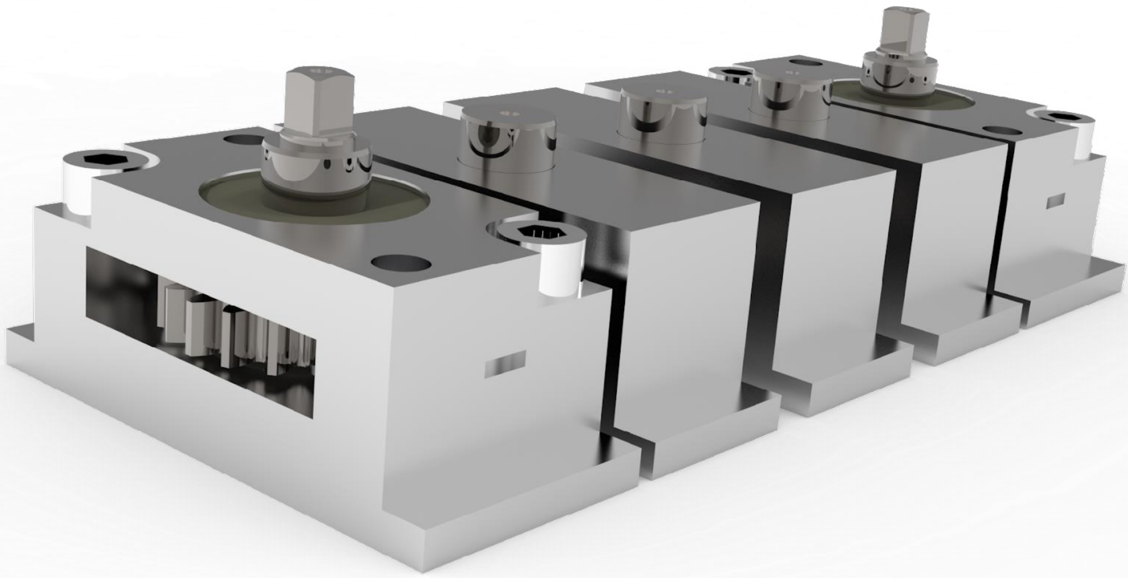
CHALMERS
UNIVERSITY OF TECHNOLOGY



Mechanical Design of Gear Train Efficiency Test Rig

Efficiency Evaluation of Geared Front Attachments in Industrial Tightening Tools

Degree Project in Mechanical Engineering

MIRANDA SHIN

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
www.chalmers.se

Preface

I am a mechanical engineering student at Chalmers University of Technology, currently undertaking my degree project at Atlas Copco within the Driveline Mechatronics department. During this project I have learned and gained better understanding of the theoretical aspects in mechanical design and construction. I have also had the opportunity to participate in a real-life product development process, acquiring valuable insights into its operations. For this I am truly thankful to the Driveline team and Atlas Copco for providing me with this opportunity to learn and gain valuable work experience. I am especially grateful to my manager, Tobias Syvertsson, an inspirational leader who believed in me.

Miranda Shin

2024-01-17

Abstract

Atlas Copco desires a test rig where they can perform gear accuracy and efficiency tests with the aim of potentially enhancing the performance of their Geared Front Attachment (GFA) tool tightening solutions. The GFA extension consist of several gears positioned on a row making it possible to perform tightening's in difficult positions. This project involves the mechanical design and assembly of a gear test rig that the company can leverage for future GFA development assessments. The degree project includes Computer Aided Design (CAD) design drawings of the rig and explanation of component selection necessary to assemble and operate the gear train test rig. The development process of the gear train test rig will be documented and discussed with regards to functionality, tolerance and fit, manufacturing, assembly, and maintenance. The project is divided into three phases, the design and construction phase, the assembly phase, and the test phase.

The final design of the gear train test rig consists of several gear modules, allowing flexibility in adjusting the number of gear steps based on the operator's testing requirements. Each gear module is clamped onto a T-slot aluminum plate. The input and output modules are placed in the beginning and at the end of the test rig gear train. The input module is connected to the power source and the output module is connected to the system pneumatic brake. The gear steps can easily be set and rearranged by changing the number of middle modules incorporated to the gear train test rig.

To validate the functionality of the assembled test rig, grease test cases have been conducted. Research indicates that power losses occur during gear meshing because of friction between interlocking gear teeth, which in this case will impact the gear test rig efficiency. Studies show that lubrication applied to gears can improve tool performance significantly (Westbroek, Leckner & Olsson, 2023). Test cases were conducted both with no applied grease on gears and with two different greases applied to the gears. These test cases validate the test rig's performance and the effects of different lubrication conditions. The conclusive test results reveal that the comparison between the two different greases did not show any significant difference, although applying grease to the gears enhances the test rig efficiency by nearly 19 %. The conclusive assessment of the constructed test rig's performance reveals that the rig will operate with a 95 % efficiency during two-gear-step test cases.

Sammanfattning

Atlas Copco är i behov av en testrigg som kan användas för noggrannhetstester och verkningsgradstudier som en forskningsbaserad grund för eventuellt framtida förbättringsbeslut för företagets Geared Front Attachment (GFA) lösningar. GFA-verktygen är en separat förlängningslösning som monteras på Atlas Copcos åtdragningsverktyg och möjliggör åtdragningar i svåra positioner. GFA lösningarna varierar i storlek och består av ett varierande antal kugghjul placerade i serie. Testriggen ska illustrera ett GFA arrangemang där det ska gå att flytta och undersöka huruvida kugghjulspositioner och antalet kugghjulssteg påverkar verktygets prestanda. Examensarbetet innefattar utvecklingen av en kugghjulstestrigg. I detta projektarbete ingår design, konstruktion, montering och sammanställning av testriggen samt testning av den färdiga kugghjulsriggen för att verifiera att testriggen är operativbar. Projektet är uppdelat i tre faser, design och konstruktionsfasen, monteringsfasen och testfasen.

Den färdiga testriggen består av separata kugghjulsmoduler, vilket möjliggör flexibilitet att kunna justera antalet kugghjul baserat på det testfall som ska utföras och undersökas. Varje kugghjulsmodul kläms fast på en T-spår aluminiumplatta. Ingångs- och utgångsmodulerna placeras i början och i slutet av ”kugghjulståget” och mittenmodulerna bestämmer antalet kugghjulssteg i testriggssystemet. Ingångsmodulen är ansluten till motorn som genererar systemets rotation och utgångsmodulen är ansluten till systemets pneumatiska broms. Antalet kugghjulsteg kan enkelt varieras genom att ändra antalet mittenmoduler.

Smörjtester utfördes för att validera funktionaliteten av kugghjulstestriggen. Undersökningar och teori visar att förluster uppstår bland annat på grund av friktion mellan kuggarna i ingrepp, vilket i detta fall kommer att påverka verkningsgraden. Tidigare studier (Westbroek, Leckner & Olsson, 2023) visar att smörjning applicerad på kugghjul kan förbättra verktygets prestanda avsevärt. Testfall utfördes både utan applicerat smörjmedel på kugghjulen och med två olika smörjmedel applicerade på kugghjulen. Dessa testfall validerar testanläggningens funktionalitet och resultaten av olika smörjmedel. De slutgiltiga testresultaten avslöjar att jämförelsen mellan de två olika smörjmedlen inte har en signifikant skillnad, även om applicering av smörjmedel på kugghjulen förbättrar testriggens verkningsgrad med nästan 19 %. Sammanfattningsvis, då kugghjulstestriggen har två kugghjulssteg erhålls en verkningsgrad på cirka 95 %.

