughness | 32 µin. 0.8 µm |

| **Machining data** | |
|---|---|
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 529 |

| **Results** | |
|---|---|
| Operation time, s | 14.0000 |

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing

## Cost Breakdown

Friday, 14 October 2022

Labyrinth Seal.dfmx

Analysis Name: 6 LABYRINTH SEAL
Part name: 6 LABYRINTH SEAL
Part number:
Part weight: 204.938 kg

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| Cost per part, $ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Process Chart | Batch size | Material | Setup | Process | Rejects | Piece part | Tooling | Total | Operation time per part, s | Initial tooling investment |
| **Low carbon steel, cold rolled, commercial quality machined/cut from stock part** | | **158.7253** | **0.0419** | **17.0103** | **0.8784** | **176.6559** | | **176.6559** | **1656.82** | |
| **Stock process** | **750** | **158.7253** | **0.0050** | **2.8859** | | **161.6162** | | **161.6162** | **588.72** | |
| Workpiece | | 158.7253 | | | | 158.7253 | | 158.7253 | | |
| Horizontal bandsaw cutoff | | | 0.0050 | 2.8859 | | 2.8909 | | 2.8909 | 588.72 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.0369** | **14.1244** | **0.8784** | **15.0397** | | **15.0397** | **1068.10** | |
| Setup/load/unload | | | 0.0369 | 1.5816 | | 1.6185 | | 1.6185 | 147.10 | |
| Finish cylindrical turn | | | | 7.1567 | | 7.1567 | | 7.1567 | 520.00 | |
| Finish cylindrical turn | | | | 0.6275 | | 0.6275 | | 0.6275 | 47.00 | |
| Finish cylindrical turn | | | | 0.6131 | | 0.6131 | | 0.6131 | 46.00 | |
| Finish cylindrical turn | | | | 1.2216 | | 1.2216 | | 1.2216 | 90.00 | |
| Finish cylindrical turn | | | | | | | | | | |
| Finish cylindrical turn | | | | 0.4074 | | 0.4074 | | 0.4074 | 31.00 | |
| Finish cylindrical turn | | | | 0.2547 | | 0.2547 | | 0.2547 | 20.00 | |
| Finish cylindrical turn | | | | 2.0909 | | 2.0909 | | 2.0909 | 153.00 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Finish cylindrical turn | | | | 0.1709 | | 0.1709 | | 0.1709 | 14.00 | |

# DFM Concurrent Costing

## Totals

Friday, 14 October 2022

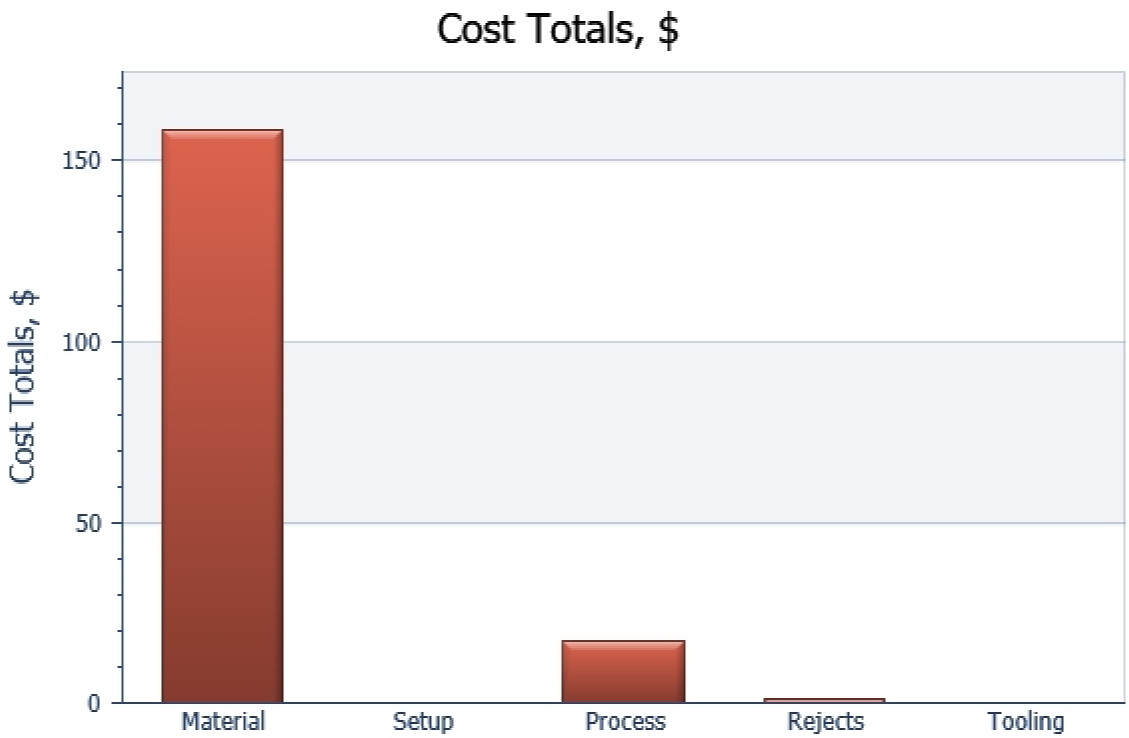
Labyrinth Seal.dfmx

| Analysis Name | 6 LABYRINTH SEAL |
|---|---|
| Part name | 6 LABYRINTH SEAL |
| Part number | |
| Material | Low carbon steel, cold rolled, commercial quality |
| Manufacturing process | Machined/cut from stock |
| Manufacturing profile | 20A BDI North America |

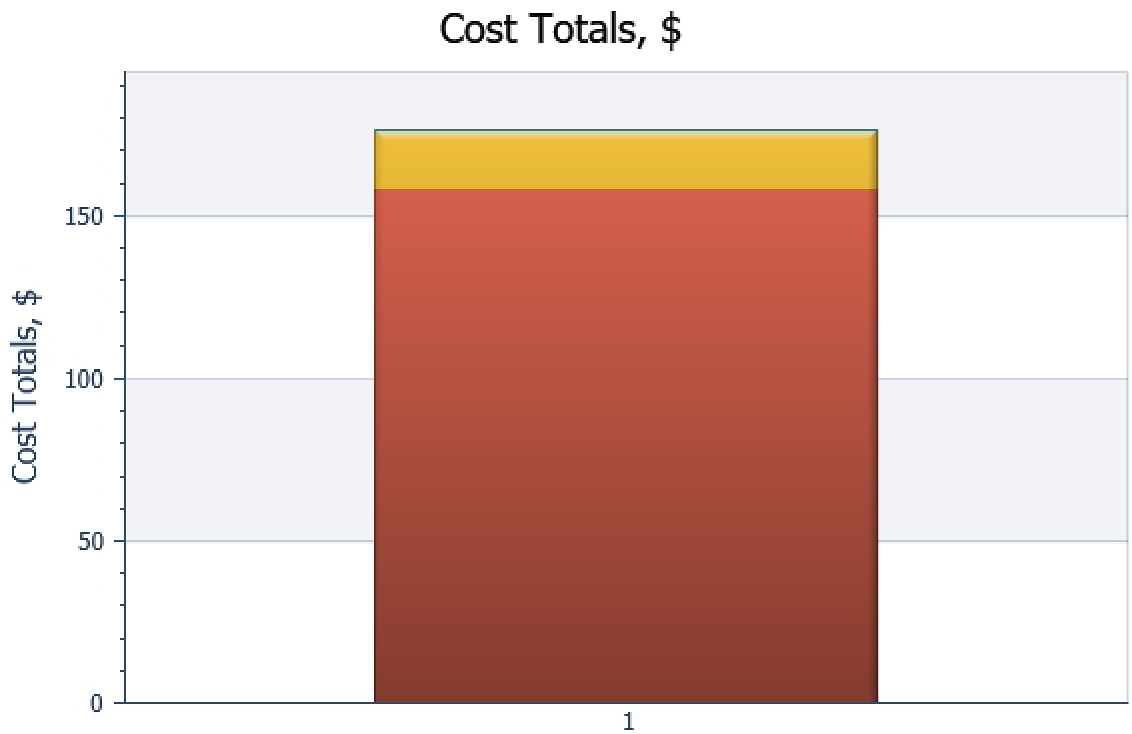
| Cost per part, $ | Value |
|---|---|
| Material | 158.7253 |
| Setup | 0.0419 |
| Process | 17.0103 |
| Rejects | 0.8784 |
| Piece part | 176.6559 |
| Tooling | 0.0000 |
| Total | 176.6559 |
| Initial tooling investment | 0.0000 |

| | |
|---|---|
| Life volume | 6,000 |
| Batch size | 750 |
| Part weight | 204.938 |


| Cost per part, $ | 6 LABYRINTH SEAL<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 6,000 |
| Material | 158.7253 |
| Setup | 0.0419 |
| Process | 17.0103 |
| Rejects | 0.8784 |
| Piece part | 176.6559 |
| Tooling | 0.0000 |
| Total | 176.6559 |
| Initial tooling investment | 0.0000 |




| Cost per part, $ | 6 LABYRINTH SEAL<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 6,000 |
| Material | 158.7253 |
| Setup | 0.0419 |
| Process | 17.0103 |
| Rejects | 0.8784 |
| Piece part | 176.6559 |
| Tooling | 0.0000 |
| Total | 176.6559 |
| Initial tooling investment | 0.0000 |




| | | |
|---|---|---|
| | Cost per part, $ | 1 6 LABYRINTH SEAL<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
| | Life volume | 6,000 |
| | Material | 158.7253 |
| | Setup | 0.0419 |
| | Process | 17.0103 |
| | Rejects | 0.8784 |
| | Piece part | 176.6559 |
| | Tooling | 0.0000 |
| | Total | 176.6559 |
| | Initial tooling investment | 0.0000 |

## Cost Totals, $

6 LABYRINTH SEAL

| | Cost per part, $ | 1 6 LABYRINTH SEAL<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|---|
| | Life volume | 6,000 |
| | Material | 158.7253 |
| | Setup | 0.0419 |
| | Process | 17.0103 |
| | Rejects | 0.8784 |
| | Piece part | 176.6559 |
| | Tooling | 0.0000 |
| | Total | 176.6559 |
| | Initial tooling investment | 0.0000 |

# Appendix Y.9

**DFM Concurrent Costing Analysis Report of Part No. 13 Spacer of Best Concept Design**

# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Executive Summary

Friday, 14 October 2022

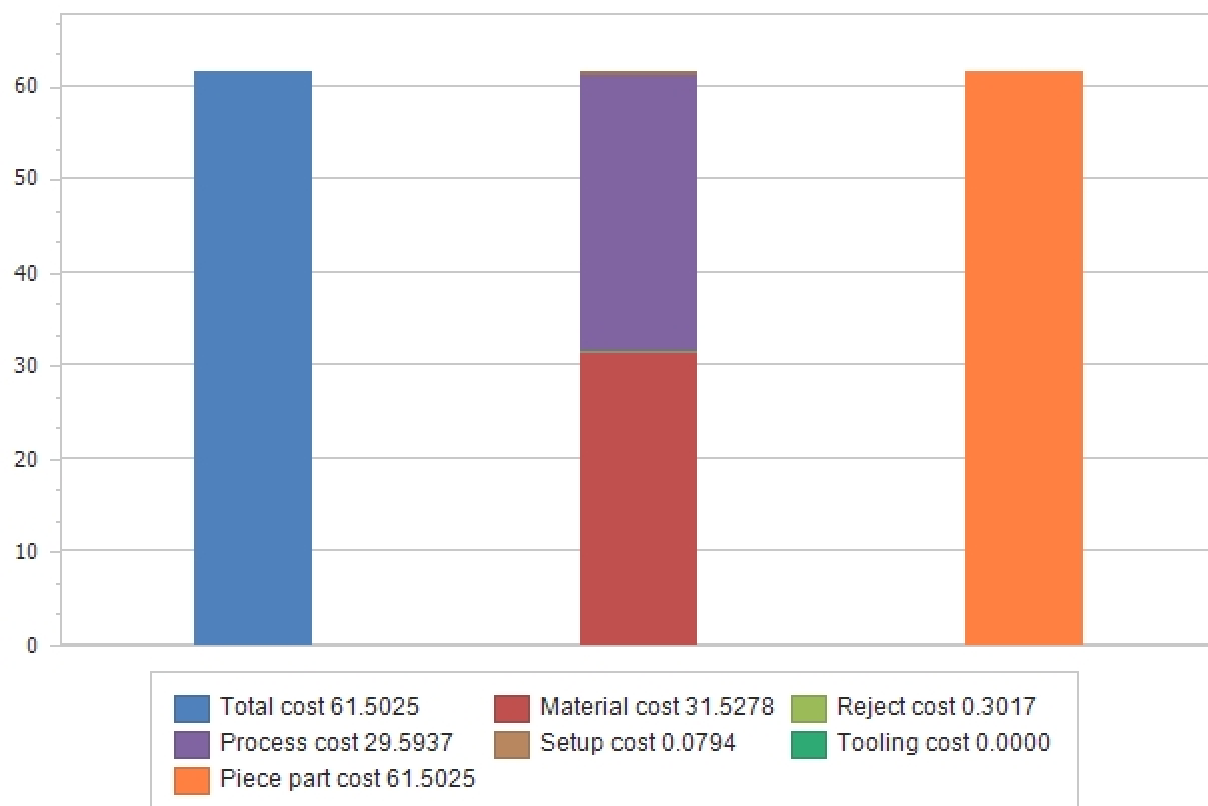
Spacer.dfmx

Analysis Name: 5 SPACER
Part name: 5 SPACER
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| | |
|---|---|
| Product life volume | 6,000 |
| Batch size | 750 |
| Total cost, $ | 61.5025 |
| Piece part cost, $ | 61.5025 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFM Concurrent Costing
# Notes

Friday, 14 October 2022

Spacer.dfmx

Analysis Name: 5 SPACER

Part name: 5 SPACER

Part number:

Material name: Low carbon steel, cold rolled, commercial quality

Manufacturing process: Machined/cut from stock

Manufacturing profile: 20A BDI North America

## Rough and finish cylindrical bore

Machining bore.

## Load bar

Load opposite side of spacer into chuck to finish face.

Analysis Name: 5 SPACER
Part name: 5 SPACER
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

## Low carbon steel, cold rolled, commercial quality machined/cut from stock part

| Part | |
|---|---|
| Part name | 5 SPACER |
| Part number | |
| Life volume | 6000 |
| Envelope shape | Solid cylinder |
| Part length, mm | 188.928 |
| Part width, mm | 155.000 |
| Part height, mm | 189.000 |
| Average thickness, mm | 45.131 |
| Forming direction | Z |

## Stock process

| Part basic data | |
|---|---|
| Batch size | 750 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Round bar or rod |
| Material hardness, Bhn | 200 |
| Material cost, $/kg | 0.838 |
| Material scrap value, $/kg | 0.110 |
| Cutoff method | Horizontal bandsaw |

| Part geometry | |
|---|---|
| Volume, $cm^3$ | 1265.204 |
| Weight, kg | 9.911 |

## Workpiece

| Bar dimensions | |
|---|---|
| Bar stock length, m | 3.048 |

| Workpiece geometry | |
|---|---|
| Length, mm | 189.000 |
| Diameter, mm | 188.928 |

## Horizontal bandsaw cutoff

| Basic process data | |
|---|---|
| Process rate, $/hr | 15.00 |
| Setup rate, $/hr | 15.00 |
| Setup time, hr | 0.25 |

| Bar loading data | |
|---|---|
| Bar loading time, s | 33.00 |

| Bandsaw cutting data | |
|---|---|
| Cutting rate, $cm^2$/min | 89.813 |
| Kerf, mm | 1.067 |

| Operation time | |
|---|---|
| Process time per part, s | 189.34 |

## Cincinnati Falcon TC-300/1000 turning center

| Basic data | |
|---|---|
| Batch size | 750 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |

| Machine tool data | |
|---|---|
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 20.40 |
| Operator rate, $/hr | 25.00 |

| | |
|---|---|
| Process rate, $/hr | 32.90 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |

| **Live tool data** | |
|---|---|
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |

| **Result** | |
|---|---|
| Cycle time per part, s | 2129.10 |
| Total setup time, hr | 1.19 |

## Setup/load/unload

| **Work handling** | |
|---|---|
| Workholding device | Face plate (3 clamps) |
| Number of reversals | 0 |
| Load/unload time, s | 147.10 |

| **Machine setup** | |
|---|---|
| Machine rate during setup, $/hr | 16.90 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 46.90 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |

| **Other costs** | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

## Rough and finish cylindrical bore

| | |
|---|---|
| Tool material | Indexable carbide |

| | |
|---|---|
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 0.000 |
| Diameter of machined surface (dm), mm | 159.200 |
| Length of machined surface (lm), mm | 155.000 |
| Finish cut allowance on radius, mm | 0.200 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed during rough cuts, m/min | 101.110 |
| Feed per revolution during rough cuts, mm | 0.319 |
| Number of rough cut passes | 16.000 |
| Depth of rough cut per pass, mm | 4.962 |
| Cutting speed during finish cut, m/min | 229.891 |
| Feed per revolution during finish cut, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 10.19 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 1467.0000 |
| Total volume removed, cm³ | 3085.387 |

## Rough and finish cylindrical turn

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 192.000 |
| Diameter of machined surface (dm), mm | 189.000 |
| Length of machined surface (lm), mm | 155.000 |
| Finish cut allowance on radius, mm | 0.200 |
| Surface roughness | 32 µin. 0.8 µm |

| Machining data | |
|---|---|
| Cutting speed during rough cuts, m/min | 229.819 |
| Feed per revolution during rough cuts, mm | 0.208 |
| Number of rough cuts | 1.000 |
| Depth of rough cut per pass, mm | 1.300 |
| Cutting speed during finish cut, m/min | 340.157 |
| Feed per revolution during finish cut, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 3.96 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 573 |

| Results | |
|---|---|
| Operation time, s | 375.0000 |
| Total volume removed, cm³ | 139.146 |

## Finish face

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 189.000 |
| Inner diameter of faced surface (d2), mm | 159.200 |
| Surface roughness | 32 µin. 0.8 µm |

| Machining data | |
|---|---|
| Cutting speed, m/min | 340.061 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Spindle speed available, rpm | 3300 |

| | |
|---|---|
| Maximum spindle speed required, rpm | 680 |
| **Results** | |
| Operation time, s | 28.0000 |

## Cutoff

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter (d1), mm | 189.000 |
| Inner diameter (d2), mm | 159.200 |
| **Machining data** | |
| Cutoff tool width, mm | 2.000 |
| Cutting speed, m/min | 152.400 |
| Feed per revolution, mm | 0.067 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 1.30 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 305 |
| **Results** | |
| Operation time, s | 62.0000 |
| Total volume removed, $cm^3$ | 16.299 |

## Load bar

| | |
|---|---|
| Length of bar, m | 3.048 |
| Operation time per part, s | 15.0000 |

## Finish face

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |

| | |
|---|---|
| Outer diameter of faced surface (d1), mm | 189.000 |
| Inner diameter of faced surface (d2), mm | 159.200 |
| Surface roughness | 32 μin. 0.8 μm |
| **Machining data** | |
| Cutting speed, m/min | 340.061 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 680 |
| **Results** | |
| Operation time, s | 35.0000 |

# DFMA® - Boothroyd Dewhurst, Inc.

## DFM Concurrent Costing

## Cost Breakdown

Friday, 14 October 2022

Spacer.dfmx

Analysis Name: 5 SPACER
Part name: 5 SPACER
Part number:
Part weight: 41.504 kg

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| | Cost per part, $ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process Chart** | **Batch size** | **Material** | **Setup** | **Process** | **Rejects** | **Piece part** | **Tooling** | **Total** | **Operation time per part, s** | **Initial tooling investment** |
| **Low carbon steel, cold rolled, commercial quality machined/cut from stock part** | | **31.5278** | **0.0794** | **29.5937** | **0.3017** | **61.5025** | | **61.5025** | **2318.44** | |
| **Stock process** | **750** | **31.5278** | **0.0050** | **0.9282** | | **32.4610** | | **32.4610** | **189.34** | |
| Workpiece | | 31.5278 | | | | 31.5278 | | 31.5278 | | |
| Horizontal bandsaw cutoff | | | 0.0050 | 0.9282 | | 0.9332 | | 0.9332 | 189.34 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.0744** | **28.6655** | **0.3017** | **29.0416** | | **29.0416** | **2129.10** | |
| Setup/load/unload | | | 0.0744 | 1.5816 | | 1.6560 | | 1.6560 | 147.10 | |
| Rough and finish cylindrical bore | | | | 20.1884 | | 20.1884 | | 20.1884 | 1467.00 | |
| Rough and finish cylindrical turn | | | | 5.1160 | | 5.1160 | | 5.1160 | 375.00 | |
| Finish face | | | | 0.3653 | | 0.3653 | | 0.3653 | 28.00 | |
| Cutoff | | | | 0.8124 | | 0.8124 | | 0.8124 | 62.00 | |
| Load bar | | | | 0.1613 | | 0.1613 | | 0.1613 | 15.00 | |
| Finish face | | | | 0.4406 | | 0.4406 | | 0.4406 | 35.00 | |

# DFMA® - Boothroyd Dewhurst, Inc.
## DFM Concurrent Costing
## Totals

Friday, 14 October 2022

Spacer.dfmx

| Analysis Name | 5 SPACER |
|---|---|
| Part name | 5 SPACER |
| Part number | |
| Material | Low carbon steel, cold rolled, commercial quality |
| Manufacturing process | Machined/cut from stock |
| Manufacturing profile | 20A BDI North America |

| Cost per part, $ | Value |
|---|---|
| Material | 31.5278 |
| Setup | 0.0794 |
| Process | 29.5937 |
| Rejects | 0.3017 |
| Piece part | 61.5025 |
| Tooling | 0.0000 |
| Total | 61.5025 |
| Initial tooling investment | 0.0000 |

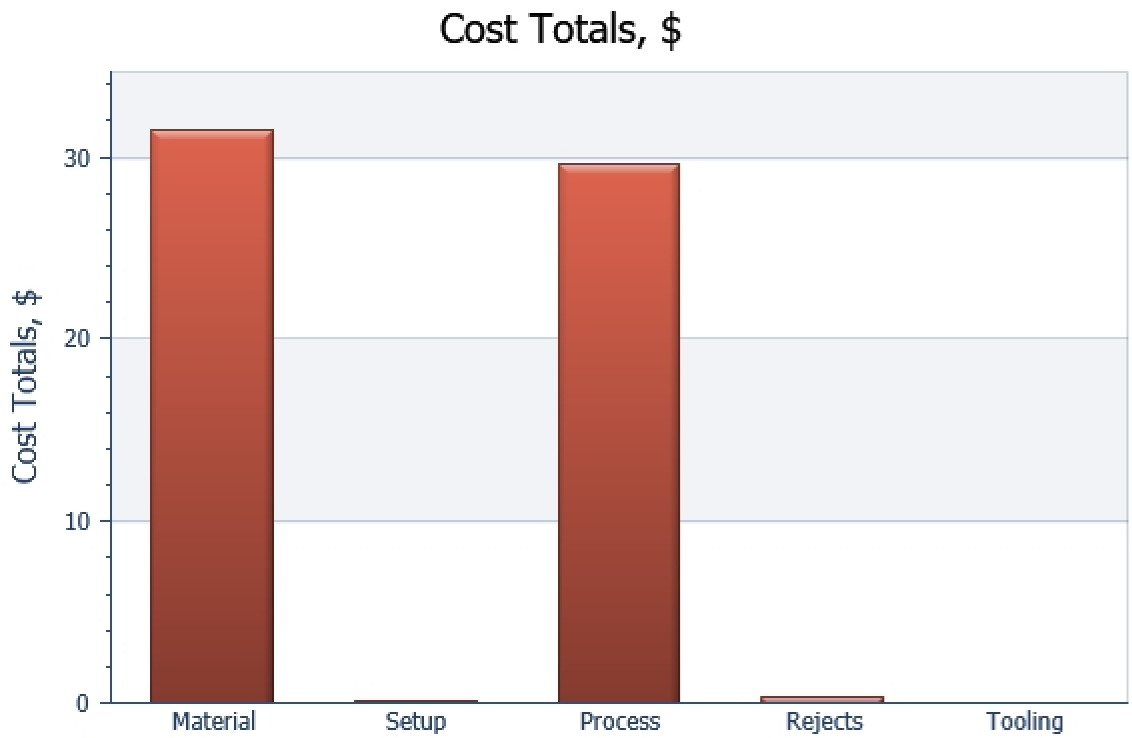
| | |
|---|---|
| Life volume | 6,000 |
| Batch size | 750 |
| Part weight | 41.504 |

# DFM Concurrent Costing
## Cost vs. Life Volume

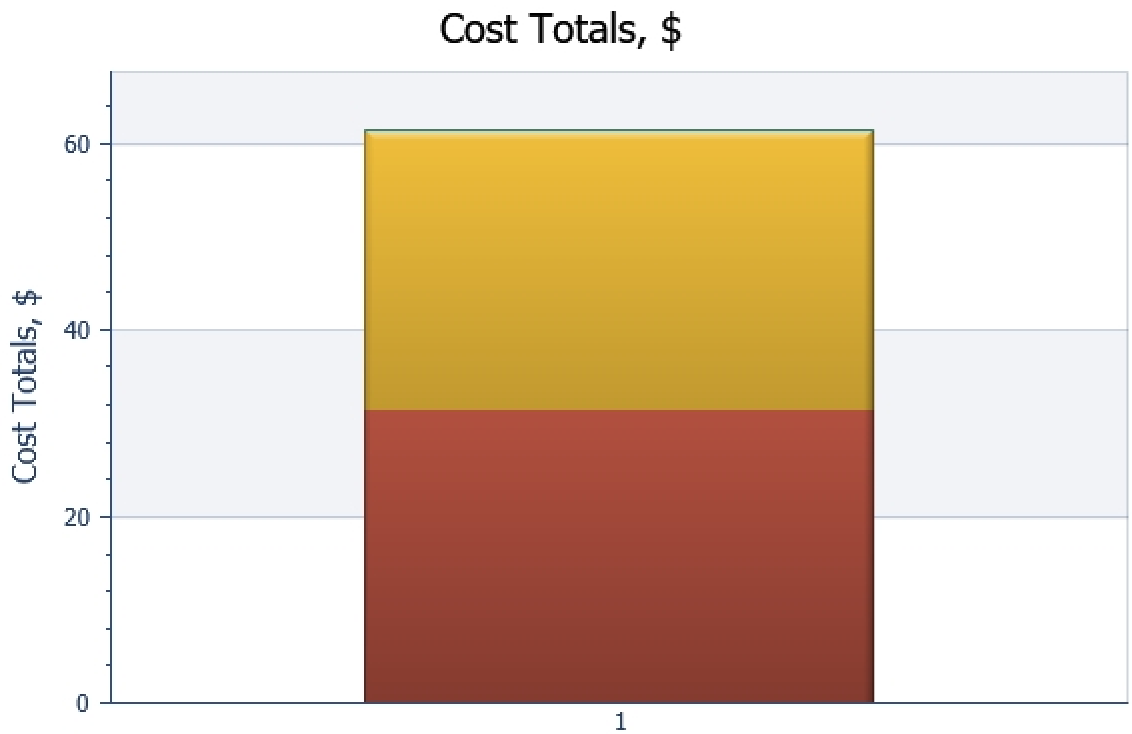
Friday, 14 October 2022

Spacer.dfmx

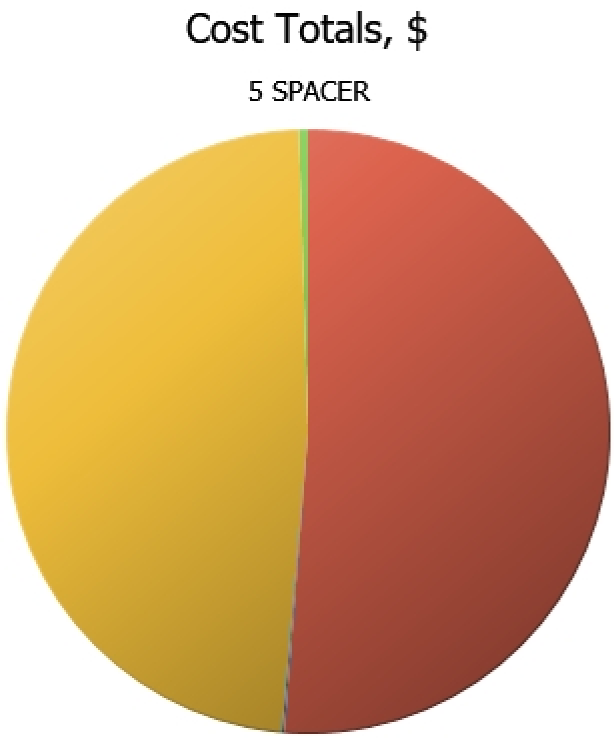

| Cost per part, $ | 5 SPACER<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 6,000 |
| Material | 31.5278 |
| Setup | 0.0794 |
| Process | 29.5937 |
| Rejects | 0.3017 |
| Piece part | 61.5025 |
| Tooling | 0.0000 |
| Total | 61.5025 |
| Initial tooling investment | 0.0000 |




| Cost per part, $ | 5 SPACER<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 6,000 |
| Material | 31.5278 |
| Setup | 0.0794 |
| Process | 29.5937 |
| Rejects | 0.3017 |
| Piece part | 61.5025 |
| Tooling | 0.0000 |
| Total | 61.5025 |
| Initial tooling investment | 0.0000 |




| | Cost per part, $ | 1 5 SPACER<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|---|
| | Life volume | 6,000 |
| | Material | 31.5278 |
| | Setup | 0.0794 |
| | Process | 29.5937 |
| | Rejects | 0.3017 |
| | Piece part | 61.5025 |
| | Tooling | 0.0000 |
| | Total | 61.5025 |
| | Initial tooling investment | 0.0000 |




| | Cost per part, $ | 1 5 SPACER<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|---|
| | Life volume | 6,000 |
| | Material | 31.5278 |
| | Setup | 0.0794 |
| | Process | 29.5937 |
| | Rejects | 0.3017 |
| | Piece part | 61.5025 |
| | Tooling | 0.0000 |
| | Total | 61.5025 |
| | Initial tooling investment | 0.0000 |