Table of Contents

1. Introduction to the Project

Tightening tools are commonly used in production industries such as the motor vehicle industry and various assembly systems around the globe. The Geared Front Attachment (GFA) solution is a separate component that can be attached to Atlas Copco's tightening tools. The GFA product consists of a variety of gears that are placed on a straight line inside of the GFA housing. The purpose of the GFA solution is to give the tool an extension and enable the tightening to be conducted in difficult positions. With each gear step in the GFA there will be efficiency losses. More gear steps should theoretically result in more efficiency losses and a less accurate tightening. Some of the efficiency losses are due to friction losses between the gears.

Atlas Copco aims to conduct efficiency tests to enhance the performance of the GFA solutions in their future tools. The gear train test rig enables the acquisition and evaluation of test data related to gear efficiency performance.

The degree project consists of three phases. The first phase contains the design and construction process of the gear module, which will constitute the gear train structure that symbolises the GFA gear arrangement. All module parts are designed in Creo Parametric 3D Modeling Software. Other components of the gear modules are ordered from suppliers such as bearings, dowel pins and screws. The second phase involves the assembly process of the gear train test rig. This phase involves laboratory work and the procurement of key components essential for the operation of the gear train test rig. Some key components that are needed to operate the rig is the pressure regulator for the pneumatic brake and an external motor providing rotation to the gear system. The third and last phase consists of testing and evaluating efficiency performances. This phase could last overdue time and must therefore be limited to a reasonable number of test cases so that a result can be conducted within the given time frame of this project. Two different lubricating greases will be tested and compared to evaluate potential efficiency differences.

1.2. Background About the Company and the GFA Tool

Atlas Copco is a Swedish B2B company that, among other things, develops assembly systems and industrial tools for production, especially the automotive industry. Atlas Copco’s tools and solutions are used in automotive manufacturing companies all around the world. According to Atlas Copco's marketing presentation (Atlas Copco, 2020) it is stated that every third car is assembled with Atlas Copco's solutions and products.

Figure 1: GFA attached to an Atlas Copco tightening tool. (Atlas Copco, n.d.1)

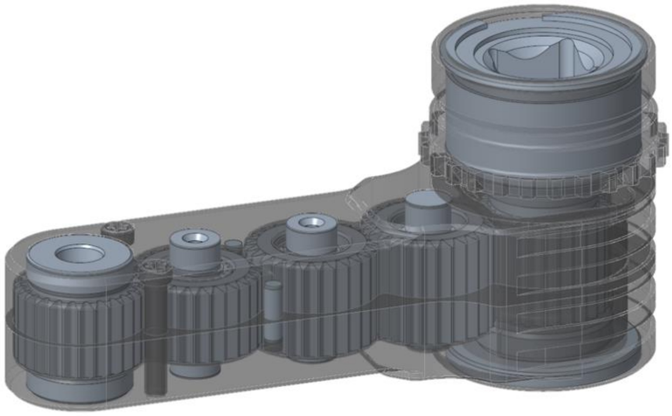


Figure 2: Rendering of a GFA extension. (Atlas Copco, n.d.2)

The GFA is an extension attached to the end of the tool and is used when tightening bolts in difficult positions and angles. The GFA extension is modular and can be mounted on all Atlas Copco electric power tools, see Figure 1. The GFA design consists of several gears that are placed in a row which gives the favourable extended qualities of the tightening tool, see Figure 2.

1.3. Purpose and Delimitations

Atlas Copco desires a test rig where they can conduct efficiency tests with the goal to improve the GFA performance in their future tools. An efficiency test rig that illustrates the GFA gear structure has not previously been made. This implies that the degree project requires design, construction, assembly, and final delivery of an operational test rig for the company. There is a study made by (Westbroek, Leckner & Olsson, 2023) showing that different greases can entail distinct improvements in both performance, efficiency, and life expectancy. The test rig should have an adaptable design with the possibility to perform various types of test cases depending on field of interest. Due to the degree project time limitation, this project will solely focus on conducting test cases regarding comparing different greases. Other test cases will be conducted by the company and will therefore not be included in this report.

2. Theoretical Foundation

To enhance the project's outcome result, it is beneficial to have a basic theoretical understanding of efficiency losses and gear theory. Several pertinent formulas that are mentioned will be implemented in the subsequent experimental phase of the gear train test rig. All mathematical formulas presented are derived from a Chalmers course literature written by (Mägi, Melkersson & Evertsson, 2017).

2.1. Gear Theory

To enhance comprehension before constructing and designing the gear train test rig, it is beneficial to familiarize oneself with fundamental principles of gear theory. Gears are used in mechanical systems to transmit motion and power. There are a wide range of applications for gear systems and a lot of different gear types. During gear meshing it is desirable to have a rolling motion between the gears. But friction occurs because of the unavoidable sliding which will generate more efficiency losses in the gear system according to (Mägi, Melkersson & Evertsson, 2017).

The gear type that will be used in this project is an external cylindrical gear with straight teeth, see Figure 3. In other words, the gear will transmit motion on the outside of the cylindrical wheel. Another commonly used gear type are gears with angle teeth. The angled configuration of the teeth generates less noise and vibration compared to the straight gear geometry.

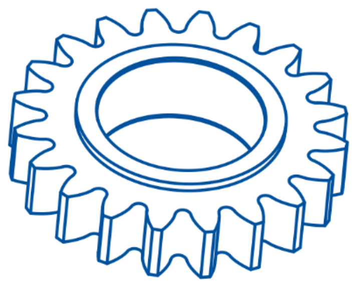


Figure 3: Cylindrical gear with straight teeth.

According to (Mägi, Melkersson & Evertsson, 2017) there are some important issues that needs to be considered when constructing and operating the gears. The fist important factor is the geometry of the gears such as kinematics, manufacturing, and control measurement. The kinematics is important regarding the condition for proper motion transmission between the gears. The precision of control measurements underscores the importance of accurately incorporating fits and tolerances in gear design.

Other important factors are the durability which can be defined with contact stress and gear root stress calculations. Also, choice of material and calculating bearing reactions are important factors to consider when analyzing and designing gear structures.

When operating the rig, it is also important to consider the choice of lubrication applied to the gears. When operating the rig, it is proven that the selection of suitable lubricating grease can significantly increase gear life expectancy according to the case study made by (Westbroek, Leckner & Olsson, 2023). The study also claims that power losses in gears, for the most part, originates from friction during gear meshing, lubricant churning, and gear windage.

The relationship between angular velocities of two gears are defined by the gear ratio. This measure is crucial and important when determining the torque of the system.

$$i = \frac{\omega_{in}}{\omega_{out}} = Gear\ ratio = \frac{Number\ of\ output\ gear\ teeth}{Number\ of\ input\ gear\ teeth} = \frac{z_{out}}{z_{in}} \quad (1.0)$$

This equation applies precisely, meaning that no speed losses arise in a gear transmission.

2.2. Efficiency Losses

When excluding transmission losses, the theoretical transmission power is given by torque T and angular velocity ω according to formula (1.1).

$$P = T \cdot \omega \tag{1.1}$$

Furthermore, this demonstrates a mathematical expression for the efficiency if there are no losses in the transmission system.

$$T_{in} \cdot \omega_{in} = T_{out} \cdot \omega_{out} \qquad \Rightarrow \qquad \frac{T_{in}}{T_{out}} = \frac{\omega_{out}}{\omega_{in}} = \frac{1}{i} \tag{1.2}$$

According to (Mägi, Melkersson & Evertsson, 2017) there will always occur torque efficiency losses in a gear transmission due to friction. For example, there are efficiency losses due to bearing friction and gear meshing. This entails that there will be less power coming out from the GFA compared to the actual input power from the tightening tool motor, see Figure 4.

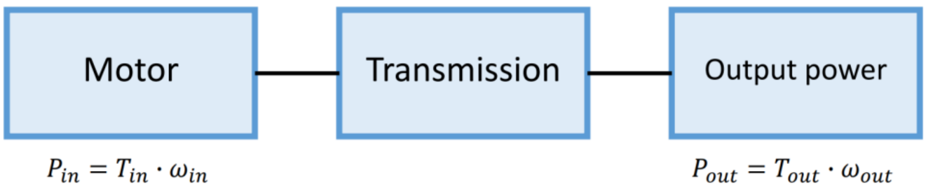


Figure 4: Theoretical illustration of the mechanical transmission in the GFA.

In conclusion, the total efficiency with regards to losses can therefore be calculated according to the following formula.

$$\eta = \frac{P_{out}}{P_{in}} = \frac{T_{out}}{T_{in}} \cdot \frac{\omega_{out}}{\omega_{in}} = \frac{T_{out}}{T_{in}} \cdot \frac{1}{i} \tag{1.3}$$

When $i = 1$, the angular velocity will stay the same in the gears. Equation 1.3 implies that we only need to measure the torque in and torque out to calculate the final efficiency performance. When the test rig is operational, it will be possible to determine the efficiency experimentally by logging the input and output data from the transducers connected to the system. The transducers will log measured input torque, input angle, output torque, and output angle. Equation 1.3 will therefore be implemented later during the test phase when conducting the gear train test rig efficiency calculation. In this case we have the same number of teeth which means that the gear ratio change $i = 1$.

2.3. Gear Meshing Losses

During the gear meshing process efficiency losses will occur. Gear meshing is when the gear teeth of two gears are interlocking with each other, transferring movement between the two gears. During this process the teeth engagement will generate a sliding speed Δv which causes the friction loss.

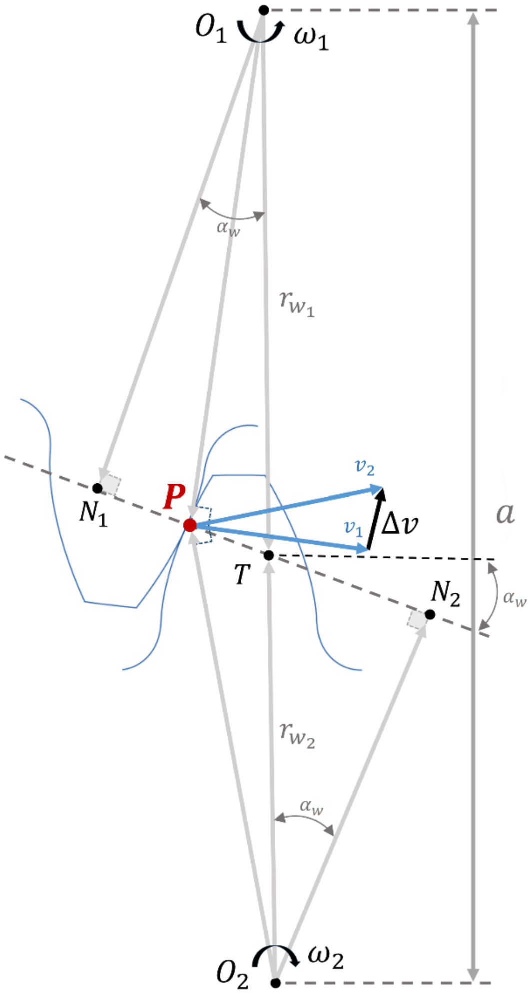


Figure 5: Illustration of a gear teeth mesh.

Figure 5 illustrates the gear meshing process. The upper gear with centre point O_1 rotates with the angle velocity ω_1. The second gear derives its motion from the first gear and rotates around O_2 with the angle velocity ω_2. The contact point P show where the two gears are meshing. The dotted line marked with the points N_1 and N_2 represent the contact normal and also the path of contact between the gears. The contact normal is the direction of the force from the gear and α_w is the angle of the contact normal. The rolling point T is the intersection where the contact normal and the radius r_{w_1} and r_{w_2} meet. When assembling the gear train test rig, the minimal centre distance between the gears $a_w = r_{w_1} + r_{w_2} = 51{,}000$ mm is determined.

3. Method and Test Rig Development

The degree project consists of three main phases. The first phase involved design and construction of test rig, followed by the second phase which included the assembly of the gear train test rig. In the third phase testing and analyses were conducted, confirming that the gear train test rig is operational for future use. Below is a brief description of the overall content and questions which will be answered and further described in detail in respective heading phase.

1. **Design and Construction**
   The design and construction phase involved the early stage of the test rig development. What is the purpose of the gear train test rig? How should it be constructed? What components needs to be ordered from suppliers and what parts needs to be designed in CAD? What dimensions should be given in the gear design to accurately obtain correct fits and tolerances when manufacturing and assembling the rig?

2. **Assembly of the Gear Train Test Rig**
   The assembly phase involved the integration of all gear modules and essential external components necessary for making the test rig operational for testing. What components needs to be integrated in the system? What risks can occur when operating the test rig and how can incidents be avoided?

3. **Testing and Analysis of the Gear Train Test Rig Performance**
   The test phase implied as a verification that the test rig was functional and will serve its purpose for the company to conduct future GFA efficiency test cases. To verify the test rig accuracy during this project, simplified test cases have been conducted regarding efficiency testing with grease. What is the test rig efficiency result?

3.1. Design and Construction of the Test Rig

As mentioned in the introduction, the project purpose is to design a gear train test rig which enables the company to conduct efficiency testing to further analyse of the GFA gear configuration. The GFA consist of several gear steps that are placed in a row, see Figure 2 on page 6. The power flow will transmit from an input gear to an output gear, creating the mechanical transmission occurring in the GFA gear arrangement, see Figure 6.

Figure 6: Simplified illustration of the power flow throughout the GFA.

3.1.1. Choice of Gear

The gear that was chosen is an external cylindrical gear with straight teeth. The main beneficial properties are the simplicity of construction and therefore lower manufacturing cost compared to a angle teeth gears. Another advantage is that straight gears are easier to align during the assembling phase. Figure 7 show the gear data profile of the chosen gear and Figure 8 show the gear dimensions taken from the CAD drawing made in Creo Parametric 3D Modeling Software.

GEAR DATA/KUGGDATA		
Accuracy grade Klass	ISO 1328	7
Pressure angle Pressvinkel		20°
Basic rack Referensprofil		ISO 53
Module Normalmodul		2.5
Number of teeth Kuggtal		20
Profile shift coefficient Profilförskjutningsfaktor		0.2141
Reference diameter Delningsdiameter		Ø50
Chordal tooth thickness Base tangent length over 3 teeth Kordakuggtjocklek kuggvidd över 3 kuggar		19.517 -0.031 -0.052
Exeptions from standard 1328.Tooth-to-tooth radial composite dev. (fi): Module >0.5 use class 10, othervise fi<=0.015		
Cutter tip radius factor, rho_aP0 Verktygets toppradiefaktor		0.2-0.4
Rolling or splines function Rullande- eller splinesfunktion		Rolling
Reference for measurement Referens för mätning		A

Figure 7: Gear data from Creo drawing.