# DFM Concurrent Costing
# Guide to Cost Reduction

Friday, 14 October 2022 | Spacer.dfmx

Analysis Name: 5 SPACER
Part name: 5 SPACER
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

For the product life volume of 6000 and the batch size of 750 you have specified, the tooling costs form 0.00% of the total cost of 61.50. The chart shows how improved equipment might reduce the machining cost in either of two ways: 1. If the machining operations could be carried out on one setup where appropriate. 2. If the various machines imposed no limitations on power or spindle speed.


| Category | Savings, $ |
|---|---|
| Machine limitations | 0.0151 |
| Rejects | 0.3017 |

# Appendix Y.10

**DFM Concurrent Costing Analysis Report of Part No. 14 Location Bush of Best Concept Design**

# DFM Concurrent Costing
# Executive Summary

Friday, 14 October 2022

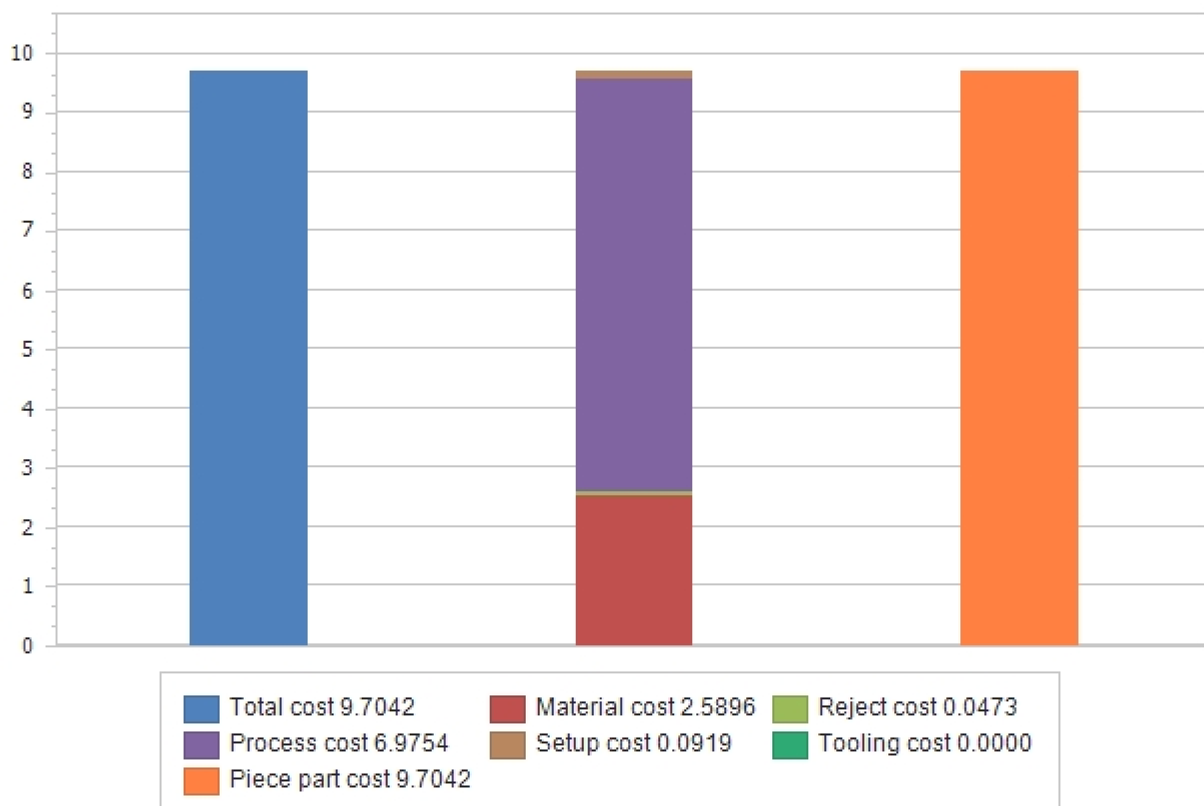
Location Bush.dfmx

Analysis Name: 10 LOCATION BUSH
Part name: 10 LOCATION BUSH
Part number:

Material name: Generic free machining carbon steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| | |
|---|---|
| Product life volume | 6,000 |
| Batch size | 750 |
| Total cost, $ | 9.7042 |
| Piece part cost, $ | 9.7042 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFM Concurrent Costing
# Notes

Friday, 14 October 2022

Location Bush.dfmx

Analysis Name: 10 LOCATION BUSH

Part name: 10 LOCATION BUSH

Part number:

Material name: Generic free machining carbon steel

Manufacturing process: Machined/cut from stock

Manufacturing profile: 20A BDI North America

## Load bar

Return parted off stock into chuck to face off rear face of location bush.

DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

# Responses

Friday, 14 October 2022

Location Bush.dfmx

Analysis Name: 10 LOCATION BUSH

Part name: 10 LOCATION BUSH

Part number:

Material name: Generic free machining carbon steel

Manufacturing process: Machined/cut from stock

Manufacturing profile: 20A BDI North America

## Generic free machining carbon steel machined/cut from stock part

| Part | |
|---|---|
| Part name | 10 LOCATION BUSH |
| Part number | |
| Life volume | 6000 |
| Envelope shape | Solid cylinder |
| Part length, mm | 180.000 |
| Part width, mm | 41.000 |
| Part height, mm | 180.000 |
| Average thickness, mm | 11.927 |
| Forming direction | Z |

## Stock process

| Part basic data | |
|---|---|
| Batch size | 750 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Round bar or rod |
| Material hardness, Bhn | 200 |
| Material cost, $/kg | 1.301 |
| Material scrap value, $/kg | 0.066 |
| Cutoff method | Horizontal bandsaw |

| Part geometry | |
|---|---|
| Volume, $cm^3$ | 303.509 |
| Weight, kg | 2.377 |

## Workpiece

| Bar dimensions | |
|---|---|
| Bar stock length, m | 3.048 |

| Workpiece geometry | |
|---|---|
| Length, mm | 180.000 |
| Diameter, mm | 41.000 |

## Horizontal bandsaw cutoff

| Basic process data | |
|---|---|
| Process rate, $/hr | 15.00 |
| Setup rate, $/hr | 15.00 |
| Setup time, hr | 0.25 |

| Bar loading data | |
|---|---|
| Bar loading time, s | 33.00 |

| Bandsaw cutting data | |
|---|---|
| Cutting rate, $cm^2$/min | 70.931 |
| Kerf, mm | 1.067 |

| Operation time | |
|---|---|
| Process time per part, s | 13.23 |

## Cincinnati Falcon TC-300/1000 turning center

| Basic data | |
|---|---|
| Batch size | 750 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |

| Machine tool data | |
|---|---|
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 20.40 |
| Operator rate, $/hr | 25.00 |

| | |
|---|---|
| Process rate, $/hr | 32.90 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |

| **Live tool data** | |
|---|---|
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |

| **Result** | |
|---|---|
| Cycle time per part, s | 528.19 |
| Total setup time, hr | 1.39 |

## Setup/load/unload

| **Work handling** | |
|---|---|
| Workholding device | 3-jaw chuck |
| Number of reversals | 0 |
| Load/unload time, s | 22.39 |

| **Machine setup** | |
|---|---|
| Machine rate during setup, $/hr | 16.90 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 46.90 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |

| **Other costs** | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

## Rough face

| | |
|---|---|
| Tool material | Indexable carbide |

| | |
|---|---|
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 190.000 |
| Inner diameter of faced surface (d2), mm | 182.000 |
| Total depth to be removed (wm), mm | 5.000 |
| **Machining data** | |
| Cutting speed, m/min | 204.792 |
| Feed per revolution, mm | 0.407 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 358 |
| **Results** | |
| Operation time, s | 9.0000 |
| Total volume removed, $cm^3$ | 11.687 |

## Finish face

| | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 193.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 476.976 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |

| Results | |
|---|---|
| Operation time, s | 64.0000 |

## Rough and finish cylindrical bore

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 0.000 |
| Diameter of machined surface (dm), mm | 150.200 |
| Length of machined surface (lm), mm | 31.000 |
| Finish cut allowance on radius, mm | 0.200 |
| Surface roughness | 32 µin. 0.8 µm |

| Machining data | |
|---|---|
| Cutting speed during rough cuts, m/min | 126.067 |
| Feed per revolution during rough cuts, mm | 0.320 |
| Number of rough cut passes | 15.000 |
| Depth of rough cut per pass, mm | 4.993 |
| Cutting speed during finish cut, m/min | 287.205 |
| Feed per revolution during finish cut, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 10.08 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |

| Results | |
|---|---|
| Operation time, s | 232.0000 |
| Total volume removed, $cm^3$ | 549.280 |

| Rough cylindrical turn | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 190.000 |
| Diameter of machined surface (dm), mm | 182.000 |
| Length of machined surface (lm), mm | 40.000 |
| **Machining data** | |
| Cutting speed, m/min | 224.942 |
| Feed per revolution, mm | 0.364 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 4.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 16.41 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 385 |
| **Results** | |
| Operation time, s | 31.0000 |
| Total volume removed, $cm^3$ | 93.494 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 180.000 |
| Length of machined surface (lm), mm | 42.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |

| | |
|---|---|
| Cutting speed, m/min | 477.012 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 844 |
| **Results** | |
| Operation time, s | 51.0000 |

## Cutoff

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter (d1), mm | 180.000 |
| Inner diameter (d2), mm | 159.200 |
| **Machining data** | |
| Cutoff tool width, mm | 2.000 |
| Cutting speed, m/min | 198.120 |
| Feed per revolution, mm | 0.067 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 1.33 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 396 |
| **Results** | |
| Operation time, s | 39.0000 |
| Total volume removed, $cm^3$ | 11.083 |

## Load bar

| | |
|---|---|
| Length of bar, m | 3.048 |

| | |
|---|---|
| Operation time per part, s | 6.8000 |

| Rough face | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 190.000 |
| Inner diameter of faced surface (d2), mm | 182.000 |
| Total depth to be removed (wm), mm | 5.000 |
| **Machining data** | |
| Cutting speed, m/min | 204.792 |
| Feed per revolution, mm | 0.407 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 358 |
| **Results** | |
| Operation time, s | 16.0000 |
| Total volume removed, $cm^3$ | 11.687 |

| Finish face | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 180.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Surface roughness | 32 µin. 0.8 µm |

| Machining data | |
|---|---|
| Cutting speed, m/min | 476.976 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |

| Machine limitations | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |

| Results | |
|---|---|
| Operation time, s | 57.0000 |

# DFMA® - Boothroyd Dewhurst, Inc.

## DFM Concurrent Costing

## Cost Breakdown

Friday, 14 October 2022

Location Bush.dfmx

Analysis Name: 10 LOCATION BUSH
Part name: 10 LOCATION BUSH
Part number:
Part weight: 1.862 kg

Material name: Generic free machining carbon steel
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| Cost per part, $ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process Chart** | **Batch size** | **Material** | **Setup** | **Process** | **Rejects** | **Piece part** | **Tooling** | **Total** | **Operation time per part, s** | **Initial tooling investment** |
| **Generic free machining carbon steel machined/cut from stock part** | | **2.5896** | **0.0919** | **6.9754** | **0.0473** | **9.7042** | | **9.7042** | **541.42** | |
| **Stock process** | **750** | **2.5896** | **0.0050** | **0.0649** | | **2.6594** | | **2.6594** | **13.23** | |
| Workpiece | | 2.5896 | | | | 2.5896 | | 2.5896 | | |
| Horizontal bandsaw cutoff | | | 0.0050 | 0.0649 | | 0.0699 | | 0.0699 | 13.23 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.0869** | **6.9106** | **0.0473** | **7.0448** | | **7.0448** | **528.19** | |
| Setup/load/unload | | | 0.0869 | 0.2407 | | 0.3276 | | 0.3276 | 22.39 | |
| Rough face | | | | 0.1015 | | 0.1015 | | 0.1015 | 9.00 | |
| Finish face | | | | 0.8619 | | 0.8619 | | 0.8619 | 64.00 | |
| Rough and finish cylindrical bore | | | | 3.1283 | | 3.1283 | | 3.1283 | 232.00 | |
| Rough cylindrical turn | | | | 0.3856 | | 0.3856 | | 0.3856 | 31.00 | |
| Finish cylindrical turn | | | | 0.6819 | | 0.6819 | | 0.6819 | 51.00 | |
| Cutoff | | | | 0.4956 | | 0.4956 | | 0.4956 | 39.00 | |
| Load bar | | | | 0.0731 | | 0.0731 | | 0.0731 | 6.80 | |
| Rough face | | | | 0.1767 | | 0.1767 | | 0.1767 | 16.00 | |

# DFM Concurrent Costing

## Cost Breakdown

Friday, 14 October 2022

Location Bush.dfmx

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Finish face | | | | 0.7653 | | 0.7653 | | 0.7653 | 57.00 | |

# DFM Concurrent Costing
## Totals

Friday, 14 October 2022

Location Bush.dfmx

| Analysis Name | 10 LOCATION BUSH |
|---|---|
| Part name | 10 LOCATION BUSH |
| Part number | |
| Material | Generic free machining carbon steel |
| Manufacturing process | Machined/cut from stock |
| Manufacturing profile | 20A BDI North America |

| Cost per part, $ | Value |
|---|---|
| Material | 2.5896 |
| Setup | 0.0919 |
| Process | 6.9754 |
| Rejects | 0.0473 |
| Piece part | 9.7042 |
| Tooling | 0.0000 |
| Total | 9.7042 |
| Initial tooling investment | 0.0000 |

| | |
|---|---|
| Life volume | 6,000 |
| Batch size | 750 |
| Part weight | 1.862 |