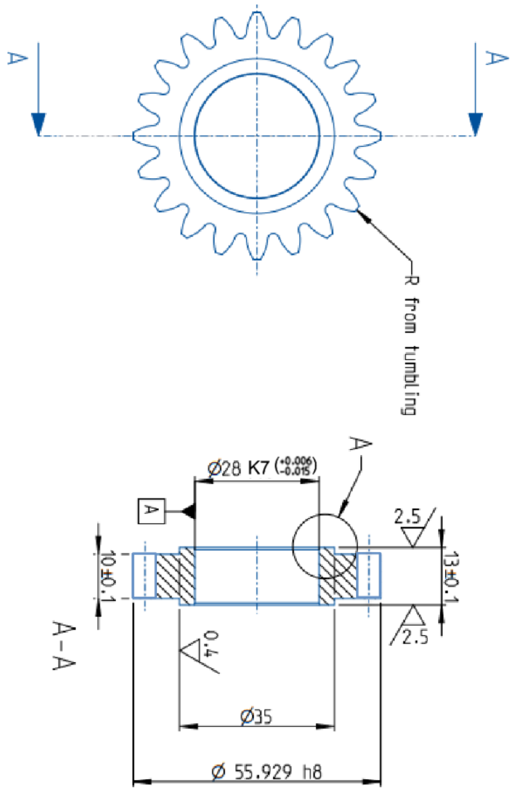
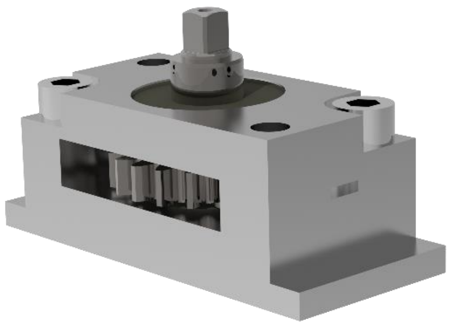


Figure 8: Gear dimensions from Creo drawing.

3.1.2. The Modules

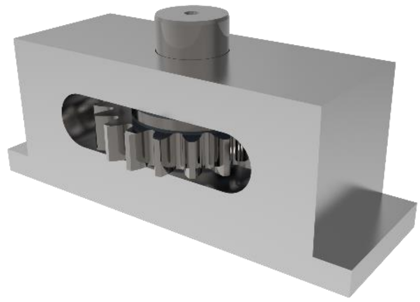
To enable a versatile gear train construction which is adaptable for various test cases, it is concluded that the best approach was to build separate modules for each gear step. A module consists of a gear, shaft, bearings, and housing. Two types of modules were designed and constructed, the **input/output module** and the **middle module**.

Input/output module



To achieve less efficiency loss, the input/output module have a gear shaft implemented in the design. This indicates that two bearings need to be mounted on each side of the gear. Due to the gear shaft geometry the input/output module required an over housing part and a separate under housing part. The assembly of the input/output module would be impossible without the incorporation of the over housing and under housing parts. Having two housing parts entailed that the construction needed dowel pins to minimize less accurate centring while assembling the construction. When implementing power to the input module, rotation will be given to the gear shaft which will transmit the motion to the first middle module, and so on, until the output module.

Middle module



The middle module has a different design compared to the input/output module. The middle module consists of a separate gear and shaft part. The gear will rotate around the axis of the shaft. Rotation with less losses will be possible with a needle bearing attached between the shaft and gear. Another difference is the dimension of the housing geometry. The middle housing has a slimmer profile, which makes it more convenient to fit the gear meshing teeth according to the $a_w = r_{w_1} + r_{w_2}$ distance described under the gear meshing theory heading, see Figure 5, showing an illustration of a gear teeth mesh. Four quantities of the middle housing modules were ordered and manufactured, making it possible to conduct up to five gear step efficiency tests.

3.1.3. Gear Input/ Output Module

The input/ output module is the first and last gear in the test rig construction. The shaft top is designed to fit Atlas Copco's IRTT-B transducers (Atlas Copco, 2023) which will log the input torque and angle, and the output torque and angle with high accuracy. Figure 9 and Figure 10 illustrates the constituent elements of the module and a BOM list providing detailed item specification for manufacturing and assembly.

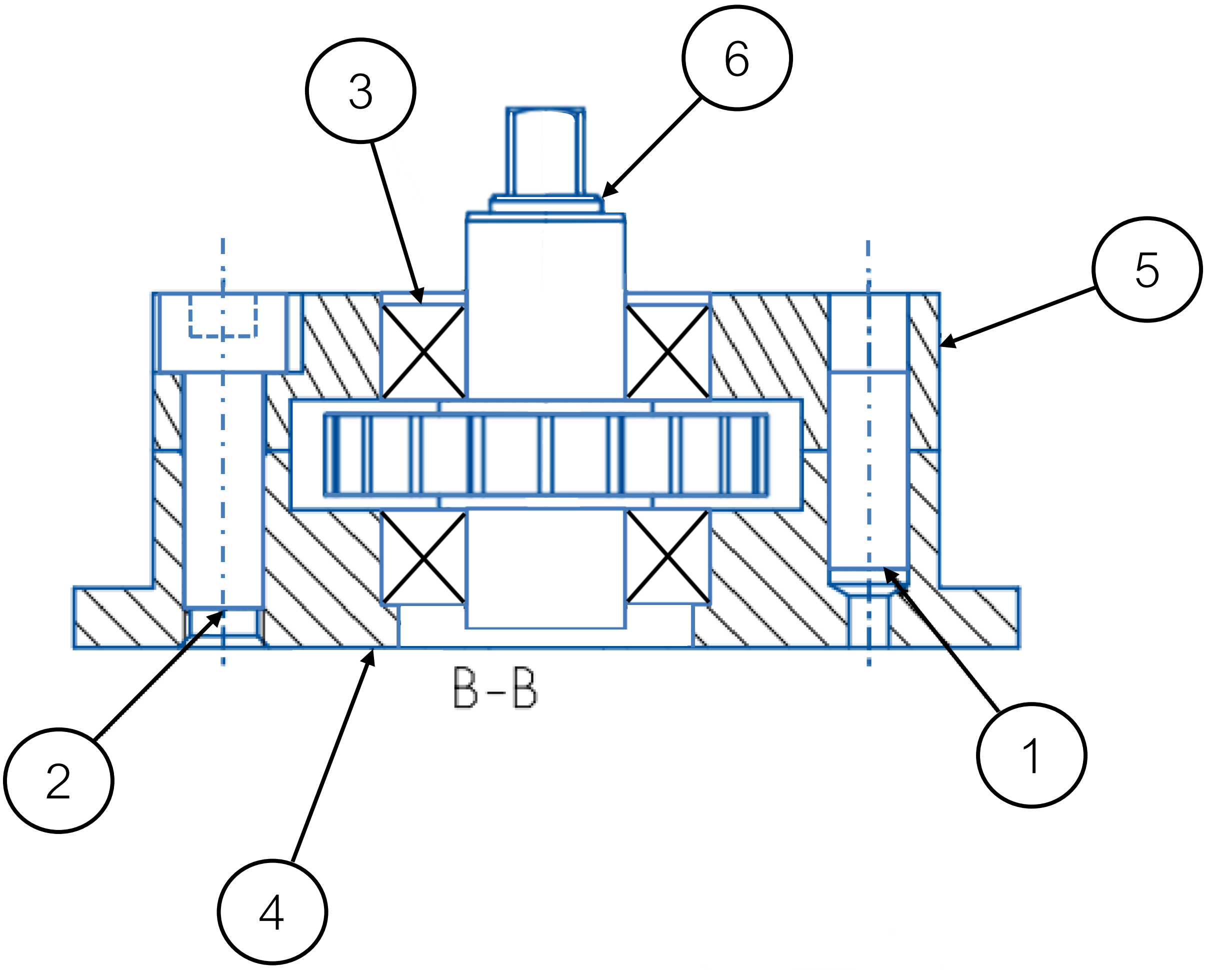


Figure 9: Assembly of input/ output module, see complete drawing A6 in Appendix.

Pos	Designation	Number	Name	Comment
6	4221 0012 88	1	GEAR SHAFT	Material: 0011 2541 03
5	4221 0012 80	1	HOUSING OVER	Alca-5 EN AW-5754 Cast Milled
4	4221 0012 60	1	HOUSING UNDER	Alca-5 EN AW-5754 Cast Milled
3	0502 1091 10	2	BALL BEARING	SKF
2	0211 1957 71	2	HEX SOCK SCREW	MC6S M10x30 H 10.9
1	0101 2407 00	2	PARALLEL PIN	CP 10x25 m6

Figure 10: Assembly BOM list, see complete drawing A6 in Appendix.

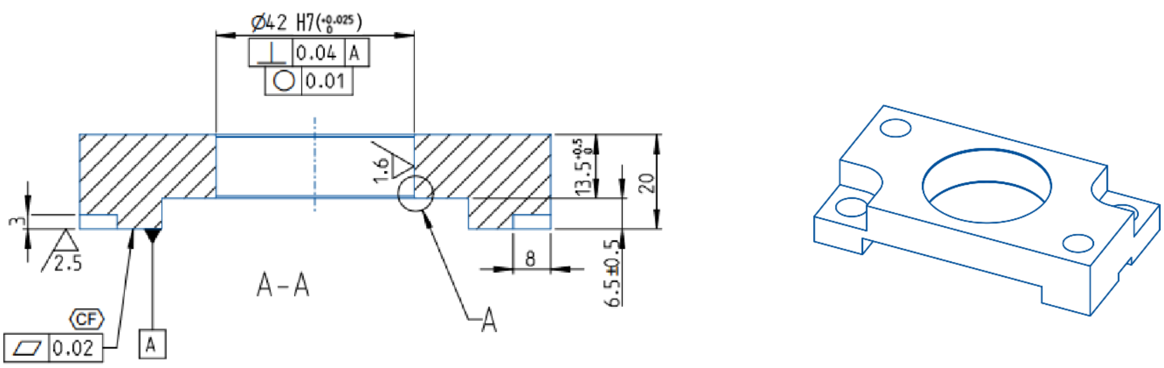


Figure 11: Over housing part, see complete drawing A2 in Appendix.

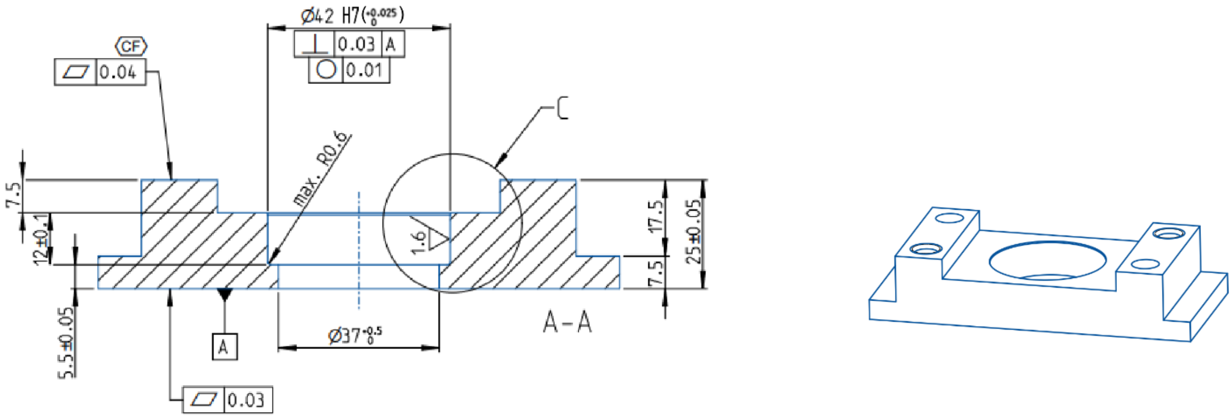


Figure 12: Under housing part, see complete drawing A1 in Appendix.

To ensure proper shaft alignment during assembly, the manufacturing processing of the over and under parts had to be processed in correct order. The processing of the dowel pin hole Ø10H7 and the bearing hole Ø42H7 was conducted after the two parts were screwed together. Assigning H-tolerances in the drawings is preferable, as H-tolerance reamers are widely available in many workshops, contributing to a smoother and more efficient manufacturing process. Because the parts were co-processed, this gives a more precise centring of the gear shaft during assembly. It is desirable that the shaft is positioned perpendicular with regards to the $\boxed{A}$ reference surface. This will generate more accurate efficiency results during the test phase. The symbol ⟨CF⟩, which stands for Continuous Feature, was assigned to the contact surface between the two housing parts to ensure that specified flatness tolerance is applied continuously along the surface (Richter, 2022). The input/output module has SKF single row deep groove ball bearings, 6004-2Z, which is mounted on each side of the gear shaft and positioned in the housing. The tolerance of the bearing hole was specified based on SKF's recommended tolerances as outlined in the SKF catalogue (SKF, 2018). The housing material is made out of aluminium, Alca-5 Cast Milled (Alumeco, n.d.), due to processing properties, material properties and reasonable price.

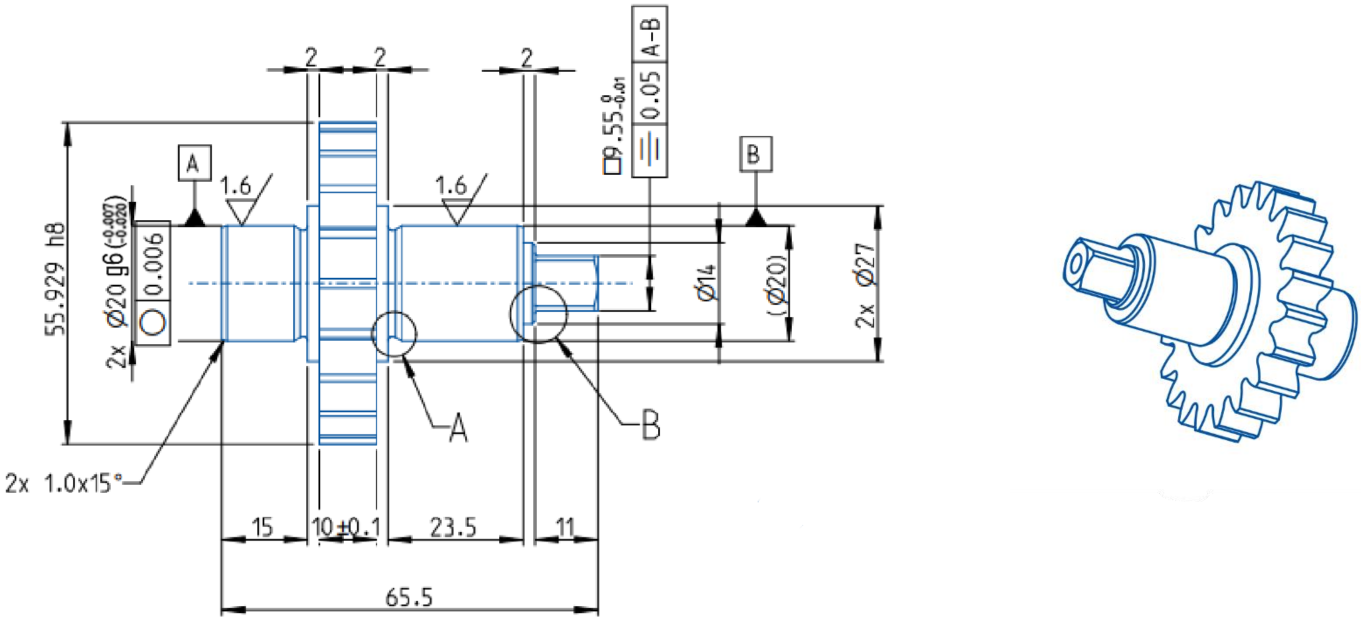


Figure 13: Gear shaft part, see complete drawing A7 in Appendix.