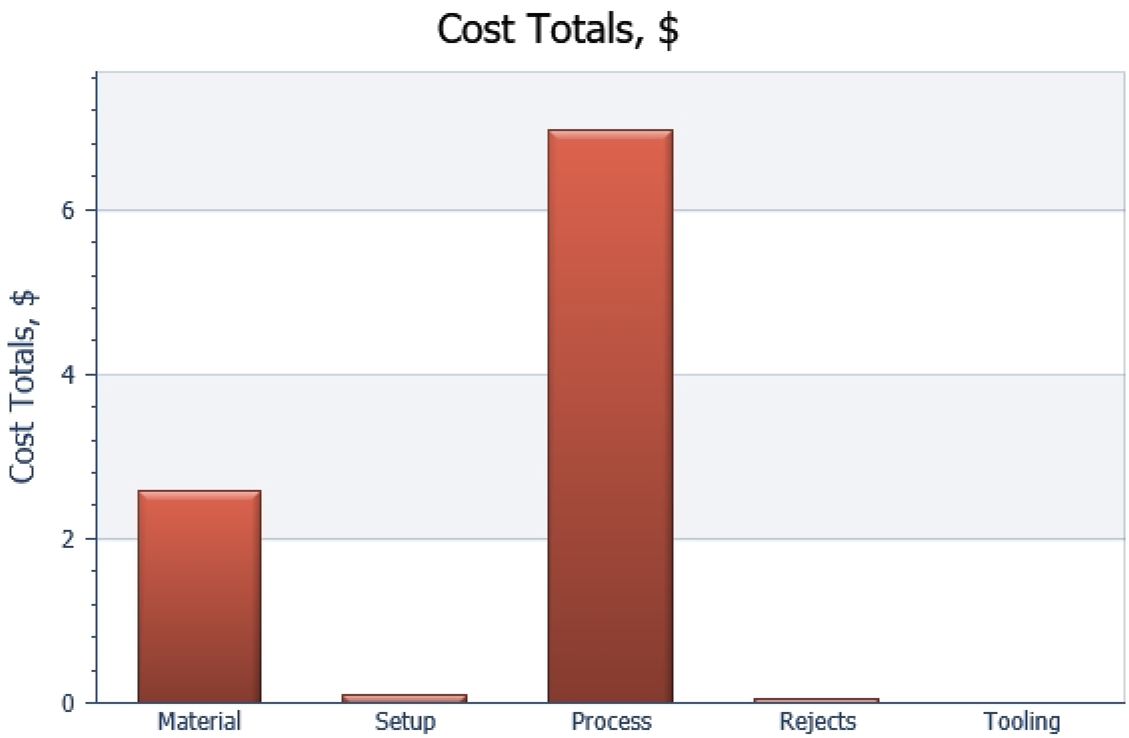
# DFM Concurrent Costing

## Cost vs. Life Volume

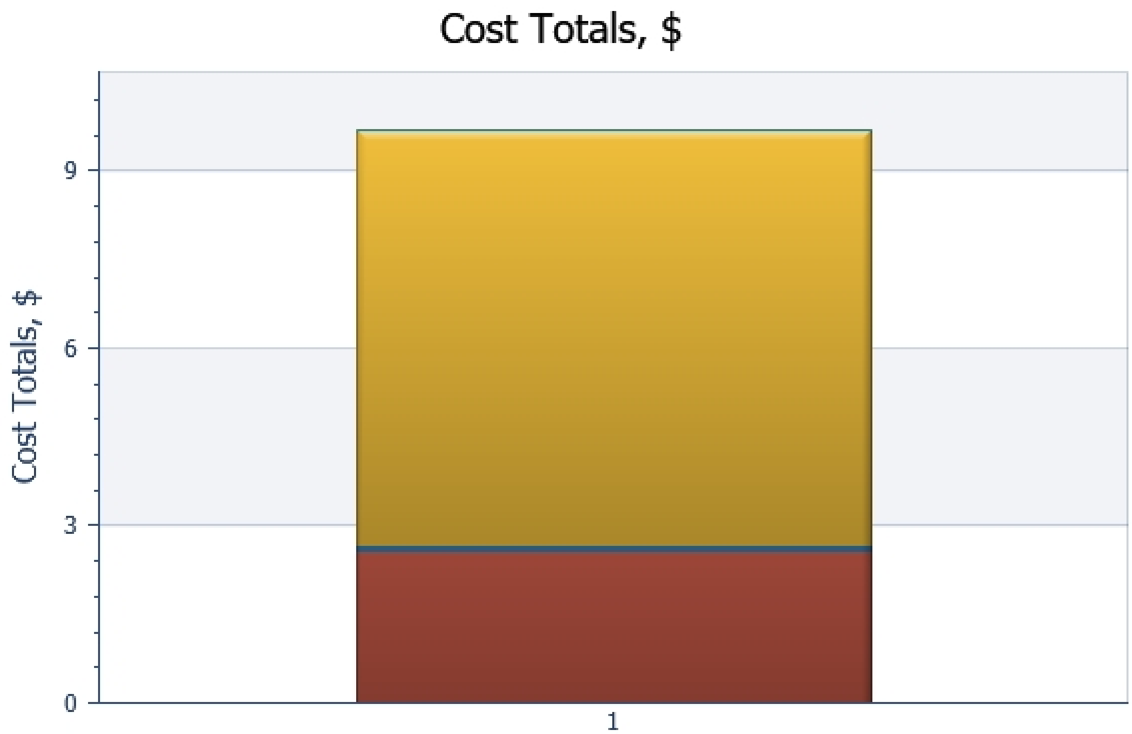
Friday, 14 October 2022

Location Bush.dfmx


| Cost per part, $ | 10 LOCATION BUSH<br>Machined/cut from stock<br>Generic free machining carbon steel |
|---|---|
| Life volume | 6,000 |
| Material | 2.5896 |
| Setup | 0.0919 |
| Process | 6.9754 |
| Rejects | 0.0473 |
| Piece part | 9.7042 |
| Tooling | 0.0000 |
| Total | 9.7042 |
| Initial tooling investment | 0.0000 |



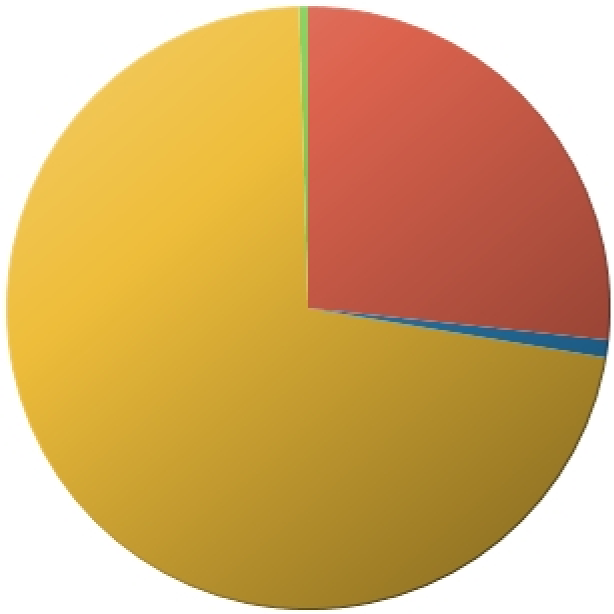

| Cost per part, $ | 10 LOCATION BUSH<br>Machined/cut from stock<br>Generic free machining carbon steel |
|---|---|
| Life volume | 6,000 |
| Material | 2.5896 |
| Setup | 0.0919 |
| Process | 6.9754 |
| Rejects | 0.0473 |
| Piece part | 9.7042 |
| Tooling | 0.0000 |
| Total | 9.7042 |
| Initial tooling investment | 0.0000 |




| | Cost per part, $ | 1 10 LOCATION BUSH<br>Machined/cut from stock<br>Generic free machining carbon steel |
|---|---|---|
| | Life volume | 6,000 |
| | Material | 2.5896 |
| | Setup | 0.0919 |
| | Process | 6.9754 |
| | Rejects | 0.0473 |
| | Piece part | 9.7042 |
| | Tooling | 0.0000 |
| | Total | 9.7042 |
| | Initial tooling investment | 0.0000 |

## Cost Totals, $

10 LOCATION BUSH



| | Cost per part, $ | 1 10 LOCATION BUSH<br>Machined/cut from stock<br>Generic free machining carbon steel |
|---|---|---|
| | Life volume | 6,000 |
| | Material | 2.5896 |
| | Setup | 0.0919 |
| | Process | 6.9754 |
| | Rejects | 0.0473 |
| | Piece part | 9.7042 |
| | Tooling | 0.0000 |
| | Total | 9.7042 |
| | Initial tooling investment | 0.0000 |

# DFM Concurrent Costing
# Guide to Cost Reduction

Friday, 14 October 2022

Location Bush.dfmx

Analysis Name: 10 LOCATION BUSH

Material name: Generic free machining carbon steel

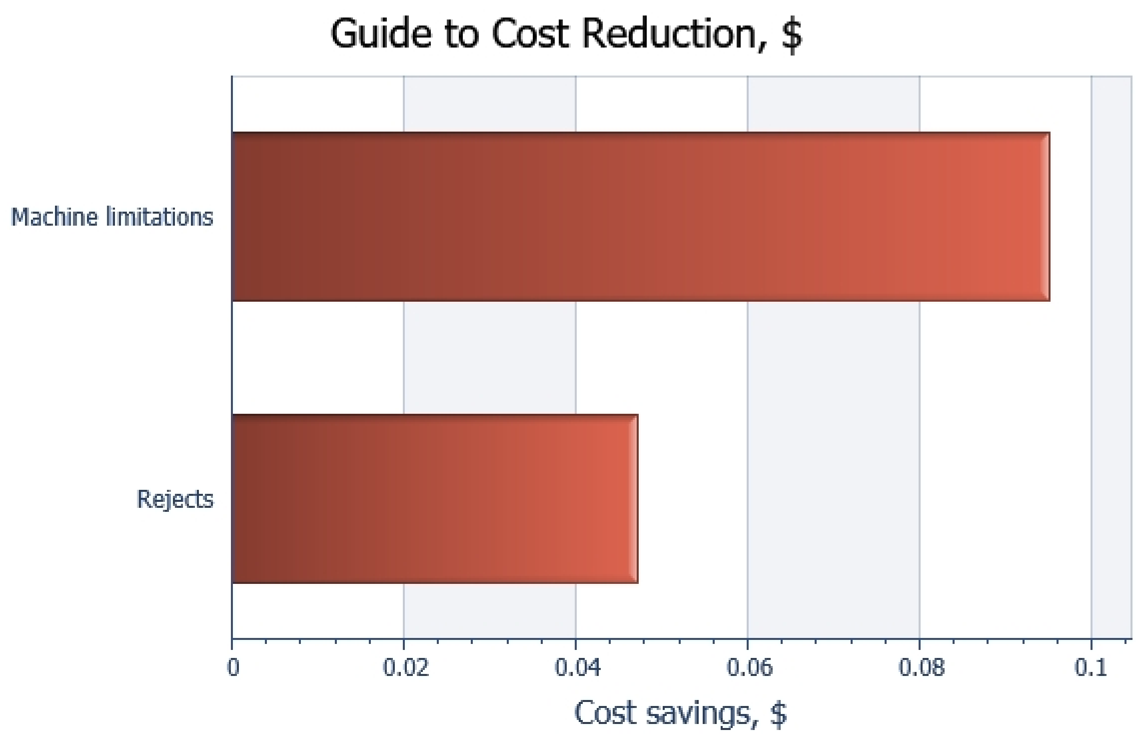
Part name: 10 LOCATION BUSH

Manufacturing process: Machined/cut from stock

Part number:

Manufacturing profile: 20A BDI North America

For the product life volume of 6000 and the batch size of 750 you have specified, the tooling costs form 0.00% of the total cost of 9.70. The chart shows how improved equipment might reduce the machining cost in either of two ways: 1. If the machining operations could be carried out on one setup where appropriate. 2. If the various machines imposed no limitations on power or spindle speed.




| Category | Savings, $ |
|---|---|
| Machine limitations | 0.0952 |
| Rejects | 0.0473 |

# Appendix Y.11

**DFM Concurrent Costing Analysis Report of Part No. 15 Adjustable Eccentric Mass of Best Concept Design**

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing

# Executive Summary

Friday, 14 October 2022

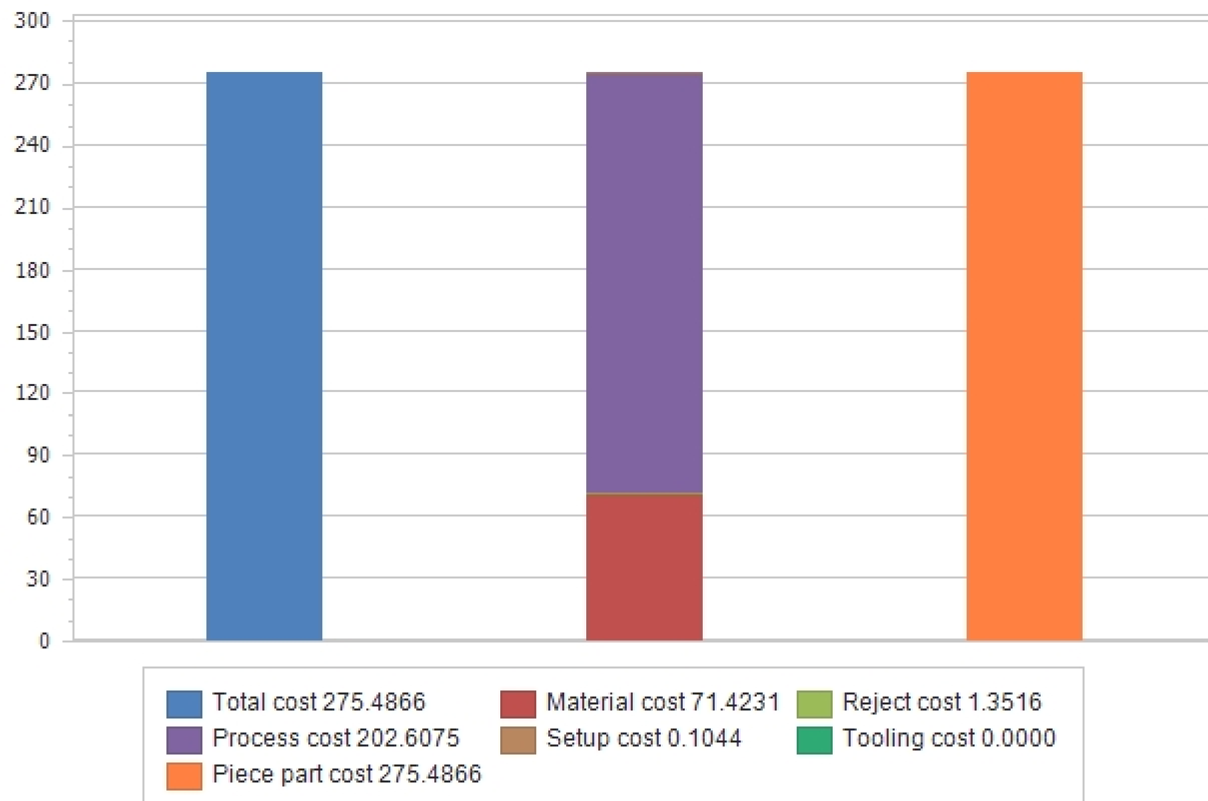
Adjustable Eccentric Mass.dfmx

Analysis Name: 15 ADJUSTABLE ECCENTRIC MASS
Part name: 15 ADJUSTABLE ECCENTRIC MASS
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| | |
|---|---|
| Product life volume | 6,000 |
| Batch size | 750 |
| Total cost, $ | 275.4866 |
| Piece part cost, $ | 275.4866 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFM Concurrent Costing
# Notes

Friday, 14 October 2022

Adjustable Eccentric Mass.dfmx

Analysis Name: 15 ADJUSTABLE ECCENTRIC MASS

Material name: Low carbon steel, cold rolled, commercial quality

Part name: 15 ADJUSTABLE ECCENTRIC MASS

Manufacturing process: Machined/cut from stock

Part number:

Manufacturing profile: 20A BDI North America

## Setup/load/unload

Custom jig to be fabricated to hold stock material for eccentric masses

## Rough and finish cylindrical bore

Bore to be roughed and finished to suit interference fit with shaft.

# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Responses

Friday, 14 October 2022

Adjustable Eccentric Mass.dfmx

Analysis Name: 15 ADJUSTABLE ECCENTRIC MASS

Part name: 15 ADJUSTABLE ECCENTRIC MASS

Part number:

Material name: Low carbon steel, cold rolled, commercial quality

Manufacturing process: Machined/cut from stock

Manufacturing profile: 20A BDI North America

## Low carbon steel, cold rolled, commercial quality machined/cut from stock part

| **Part** | |
|---|---|
| Part name | 15 ADJUSTABLE ECCENTRIC MASS |
| Part number | |
| Life volume | 6000 |
| Envelope shape | Solid block |
| Part length, mm | 573.073 |
| Part width, mm | 40.000 |
| Part height, mm | 449.330 |
| Average thickness, mm | 22.753 |
| Forming direction | Z |

## Stock process

| **Part basic data** | |
|---|---|
| Batch size | 750 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Rectangular bar |
| Material hardness, Bhn | 200 |
| Material cost, $/kg | 0.838 |
| Material scrap value, $/kg | 0.110 |
| Cutoff method | Horizontal bandsaw |

| **Part geometry** | |
|---|---|
| Volume, cm³ | 5858.886 |
| Weight, kg | 45.895 |

## Workpiece

| Bar dimensions | |
|---|---|
| Bar stock length, m | 3.048 |

| Workpiece geometry | |
|---|---|
| Length, mm | 449.330 |
| Section width, mm | 573.073 |
| Section depth, mm | 40.000 |

## Horizontal bandsaw cutoff

| Basic process data | |
|---|---|
| Process rate, $/hr | 15.00 |
| Setup rate, $/hr | 15.00 |
| Setup time, hr | 0.25 |

| Bar loading data | |
|---|---|
| Bar loading time, s | 33.00 |

| Bandsaw cutting data | |
|---|---|
| Cutting rate, $cm^2$/min | 70.443 |
| Kerf, mm | 1.067 |

| Operation time | |
|---|---|
| Process time per part, s | 200.75 |

## Cincinnati Falcon TC-300/1000 turning center

| Basic data | |
|---|---|
| Batch size | 750 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |

| Machine tool data | |
|---|---|

| | |
|---|---|
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 20.40 |
| Operator rate, $/hr | 25.00 |
| Process rate, $/hr | 32.90 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |

| **Live tool data** | |
|---|---|
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |

| **Result** | |
|---|---|
| Cycle time per part, s | 18612.01 |
| Total setup time, hr | 1.59 |

## Setup/load/unload

| **Work handling** | |
|---|---|
| Workholding device | Jig |
| Number of reversals | 0 |
| Load/unload time, s | 69.01 |

| **Machine setup** | |
|---|---|
| Machine rate during setup, $/hr | 16.90 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 46.90 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |

**Other costs**

| | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

| Rough and finish multiple peripheral end mill (live tool) | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 456.000 |
| Length of surface to be milled (lc), mm | 580.000 |
| Total depth of material removed (dt), mm | 40.000 |
| Finish cut allowance, mm | 0.200 |
| Number of features milled | 1 |
| Surface roughness | 250 µin. 6.3 µm |
| **Machining data** | |
| Tool diameter, mm | 50.800 |
| Number of teeth | 4.000 |
| Cutting speed during rough cuts, m/min | 3.783 |
| Feed per tooth during rough cuts, mm | 0.178 |
| Feed speed during rough cuts, mm/s | 0.281 |
| Number of rough cut passes | 8.000 |
| Depth of rough cut per pass, mm | 4.975 |
| Cutting speed during finish cut, m/min | 176.784 |
| Feed per tooth during finish cut, mm | 0.269 |
| Feed speed during finish cut, mm/s | 19.891 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 2.61 |
| Power required, kW | 2.61 |
| Spindle speed available, rpm | 3000 |
| Spindle speed required, rpm | 1108 |
| **Results** | |
| Operation time, s | 18006.0000 |
| Total volume removed, cm³ | 10579.223 |

| Rough and finish cylindrical bore | |
| --- | --- |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 0.000 |
| Diameter of machined surface (dm), mm | 180.200 |
| Length of machined surface (lm), mm | 40.000 |
| Finish cut allowance on radius, mm | 0.300 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Cutting speed during rough cuts, m/min | 100.939 |
| Feed per revolution during rough cuts, mm | 0.320 |
| Number of rough cut passes | 18.000 |
| Depth of rough cut per pass, mm | 4.989 |
| Cutting speed during finish cut, m/min | 229.891 |
| Feed per revolution during finish cut, mm | 0.096 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 10.26 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 466.0000 |
| Total volume removed, $cm^3$ | 1020.144 |

| Drill multiple holes | |
| --- | --- |
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 14.500 |
| Length of drilled holes (lh), mm | 40.000 |

| | |
|---|---|
| Number of identical holes drilled | 10 |
| Number of holes drilled simultaneously | 5 |
| **Machining data** | |
| Cutting speed, m/min | 65.762 |
| Feed per revolution, mm | 0.296 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 1443 |
| **Results** | |
| Operation time, s | 25.0000 |
| Total volume removed, cm³ | 66.052 |

| Tap multiple holes (Metric, fine) | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 16.000 |
| Length to be tapped (lt), mm | 4.000 |
| Number of holes tapped | 10 |
| Holes tapped simultaneously | 5 |
| **Machining data** | |
| Thread pitch, mm | 1.500 |
| Cutting speed, m/min | 6.531 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 3300 |
| **Results** | |

| | |
|---|---|
| Operation time, s | 10.0000 |

## Drill multiple holes

| | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 9.500 |
| Length of drilled holes (lh), mm | 20.000 |
| Number of identical holes drilled | 4 |
| Number of holes drilled simultaneously | 1 |
| **Machining data** | |
| Cutting speed, m/min | 95.363 |
| Feed per revolution, mm | 0.224 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Power required, kW | 3.00 |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 3195 |
| **Results** | |
| Operation time, s | 22.0000 |
| Total volume removed, cm³ | 5.671 |

## Tap multiple holes (Metric, fine)

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 10.000 |
| Length to be tapped (lt), mm | 20.000 |
| Number of holes tapped | 4 |
| Holes tapped simultaneously | 1 |
| **Machining data** | |

| | |
|---|---|
| Thread pitch, mm | 1.000 |
| Cutting speed, m/min | 4.082 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 3300 |

| **Results** | |
|---|---|
| Operation time, s | 14.0000 |

## DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing

# Cost Breakdown

Friday, 14 October 2022

Adjustable Eccentric Mass.dfmx

Analysis Name: 15 ADJUSTABLE ECCENTRIC MASS

Part name: 15 ADJUSTABLE ECCENTRIC MASS

Part number:

Part weight: 80.683 kg

Material name: Low carbon steel, cold rolled, commercial quality

Manufacturing process: Machined/cut from stock

Manufacturing profile: 20A BDI North America

| | | | | Cost per part, $ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process Chart** | **Batch size** | **Material** | **Setup** | **Process** | **Rejects** | **Piece part** | **Tooling** | **Total** | **Operation time per part, s** | **Initial tooling investment** |
| **Low carbon steel, cold rolled, commercial quality machined/cut from stock part** | | **71.4231** | **0.1044** | **202.6075** | **1.3516** | **275.4866** | | **275.4866** | **18812.76** | |
| **Stock process** | **750** | **71.4231** | **0.0050** | **0.9840** | | **72.4122** | | **72.4122** | **200.75** | |
| Workpiece | | 71.4231 | | | | 71.4231 | | 71.4231 | | |
| Horizontal bandsaw cutoff | | | 0.0050 | 0.9840 | | 0.9890 | | 0.9890 | 200.75 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.0994** | **201.6234** | **1.3516** | **203.0745** | | **203.0745** | **18612.01** | |
| Setup/load/unload | | | 0.0994 | 0.7420 | | 0.8414 | | 0.8414 | 69.01 | |
| Rough and finish multiple peripheral end mill (live tool) | | | | 193.6906 | | 193.6906 | | 193.6906 | 18006.00 | |
| Rough and finish cylindrical bore | | | | 6.3501 | | 6.3501 | | 6.3501 | 466.00 | |
| Drill multiple holes | | | | 0.3258 | | 0.3258 | | 0.3258 | 25.00 | |
| Tap multiple holes (Metric, fine) | | | | 0.1075 | | 0.1075 | | 0.1075 | 10.00 | |
| Drill multiple holes | | | | 0.2570 | | 0.2570 | | 0.2570 | 22.00 | |
| Tap multiple holes (Metric, fine) | | | | 0.1505 | | 0.1505 | | 0.1505 | 14.00 | |

# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Totals

Friday, 14 October 2022

Adjustable Eccentric Mass.dfmx

| Analysis Name | 15 ADJUSTABLE ECCENTRIC MASS |
|---|---|
| Part name | 15 ADJUSTABLE ECCENTRIC MASS |
| Part number | |
| Material | Low carbon steel, cold rolled, commercial quality |
| Manufacturing process | Machined/cut from stock |
| Manufacturing profile | 20A BDI North America |

| Cost per part, $ | Value |
|---|---|
| Material | 71.4231 |
| Setup | 0.1044 |
| Process | 202.6075 |
| Rejects | 1.3516 |
| Piece part | 275.4866 |
| Tooling | 0.0000 |
| Total | 275.4866 |
| Initial tooling investment | 0.0000 |

| | |
|---|---|
| Life volume | 6,000 |
| Batch size | 750 |
| Part weight | 80.683 |


| Cost per part, $ | 15 ADJUSTABLE ECCENTRIC MASS<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 6,000 |
| Material | 71.4231 |
| Setup | 0.1044 |
| Process | 202.6075 |
| Rejects | 1.3516 |
| Piece part | 275.4866 |
| Tooling | 0.0000 |
| Total | 275.4866 |
| Initial tooling investment | 0.0000 |

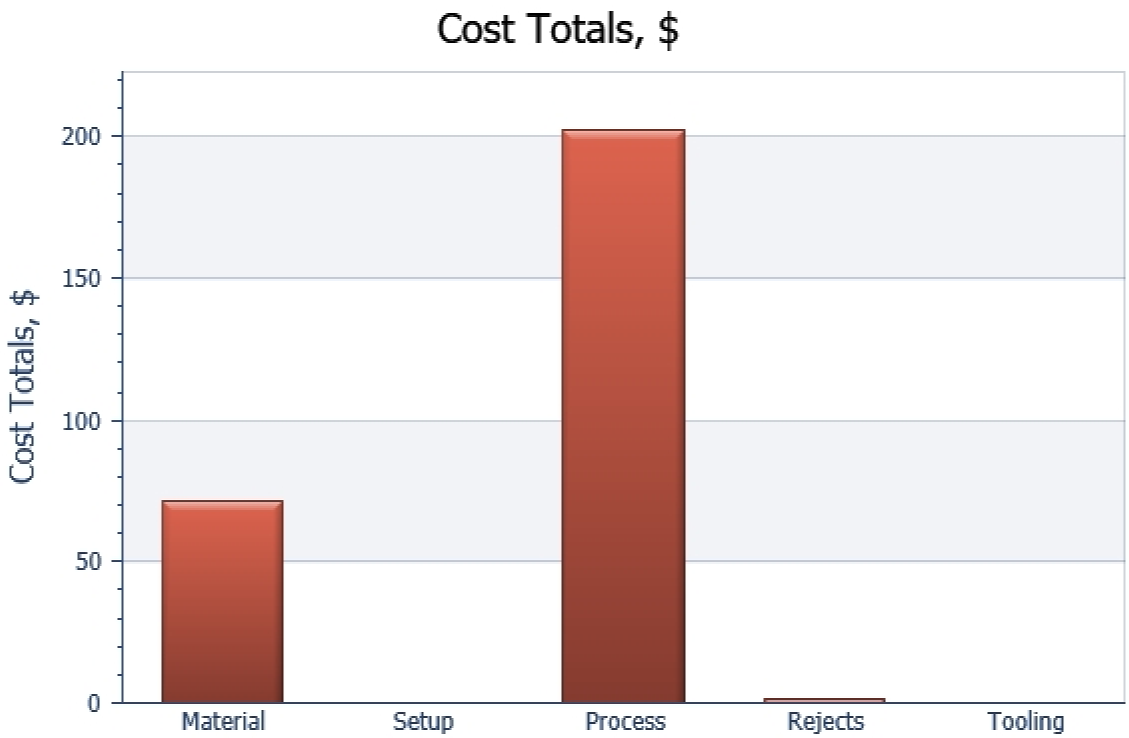
# DFMA® - Boothroyd Dewhurst, Inc.

## DFM Concurrent Costing

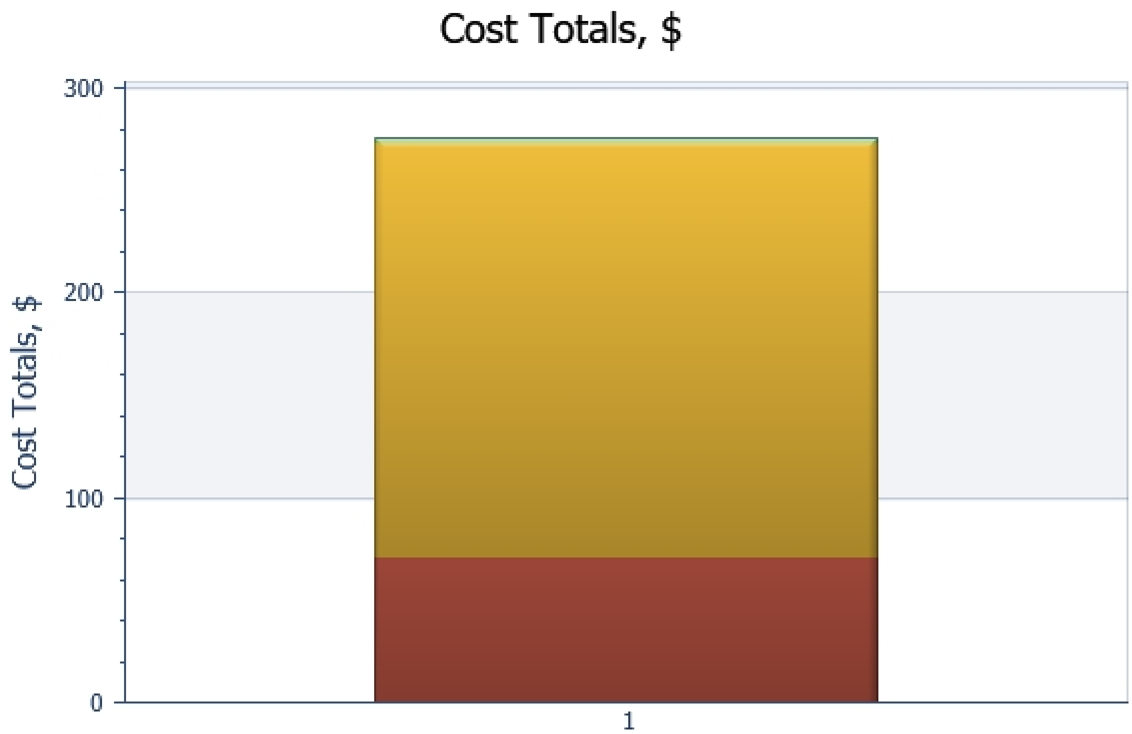
## Cost Totals

Friday, 14 October 2022

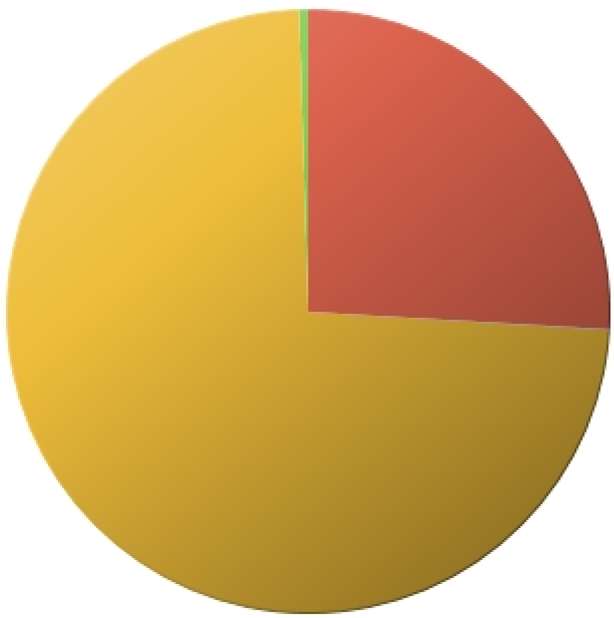
Adjustable Eccentric Mass.dfmx




| | |
|---|---|
| Cost per part, $ | 15 ADJUSTABLE ECCENTRIC MASS<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
| Life volume | 6,000 |
| Material | 71.4231 |
| Setup | 0.1044 |
| Process | 202.6075 |
| Rejects | 1.3516 |
| Piece part | 275.4866 |
| Tooling | 0.0000 |
| Total | 275.4866 |
| Initial tooling investment | 0.0000 |




| | Cost per part, $ | 1 15 ADJUSTABLE ECCENTRIC MASS<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|---|
| | Life volume | 6,000 |
| | Material | 71.4231 |
| | Setup | 0.1044 |
| | Process | 202.6075 |
| | Rejects | 1.3516 |
| | Piece part | 275.4866 |
| | Tooling | 0.0000 |
| | Total | 275.4866 |
| | Initial tooling investment | 0.0000 |