Atlas Copco uses specific material article numbers for referencing purposes in their manufacturing processes, see drawing A7 in Appendix. The gear shaft material is made in steel due to its high tensile strength and high endurance. As earlier mentioned, the gear shaft adapter is designed to fit the reference IRTT-B transducers (Atlas Copco, 2023) which measures the input and output angle and torque. Unlike the middle module, the input/output module integrates a combined gear and shaft as a single unit.

Two SKF 6004-2Z ball bearings were mounted on each side of the gear shaft, which was placed in the housing part respectively. The 6004-2Z ball bearing has a simple, versatile, and robust design with low friction, low noise, and low vibration (SKF, 2023). The shaft tolerance is Ø20g6 and the fit between the shaft and bearing is a clearance fit, which entails space between the bearing inner ring hole and the shaft. Having a clearance fit with space between the bearing and the shaft facilitates the assembly of the input/output module without requiring special mounting equipment. It is beneficial with a clearance fit for easy maintenance, although an interference fit would entail better precision and accuracy. In this case it was decided to implement an easy construction and easy assembly

3.1.4. Gear Middle Module

The middle module refers to the module or modules situated between the input and output modules. The number of middle modules incorporated into the gear test rig will determine the gear steps, mirroring the construction of the GFA gear. The shaft is fixed, and the rotation of the gear is facilitated by a needle bearing positioned between the gear and the shaft. See Figure 14 and Figure 15 which show the constituent elements of the module and a BOM list providing detailed item specification for manufacturing and assembly.

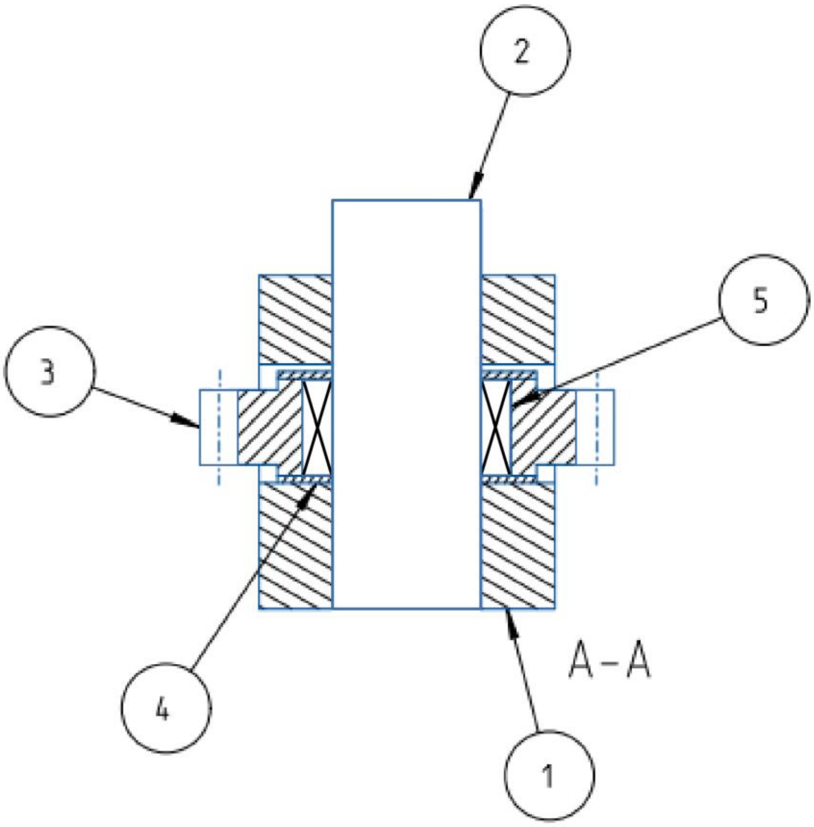


Figure 14: Assembly of the middle module, see complete drawing A8 in Appendix.

Pos	Designation	Number	Name	Comment
5	RNA4902-XL	1	NEEDLE BEARING	Schaeffler: Fw=20, D=28, B=13
4	AS2035	2	WASHER	Schaeffler: d=20, D=35, B=1
3	4221001284	1	GEAR	Material: 0011 2541 03
2	4221001283	1	SHAFT	Material: 0011 2258 02
1	4221001282	1	MIDDLE HOUSING	Material: Alca-5

Figure 15: BOM list, see complete drawing A8 in Appendix.

The middle module housing, see Figure 16, is made of aluminium, Alca-5 Cast Milled (Alumeco, n.d.), due to processing properties, material properties and reasonable price. The corresponding shaft can be seen in Figure 17. The fit tolerance combination is Ø20 N7/h6 resulting in the limits of 19,987 mm – 20,000 mm and the hole size limits of 19,972 mm – 19,993 mm. This configuration most likely indicates a press fit, requiring the shaft to be pressed into the housing hole during the module assembly process. During the module assembly process, the Schaeffler needle bearing (Schaeffler, 2023) was first pressed into the gear. Once the gear and bearing are assembled, they are positioned within the housing component, with washers placed on each side of the bearing to minimize wear on the aluminium housing. Subsequently, the shaft can be pressed into the middle housing part, passing through the bearing and gear.

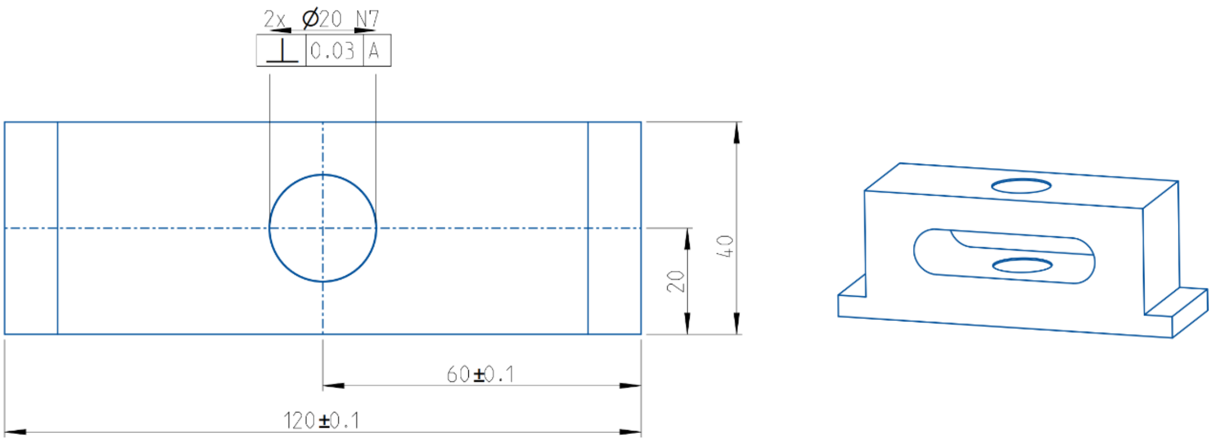


Figure 16: Housing part of the middle module, see complete drawing A3 in Appendix.

Figure 17: Shaft part to the middle module, see complete drawing A4 in Appendix.

3.2. Assembly of the Gear Train Test Rig

The gear train test rig comprises both self-designed parts created in Creo and components procured from suppliers. All self-designed parts required a detailed drawing of the construction for the manufacturing process (see all drawings in Appendix). All parts and components were compiled into a purchase list which was sent to Atlas Copco's purchasing department for approval, see Table 1. All parts for the assembly can be seen in Figure 18.

Purchase list			
Article number	**Qty**	**Product name**	**Material & Comments**
4221 0012 60	2	HOUSING UNDER	Alca-5 EN AW-5754 Cast Milled
4221 0012 80	2	HOUSING OVER	Alca-5 EN AW-5754 Cast Milled
4221 0012 82	4	MIDDLE HOUSING	Alca-5 EN AW-5754 Cast Milled
4221 0012 83	4	SHAFT	0011 2258 02 Hardened HRC 60±2
4221 0012 84	4	GEAR	0011 2541 03
4221 0012 88	2	GEAR SHAFT	0011 2541 03
4221 0012 91	1	Mått bricka för kuggtest	Stål
4221 0012 92	6	Distanskloss för kugghjul	Stål
0211 1957 71	6	HEX SOCK SCREW	MC6S M10x30 H 10.9
0101 2407 00	6	DOWEL PIN	CP 10x25 m6
0502 1091 10	4	BALL BEARING	6004-2Z, BALL BEARING/KULLAGER
RNA4902-XL	4	NEEDLE BEARING	Schaeffler: Fw=20, D=28, B=13
AS2035	10	WASHER	Schaeffler: d=20, D=35, B=1

Table 1: Purchase list that was given to Atlas Copco's purchasing department.

Figure 18: Order delivery.

3.2.1. Middle Module Assembly Process

The middle module assembly process required a press fit between the housing and shaft. The essential components needed to assemble the module is shown in Figure 19. The first step in the middle housing assembly is to fit the Schaeffler needle bearing to the gear, see Figure 20 and 21. After mounting the needle bearing onto the gear, lubrication is applied to the needles within the inner part of the needle bearing, see Figure 22. The shaft will then slide smoothly through the needle bearing when pressing the shaft through the housing, see Figure 23 and 24. Same assembly steps were applied to the remaining module components.

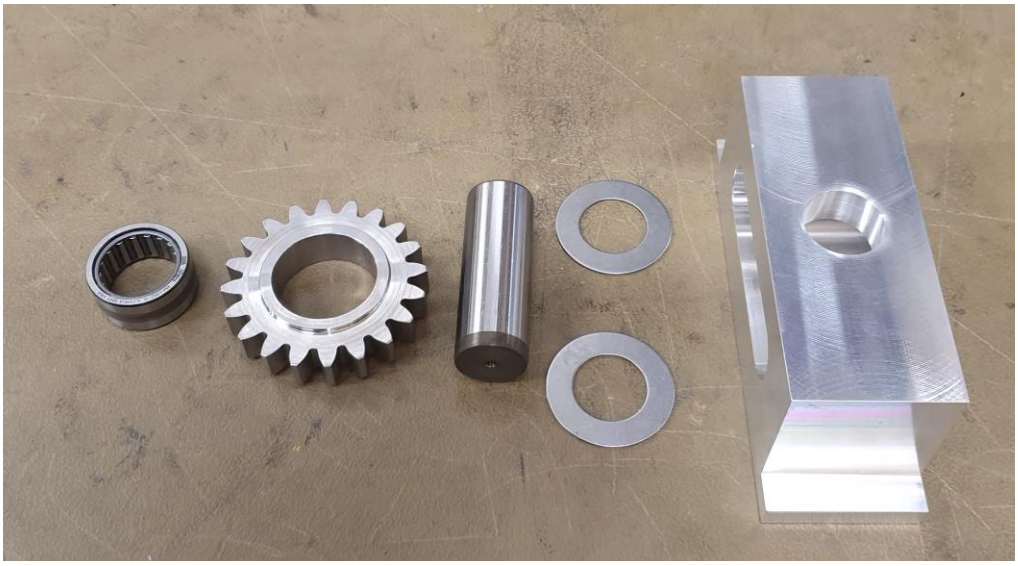


Figure 19: All components for the middle module assembly.

Figure 20: Before press fit.

Figure 21: After press fit.

Figure 22: Lubrication after press fit.

Figure 23: Before shaft press fit.

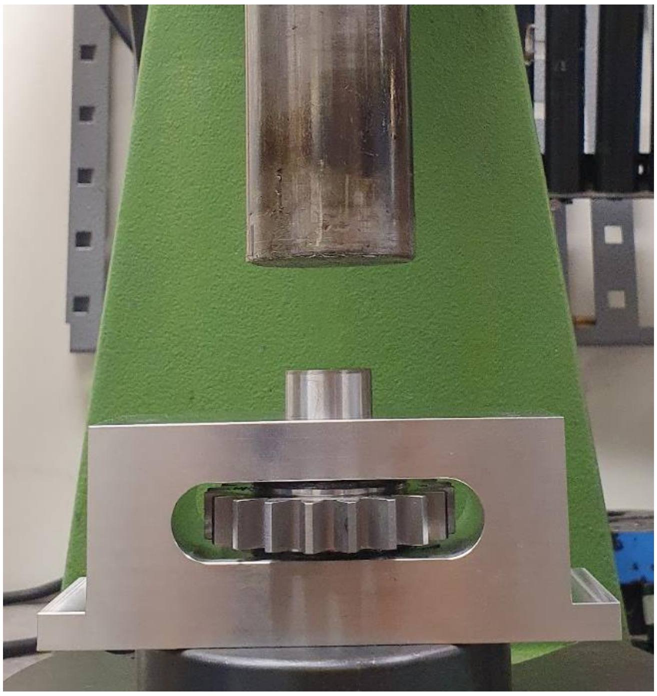


Figure 24: After shaft press fit.

3.2.2. Assembly of Subsystems Required to Operationalize the Rig

Upon completing the assembly of all modules, the subsequent phase in the gear train test rig assembly involved collecting essential parts required to operationalize the test rig. In this case, T-slot aluminum profiles proved to be an easy and efficient option for constructing the test rig. An old test rig was disassembled, and its T-slot aluminum profiles was reused as a base plate for the gear train test rig.

To conduct tests on the rig, a power source is required to transmit power to the input module. One easy way to implement power to the system is to use an Atlas Copco Fixtured Nutrunner QST tool (Atlas Copco, 2023). This tool will function as the motor, ensuring a consistent power supply, while the brake regulates torque within the gear system. A pneumatic brake was selected as the system brake, with its regulation managed by a pressure regulator controlled by the compressed air available in the workshop, see Figure 25. The reference IRTT transducers, which in this case measures torque and angle, were implemented to the system between the motor shaft and the input module and between the output module and the pneumatic brake, see Figure 26. The test rig construction enables versatile testing depending on how many gear steps the test requires.