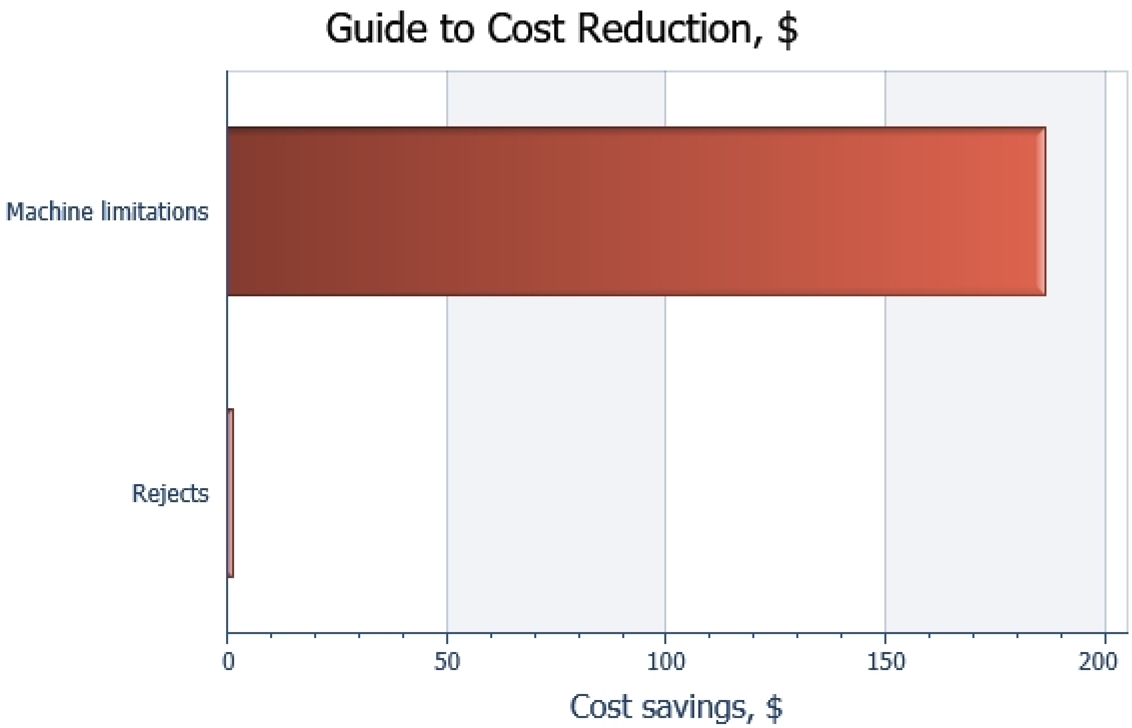

| | Cost per part, $ | 1 15 ADJUSTABLE ECCENTRIC MASS<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|---|
| | Life volume | 6,000 |
| | Material | 71.4231 |
| | Setup | 0.1044 |
| | Process | 202.6075 |
| | Rejects | 1.3516 |
| | Piece part | 275.4866 |
| | Tooling | 0.0000 |
| | Total | 275.4866 |
| | Initial tooling investment | 0.0000 |

# DFM Concurrent Costing
# Guide to Cost Reduction

Friday, 14 October 2022 | Adjustable Eccentric Mass.dfmx

Analysis Name: 15 ADJUSTABLE ECCENTRIC MASS
Material name: Low carbon steel, cold rolled, commercial quality
Part name: 15 ADJUSTABLE ECCENTRIC MASS
Manufacturing process: Machined/cut from stock
Part number:
Manufacturing profile: 20A BDI North America

For the product life volume of 6000 and the batch size of 750 you have specified, the tooling costs form 0.00% of the total cost of 275.49. The chart shows how improved equipment might reduce the machining cost in either of two ways: 1. If the machining operations could be carried out on one setup where appropriate. 2. If the various machines imposed no limitations on power or spindle speed.




| Category | Savings, $ |
|---|---:|
| Machine limitations | 186.3797 |
| Rejects | 1.3516 |

# Appendix Y.12

**DFM Concurrent Costing Analysis Report of Part No. 16 Fixed Eccentric Mass of Best Concept Design**

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing
# Executive Summary

Friday, 14 October 2022

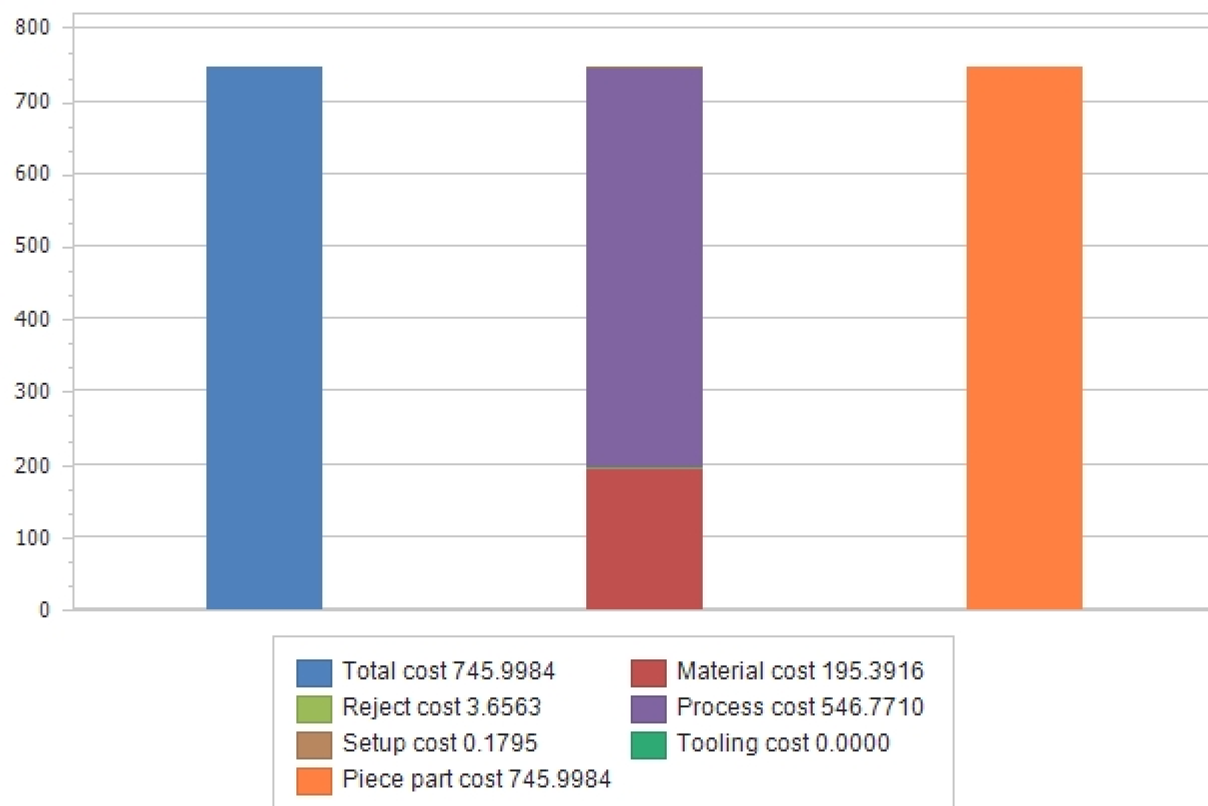
Fixed Eccentric Mass.dfmx

Analysis Name: 16 FIXED ECCENTRIC MASS
Part name: Fixed Eccentric Mass
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| | |
|---|---|
| Product life volume | 6,000 |
| Batch size | 750 |
| Total cost, $ | 745.9984 |
| Piece part cost, $ | 745.9984 |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing

## Notes

Friday, 14 October 2022

Fixed Eccentric Mass.dfmx

Analysis Name: 16 FIXED ECCENTRIC MASS

Material name: Low carbon steel, cold rolled, commercial quality

Part name: Fixed Eccentric Mass

Manufacturing process: Machined/cut from stock

Part number:

Manufacturing profile: 20A BDI North America

### Setup/load/unload

Jig to be fabricated to mount stock material to machine eccentric mass

### Counterdrill multiple holes (live tool)

Scoekt head cap screw for counterbore hole.

### Load bar

Rotate component 90° such that outer 10mm tapped holes can be completed.

# DFMA® - Boothroyd Dewhurst, Inc.

DFM Concurrent Costing

Responses

Friday, 14 October 2022

Fixed Eccentric Mass.dfmx

Analysis Name: 16 FIXED ECCENTRIC MASS
Part name: Fixed Eccentric Mass
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

## Low carbon steel, cold rolled, commercial quality machined/cut from stock part

| Part | |
|---|---|
| Part name | Fixed Eccentric Mass |
| Part number | |
| Life volume | 6000 |
| Envelope shape | Solid block |
| Part length, mm | 573.073 |
| Part width, mm | 109.000 |
| Part height, mm | 449.669 |
| Average thickness, mm | 65.387 |
| Forming direction | Z |

## Stock process

| Part basic data | |
|---|---|
| Batch size | 750 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Rectangular bar |
| Material hardness, Bhn | 200 |
| Material cost, $/kg | 0.838 |
| Material scrap value, $/kg | 0.110 |
| Cutoff method | Horizontal bandsaw |

| Part geometry | |
|---|---|
| Volume, $cm^3$ | 16849.846 |
| Weight, kg | 131.991 |

## Workpiece

| Bar dimensions | |
|---|---|
| Bar stock length, m | 3.048 |

| Workpiece geometry | |
|---|---|
| Length, mm | 449.669 |
| Section width, mm | 573.073 |
| Section depth, mm | 109.000 |

## Horizontal bandsaw cutoff

| Basic process data | |
|---|---|
| Process rate, $/hr | 15.00 |
| Setup rate, $/hr | 15.00 |
| Setup time, hr | 0.25 |

| Bar loading data | |
|---|---|
| Bar loading time, s | 33.00 |

| Bandsaw cutting data | |
|---|---|
| Cutting rate, $cm^2$/min | 93.380 |
| Kerf, mm | 1.067 |

| Operation time | |
|---|---|
| Process time per part, s | 406.86 |

## Cincinnati Falcon TC-300/1000 turning center

| Basic data | |
|---|---|
| Batch size | 750 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |

| Machine tool data | |
|---|---|
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 20.40 |

| | |
|---|---|
| Operator rate, $/hr | 25.00 |
| Process rate, $/hr | 32.90 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |

| **Live tool data** | |
|---|---|
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |

| **Result** | |
|---|---|
| Cycle time per part, s | 50393.81 |
| Total setup time, hr | 2.79 |

## Setup/load/unload

| **Work handling** | |
|---|---|
| Workholding device | Jig |
| Number of reversals | 0 |
| Load/unload time, s | 93.61 |

| **Machine setup** | |
|---|---|
| Machine rate during setup, $/hr | 16.90 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 46.90 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |

| **Other costs** | |
|---|---|
| Tool, fixture or program cost, $ | 0 |

## Rough and finish single peripheral end mill (live tool)

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 455.000 |
| Length of surface to be milled (lc), mm | 580.000 |
| Total depth of material removed (dt), mm | 109.000 |
| Finish cut allowance, mm | 0.200 |
| Surface roughness | 250 µin. 6.3 µm |

| **Machining data** | |
|---|---|
| Tool diameter, mm | 50.800 |
| Number of teeth | 4.000 |
| Cutting speed during rough cuts, m/min | 3.814 |
| Feed per tooth during rough cuts, mm | 0.178 |
| Feed speed during rough cuts, mm/s | 0.283 |
| Number of rough cut passes | 22.000 |
| Depth of rough cut per pass, mm | 4.945 |
| Cutting speed during finish cut, m/min | 176.784 |
| Feed per tooth during finish cut, mm | 0.269 |
| Feed speed during finish cut, mm/s | 19.891 |
| Special tooling cost, $ | 0.000 |

| **Machine limitations** | |
|---|---|
| Power available, kW | 2.61 |
| Power required, kW | 2.61 |
| Spindle speed available, rpm | 3000 |
| Spindle speed required, rpm | 1108 |

| **Results** | |
|---|---|
| Operation time, s | 49056.0000 |
| Total volume removed, $cm^3$ | 28765.163 |

## Rough and finish cylindrical bore

| | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |

| | |
|---|---|
| Diameter of work surface (dw), mm | 0.000 |
| Diameter of machined surface (dm), mm | 150.000 |
| Length of machined surface (lm), mm | 109.000 |
| Finish cut allowance on radius, mm | 0.200 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Cutting speed during rough cuts, m/min | 100.953 |
| Feed per revolution during rough cuts, mm | 0.320 |
| Number of rough cut passes | 15.000 |
| Depth of rough cut per pass, mm | 4.987 |
| Cutting speed during finish cut, m/min | 229.891 |
| Feed per revolution during finish cut, mm | 0.096 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 10.25 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 879.0000 |
| Total volume removed, cm³ | 1926.198 |

| **Finish single slot end mill (live tool)** | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Width of surface to be milled (wc), mm | 14.000 |
| Length of surface to be milled (lc), mm | 109.000 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Tool diameter, mm | 14.000 |
| Number of teeth | 4.000 |

| | |
|---|---|
| Cutting speed, m/min | 128.101 |
| Feed per tooth, mm | 0.071 |
| Feed speed, mm/s | 13.783 |
| Number of passes | 1.000 |
| Width per pass, mm | 14.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3000 |
| Spindle speed required, rpm | 2912 |
| **Results** | |
| Operation time, s | 18.0000 |

| **Drill multiple holes** | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 14.000 |
| Length of drilled holes (lh), mm | 50.000 |
| Number of identical holes drilled | 6 |
| Number of holes drilled simultaneously | 6 |
| **Machining data** | |
| Cutting speed, m/min | 60.929 |
| Feed per revolution, mm | 0.276 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Power required, kW | 20.88 |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 1385 |
| **Results** | |
| Operation time, s | 19.0000 |

| | |
|---|---|
| Total volume removed, $cm^3$ | 46.182 |

| Tap multiple holes (Metric, fine) | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 16.000 |
| Length to be tapped (lt), mm | 2.000 |
| Number of holes tapped | 6 |
| Holes tapped simultaneously | 6 |
| **Machining data** | |
| Thread pitch, mm | 2.000 |
| Cutting speed, m/min | 6.531 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 9.0000 |

| Counterdrill multiple holes (live tool) | |
|---|---|
| Tool material | Carbide |
| Include tool replacement cost? | Yes |
| Diameter of counterdrill (dh), mm | 25.550 |
| Dia. of holes to be counterdrilled (dw), mm | 25.500 |
| Length to be counterdrilled (lh), mm | 20.000 |
| Number of holes counterdrilled | 2 |
| Holes counterdrilled simultaneously | 1 |
| **Machining data** | |
| Cutting speed, m/min | 100.075 |
| Feed per revolution, mm | 0.509 |

| | |
|---|---|
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 2.61 |
| Power required, kW | 0.08 |
| Spindle speed available, rpm | 3000 |
| Spindle speed required, rpm | 1247 |
| **Results** | |
| Operation time, s | 18.0000 |
| Total volume removed, cm³ | 0.080 |

| **Drill multiple holes** | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 14.000 |
| Length of drilled holes (lh), mm | 89.000 |
| Number of identical holes drilled | 2 |
| Number of holes drilled simultaneously | 2 |
| **Machining data** | |
| Cutting speed, m/min | 20.300 |
| Feed per revolution, mm | 0.225 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Power required, kW | 1.89 |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 461 |
| **Results** | |
| Operation time, s | 74.0000 |
| Total volume removed, cm³ | 27.401 |

| Tap multiple holes (Metric, fine) | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 16.000 |
| Length to be tapped (lt), mm | 89.000 |
| Number of holes tapped | 2 |
| Holes tapped simultaneously | 2 |
| **Machining data** | |
| Thread pitch, mm | 2.000 |
| Cutting speed, m/min | 6.531 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 10.0000 |

| Load bar | |
|---|---|
| Length of bar, m | 3.048 |
| Operation time per part, s | 153.2000 |

| Drill multiple holes | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled holes (dh), mm | 9.000 |
| Length of drilled holes (lh), mm | 24.500 |
| Number of identical holes drilled | 2 |
| Number of holes drilled simultaneously | 2 |
| **Machining data** | |

| | |
|---|---|
| Cutting speed, m/min | 26.336 |
| Feed per revolution, mm | 0.182 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Power required, kW | 1.28 |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 931 |
| **Results** | |
| Operation time, s | 21.0000 |
| Total volume removed, cm³ | 3.117 |

## Tap multiple holes (Metric, fine)

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of holes to be tapped (dh), mm | 10.000 |
| Length to be tapped (lt), mm | 24.500 |
| Number of holes tapped | 2 |
| Holes tapped simultaneously | 2 |
| **Machining data** | |
| Thread pitch, mm | 1.000 |
| Cutting speed, m/min | 4.082 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 9.0000 |

## Drill single hole

| | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of drilled hole (dh), mm | 10.200 |
| Length of drilled hole (lh), mm | 29.250 |
| **Machining data** | |
| Cutting speed, m/min | 25.937 |
| Feed per revolution, mm | 0.200 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 0.78 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 809 |
| **Results** | |
| Operation time, s | 24.0000 |
| Total volume removed, $cm^3$ | 2.390 |

| **Tap single hole (Metric, fine)** | |
|---|---|
| Tool material | High-speed steel |
| Include tool replacement cost? | Yes |
| Diameter of hole to be tapped (dh), mm | 12.000 |
| Length to be tapped (lt), mm | 29.250 |
| **Machining data** | |
| Thread pitch, mm | 0.800 |
| Cutting speed, m/min | 4.899 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Spindle speed required, rpm | 3300 |
| **Results** | |

| | |
|---|---|
| Operation time, s | 10.0000 |

# DFM Concurrent Costing
## Cost Breakdown

Friday, 14 October 2022

Fixed Eccentric Mass.dfmx

Analysis Name: 16 FIXED ECCENTRIC MASS
Part name: Fixed Eccentric Mass
Part number:
Part weight: 220.028 kg

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

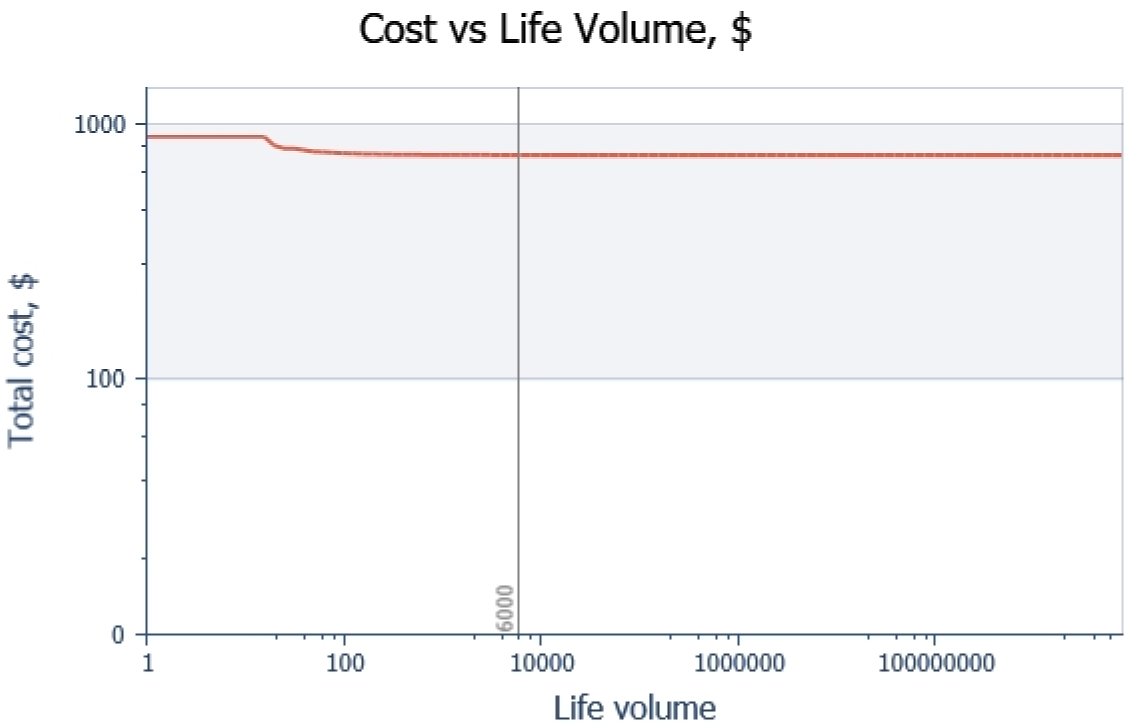
| Cost per part, $ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Process Chart | Batch size | Material | Setup | Process | Rejects | Piece part | Tooling | Total | Operation time per part, s | Initial tooling investment |
| **Low carbon steel, cold rolled, commercial quality machined/cut from stock part** | | **195.3916** | **0.1795** | **546.7710** | **3.6563** | **745.9984** | | **745.9984** | **50800.67** | |
| **Stock process** | **750** | **195.3916** | **0.0050** | **1.9944** | | **197.3910** | | **197.3910** | **406.86** | |
| Workpiece | | 195.3916 | | | | 195.3916 | | 195.3916 | | |
| Horizontal bandsaw cutoff | | | 0.0050 | 1.9944 | | 1.9994 | | 1.9994 | 406.86 | |
| **Cincinnati Falcon TC-300/1000 turning center** | | | **0.1745** | **544.7766** | **3.6563** | **548.6074** | | **548.6074** | **50393.81** | |
| Setup/load/unload | | | 0.1745 | 1.0065 | | 1.1809 | | 1.1809 | 93.61 | |
| Rough and finish single peripheral end mill (live tool) | | | | 527.5289 | | 527.5289 | | 527.5289 | 49056.00 | |
| Rough and finish cylindrical bore | | | | 12.0570 | | 12.0570 | | 12.0570 | 879.00 | |
| Finish single slot end mill (live tool) | | | | 0.2211 | | 0.2211 | | 0.2211 | 18.00 | |
| Drill multiple holes | | | | 0.2516 | | 0.2516 | | 0.2516 | 19.00 | |
| Tap multiple holes (Metric, fine) | | | | 0.0968 | | 0.0968 | | 0.0968 | 9.00 | |
| Counterdrill multiple holes (live tool) | | | | 0.2051 | | 0.2051 | | 0.2051 | 18.00 | |
| Drill multiple holes | | | | 0.9301 | | 0.9301 | | 0.9301 | 74.00 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tap multiple holes (Metric, fine) | | | | 0.1075 | | 0.1075 | | 0.1075 | 10.00 | |
| Load bar | | | | 1.6472 | | 1.6472 | | 1.6472 | 153.20 | |
| Drill multiple holes | | | | 0.2484 | | 0.2484 | | 0.2484 | 21.00 | |
| Tap multiple holes (Metric, fine) | | | | 0.0968 | | 0.0968 | | 0.0968 | 9.00 | |
| Drill single hole | | | | 0.2722 | | 0.2722 | | 0.2722 | 24.00 | |
| Tap single hole (Metric, fine) | | | | 0.1075 | | 0.1075 | | 0.1075 | 10.00 | |

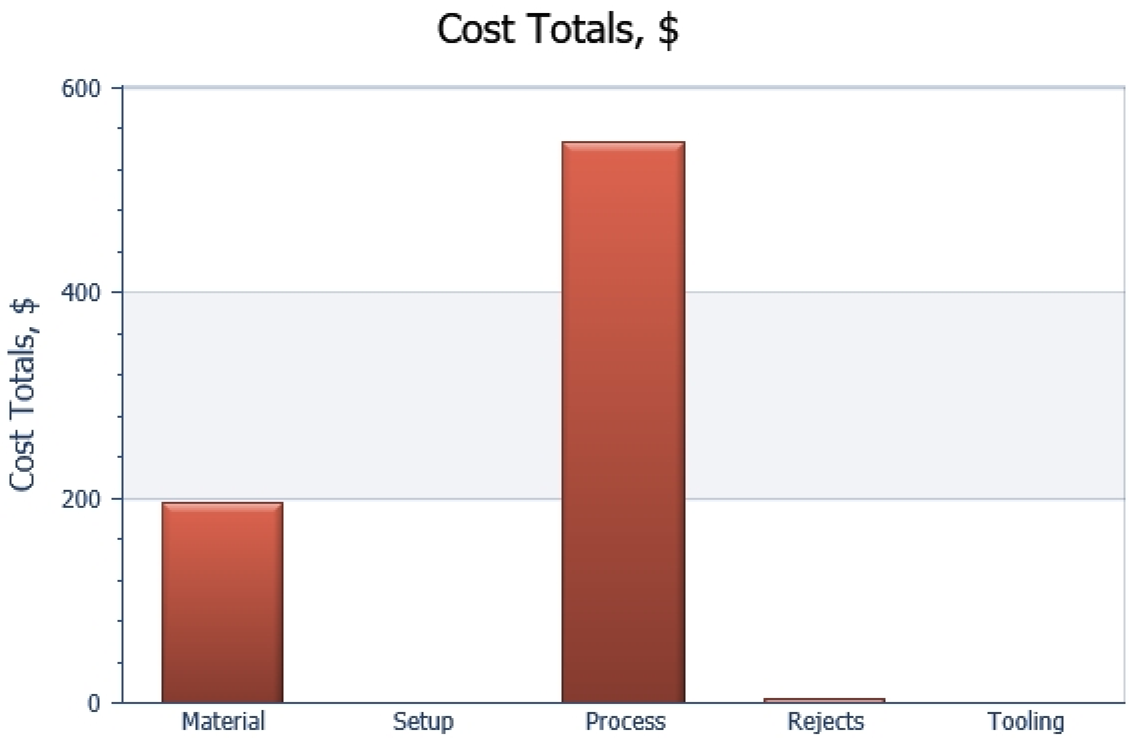
| Analysis Name | 16 FIXED ECCENTRIC MASS |
|---|---|
| Part name | Fixed Eccentric Mass |
| Part number | |
| Material | Low carbon steel, cold rolled, commercial quality |
| Manufacturing process | Machined/cut from stock |
| Manufacturing profile | 20A BDI North America |

| Cost per part, $ | Value |
|---|---|
| Material | 195.3916 |
| Setup | 0.1795 |
| Process | 546.7710 |
| Rejects | 3.6563 |
| Piece part | 745.9984 |
| Tooling | 0.0000 |
| Total | 745.9984 |
| Initial tooling investment | 0.0000 |

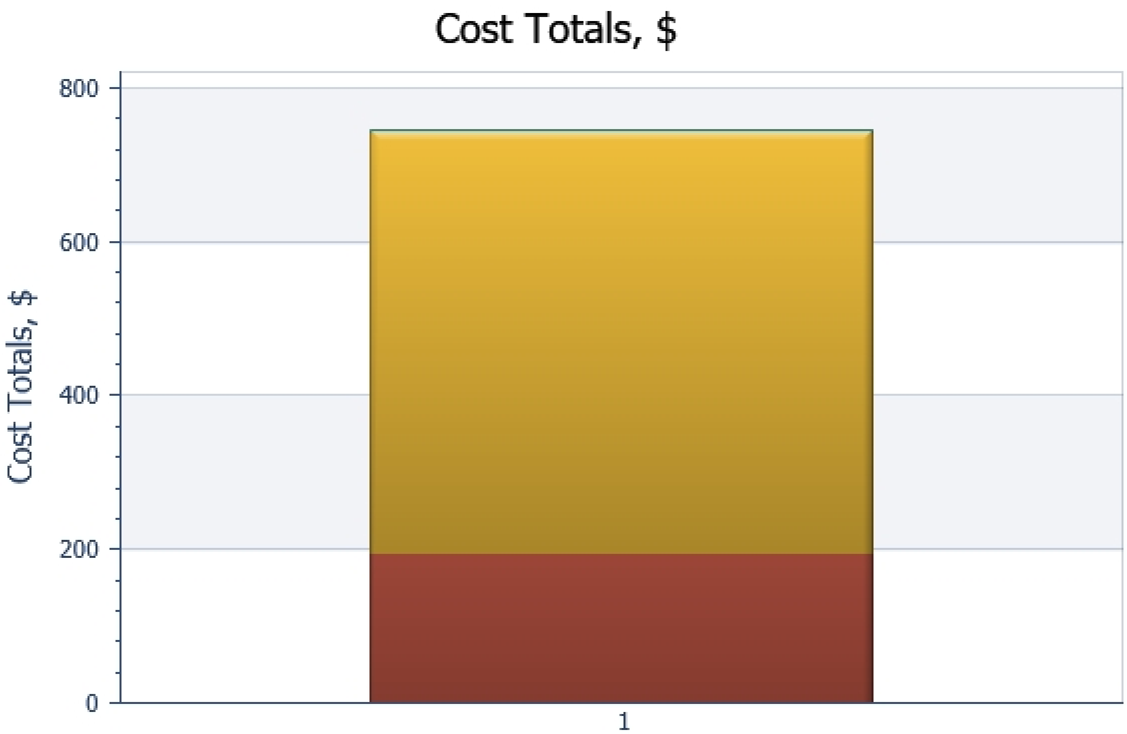
| | |
|---|---|
| Life volume | 6,000 |
| Batch size | 750 |
| Part weight | 220.028 |



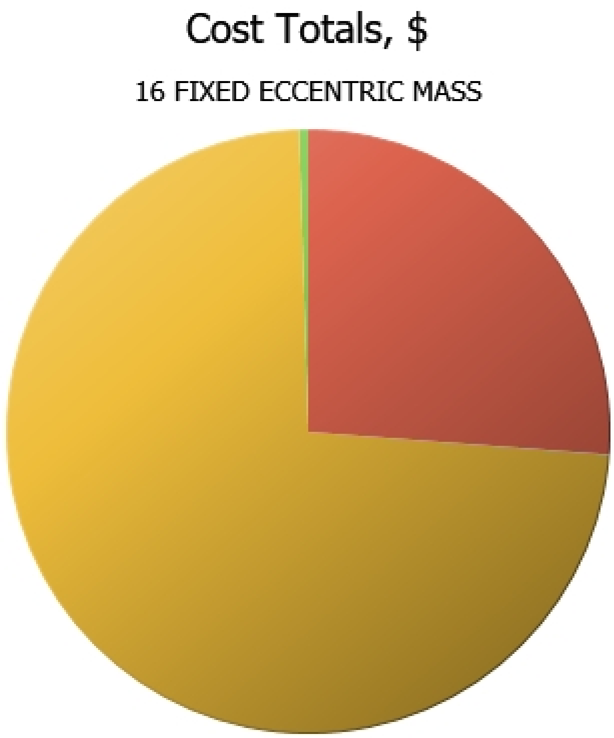

| Cost per part, $ | 16 FIXED ECCENTRI MASS<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 6,000 |
| Material | 195.3916 |
| Setup | 0.1795 |
| Process | 546.7710 |
| Rejects | 3.6563 |
| Piece part | 745.9984 |
| Tooling | 0.0000 |
| Total | 745.9984 |
| Initial tooling investment | 0.0000 |




| Cost per part, $ | 16 FIXED ECCENTRIC MASS<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
|---|---|
| Life volume | 6,000 |
| Material | 195.3916 |
| Setup | 0.1795 |
| Process | 546.7710 |
| Rejects | 3.6563 |
| Piece part | 745.9984 |
| Tooling | 0.0000 |
| Total | 745.9984 |
| Initial tooling investment | 0.0000 |




| | | |
|---|---|---|
| | Cost per part, $ | 1 16 FIXED ECCENTRIC MASS<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
| | Life volume | 6,000 |
| | Material | 195.3916 |
| | Setup | 0.1795 |
| | Process | 546.7710 |
| | Rejects | 3.6563 |
| | Piece part | 745.9984 |
| | Tooling | 0.0000 |
| | Total | 745.9984 |
| | Initial tooling investment | 0.0000 |




| | | |
|---|---|---|
| | Cost per part, $ | 1 16 FIXED ECCENTRIC MASS<br>Machined/cut from stock<br>Low carbon steel, cold rolled, commercial quality |
| | Life volume | 6,000 |
| | Material | 195.3916 |
| | Setup | 0.1795 |
| | Process | 546.7710 |
| | Rejects | 3.6563 |
| | Piece part | 745.9984 |
| | Tooling | 0.0000 |
| | Total | 745.9984 |
| | Initial tooling investment | 0.0000 |

# Appendix Y.13

**DFM Concurrent Costing Analysis Report of Part No. 17 Locking Cap of Best Concept Design**

DFMA® - Boothroyd Dewhurst, Inc.

# DFM Concurrent Costing
# Executive Summary

Monday, 10 October 2022

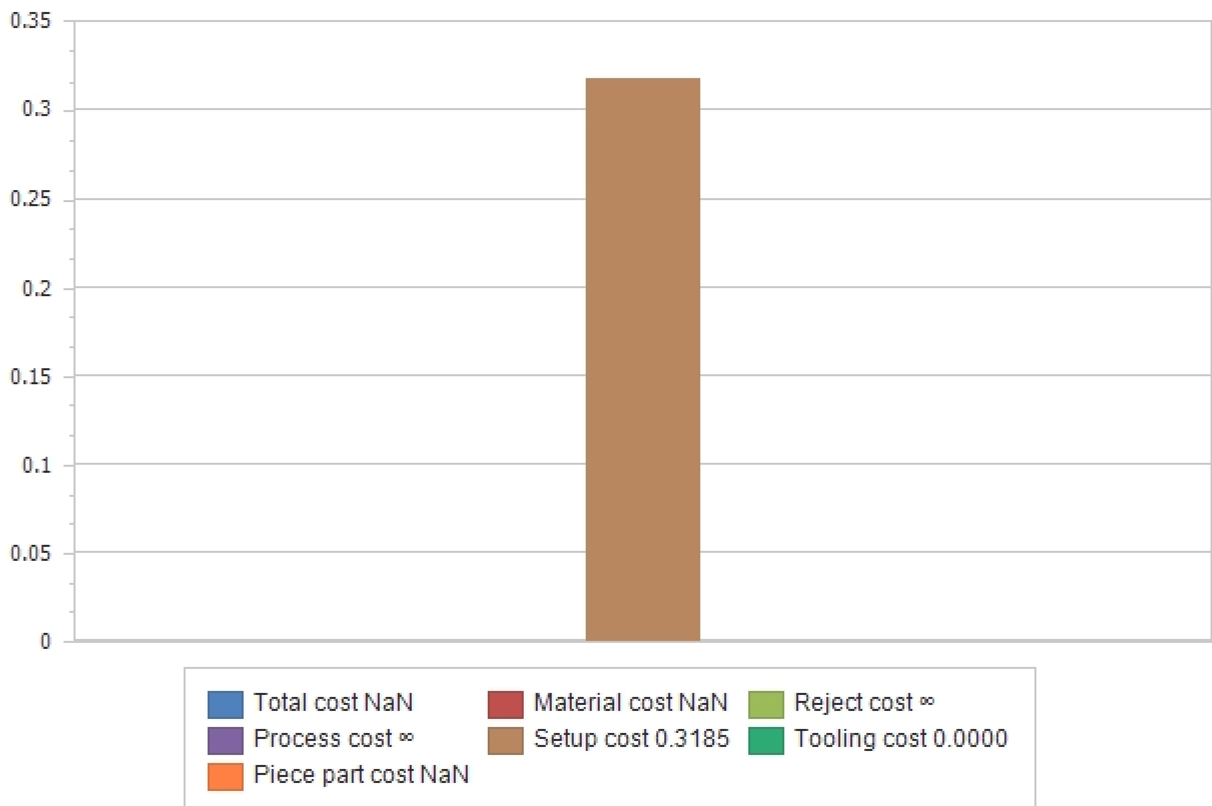
Locking Cap.dfmx

Analysis Name: 36 LOCKING CAP
Part name: 36 LOCKING CAP
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

| | |
|---|---|
| Product life volume | 1,500 |
| Batch size | 187 |
| Total cost, $ | NaN |
| Piece part cost, $ | NaN |
| Initial tooling investment, $ | 0 |

**The chart shows a breakdown of cost per part, $**



# DFM Concurrent Costing Responses

Monday, 10 October 2022

Locking Cap.dfmx

Analysis Name: 36 LOCKING CAP
Part name: 36 LOCKING CAP
Part number:

Material name: Low carbon steel, cold rolled, commercial quality
Manufacturing process: Machined/cut from stock
Manufacturing profile: 20A BDI North America

## Low carbon steel, cold rolled, commercial quality machined/cut from stock part

| Part | |
|---|---|
| Part name | 36 LOCKING CAP |
| Part number | |
| Life volume | 1500 |
| Envelope shape | Solid cylinder |
| Part length, mm | 4316.568 |
| Part width, mm | 533.400 |
| Part height, mm | 4318.000 |
| Average thickness, mm | 472.476 |
| Forming direction | Z |

## Stock process

| Part basic data | |
|---|---|
| Batch size | 187 |
| Overall plant efficiency, % | 85.00 |
| Stock material form | Round bar or rod |
| Material hardness, Bhn | 200 |
| Material cost, $/kg | 0.838 |
| Material scrap value, $/kg | 0.110 |
| Cutoff method | Horizontal bandsaw |

| Part geometry | |
|---|---|
| Volume, cm³ | 6914284.993 |
| Weight, kg | 54162.048 |

## Workpiece

| | |
|---|---|
| **Bar dimensions** | |
| Bar stock length, m | 3.048 |
| **Workpiece geometry** | |
| Length, mm | 4318.000 |
| Diameter, mm | 533.400 |

## Horizontal bandsaw cutoff

| | |
|---|---|
| **Basic process data** | |
| Process rate, $/hr | 15.00 |
| Setup rate, $/hr | 15.00 |
| Setup time, hr | 0.25 |
| **Bar loading data** | |
| Bar loading time, s | 33.00 |
| **Bandsaw cutting data** | |
| Cutting rate, cm²/min | 74.439 |
| Kerf, mm | 1.067 |
| **Operation time** | |
| Process time per part, s | ∞ |

## Cincinnati Falcon TC-300/1000 turning center

| | |
|---|---|
| **Basic data** | |
| Batch size | 187 |
| Material hardness, Bhn | 200 |
| Rejects, % | 0.50 |
| **Machine tool data** | |
| Number of machines per operator | 2.00 |
| Parts processed simultaneously | 1 |
| Machine rate, $/hr | 20.40 |
| Operator rate, $/hr | 25.00 |

| | |
|---|---|
| Process rate, $/hr | 32.90 |
| Power available, kW | 20.88 |
| Tool positioning or index time, s | 1.00 |
| Tool change time, s | 7.00 |
| Maximum spindle speed, rpm | 3300.00 |
| Maximum depth of cut, mm | 5.080 |
| **Live tool data** | |
| Live tool power, kW | 2.61 |
| Live tool spindle speed, rpm | 3000.00 |
| Live tool depth of cut, mm | 5.080 |
| **Result** | |
| Cycle time per part, s | 58041.70 |
| Total setup time, hr | 1.19 |

## Setup/load/unload

| | |
|---|---|
| **Work handling** | |
| Workholding device | Face plate (3 clamps) |
| Number of reversals | 0 |
| Load/unload time, s | 239.40 |
| **Machine setup** | |
| Machine rate during setup, $/hr | 16.90 |
| Setup operator rate, $/hr | 30.00 |
| Setup rate, $/hr | 46.90 |
| Basic setup time, hr | 0.39 |
| Setup time per tool, hr | 0.20 |
| **Other costs** | |
| Tool, fixture or program cost, $ | 0 |

## Drill single hole

| | |
|---|---|
| Tool material | High-speed steel |

| | |
|---|---|
| Include tool replacement cost? | Yes |
| Diameter of drilled hole (dh), mm | 26.000 |
| Length of drilled hole (lh), mm | 21.000 |
| **Machining data** | |
| Cutting speed, m/min | 30.326 |
| Feed per revolution, mm | 0.464 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 5.41 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 371 |
| **Results** | |
| Operation time, s | 18.0000 |
| Total volume removed, cm³ | 11.150 |

| **Rough face** | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 180.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Total depth to be removed (wm), mm | 2.000 |
| **Machining data** | |
| Cutting speed, m/min | 200.043 |
| Feed per revolution, mm | 0.258 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 2.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |

| | |
|---|---|
| Maximum power required, kW | 6.57 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 44.0000 |
| Total volume removed, cm³ | 50.894 |

| **Finish face** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 180.000 |
| Inner diameter of faced surface (d2), mm | 0.000 |
| Surface roughness | 63 µin. 1.6 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.061 |
| Feed per revolution, mm | 0.096 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 55.0000 |

| **Rough cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 180.000 |
| Diameter of machined surface (dm), mm | 173.000 |

| | |
|---|---|
| Length of machined surface (lm), mm | 21.000 |
| **Machining data** | |
| Cutting speed, m/min | 167.335 |
| Feed per revolution, mm | 0.341 |
| Number of passes | 1.000 |
| Depth of cut per pass, mm | 3.500 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 12.72 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 302 |
| **Results** | |
| Operation time, s | 19.0000 |
| Total volume removed, cm³ | 40.755 |

| **Rough cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 173.000 |
| Diameter of machined surface (dm), mm | 153.000 |
| Length of machined surface (lm), mm | 6.000 |
| **Machining data** | |
| Cutting speed, m/min | 149.352 |
| Feed per revolution, mm | 0.407 |
| Number of passes | 2.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |

| | |
|---|---|
| Power available, kW | 20.88 |
| Maximum power required, kW | 19.38 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 301 |
| **Results** | |
| Operation time, s | 19.0000 |
| Total volume removed, cm³ | 30.725 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 170.000 |
| Length of machined surface (lm), mm | 6.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 637 |
| **Results** | |
| Operation time, s | 15.0000 |

| **Finish cylindrical turn** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 150.000 |

| | |
|---|---|
| Length of machined surface (lm), mm | 15.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 722 |
| **Results** | |
| Operation time, s | 25.0000 |

| **Cutoff** | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter (d1), mm | 170.000 |
| Inner diameter (d2), mm | 26.000 |
| **Machining data** | |
| Cutoff tool width, mm | 9.000 |
| Cutting speed, m/min | 152.400 |
| Feed per revolution, mm | 0.122 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 10.62 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 1866 |
| **Results** | |
| Operation time, s | 86.0000 |
| Total volume removed, $cm^3$ | 199.505 |

| Load bar | |
|---|---|
| Length of bar, m | 3.048 |
| Operation time per part, s | 57416.3000 |

| Rough cylindrical turn | |
|---|---|
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of work surface (dw), mm | 173.000 |
| Diameter of machined surface (dm), mm | 153.000 |
| Length of machined surface (lm), mm | 11.180 |
| **Machining data** | |
| Cutting speed, m/min | 149.352 |
| Feed per revolution, mm | 0.407 |
| Number of passes | 2.000 |
| Depth of cut per pass, mm | 5.000 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Power available, kW | 20.88 |
| Maximum power required, kW | 19.38 |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 301 |
| **Results** | |
| Operation time, s | 32.0000 |
| Total volume removed, $cm^3$ | 57.251 |

| Finish cylindrical turn | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Diameter of machined surface (dm), mm | 170.000 |

| | |
|---|---|
| Length of machined surface (lm), mm | 11.180 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.157 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 637 |
| **Results** | |
| Operation time, s | 22.0000 |

| **Finish face** | |
|---|---|
| Tool change needed? | No |
| Tool material | Indexable carbide |
| Include tool replacement cost? | Yes |
| Outer diameter of faced surface (d1), mm | 150.000 |
| Inner diameter of faced surface (d2), mm | 26.000 |
| Surface roughness | 32 µin. 0.8 µm |
| **Machining data** | |
| Cutting speed, m/min | 340.061 |
| Feed per revolution, mm | 0.068 |
| Special tooling cost, $ | 0.000 |
| **Machine limitations** | |
| Spindle speed available, rpm | 3300 |
| Maximum spindle speed required, rpm | 3300 |
| **Results** | |
| Operation time, s | 51.0000 |