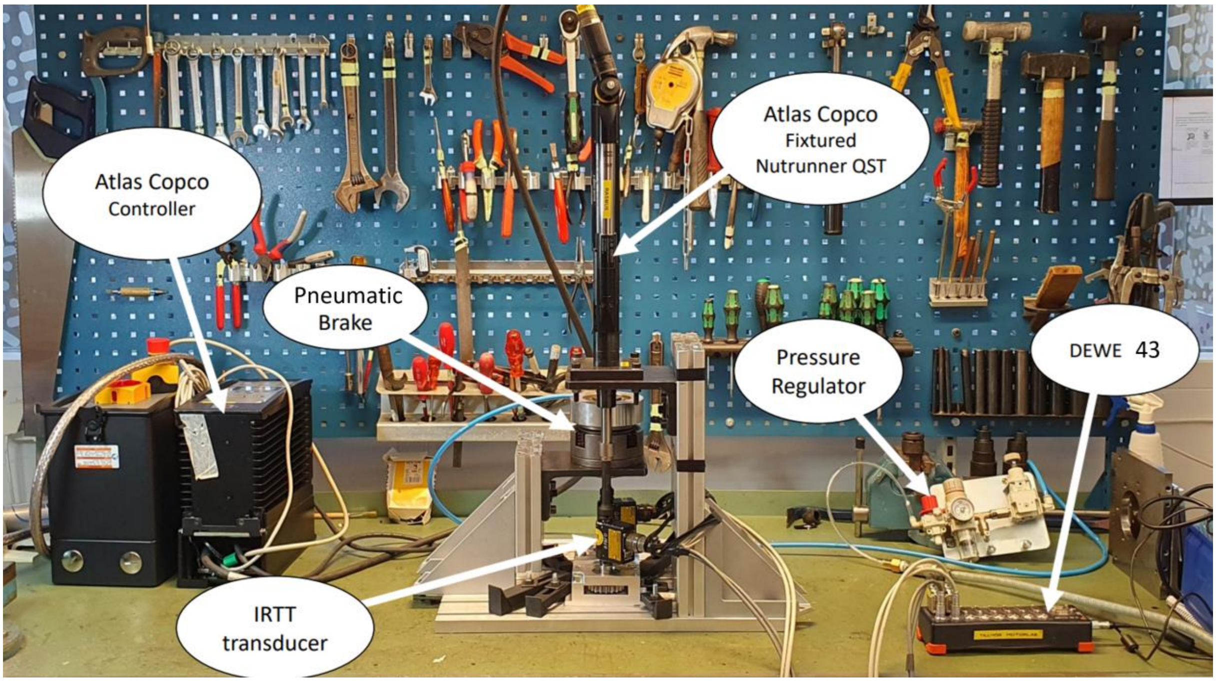


Figure 25: All subsystems required to operationalize the test rig.

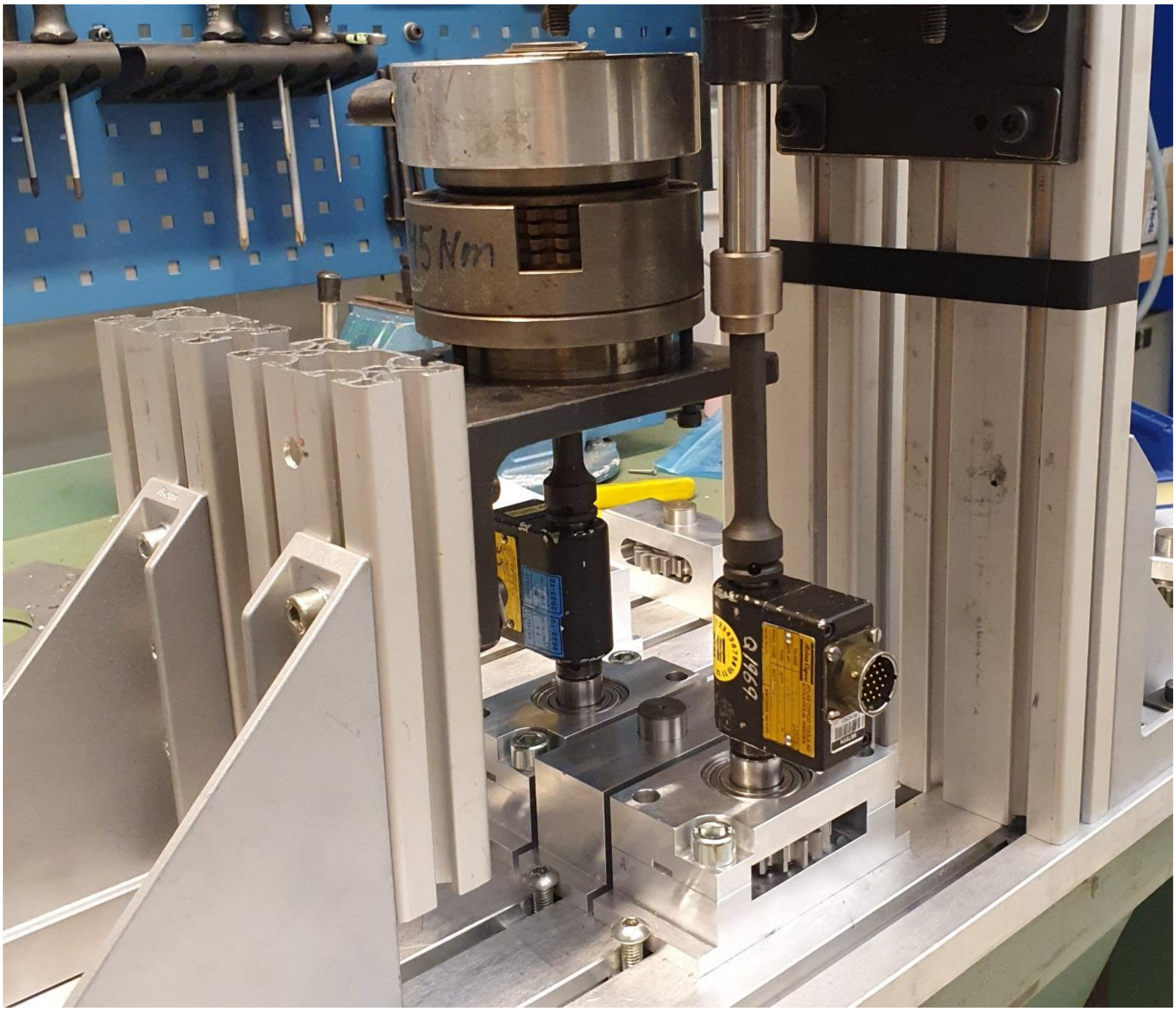


Figure 26: Two step GFA test rig arrangement.

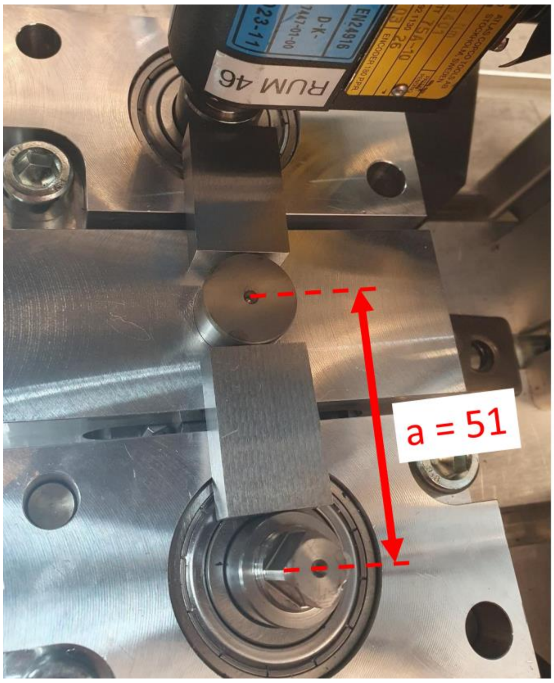


Figure 27: Distance bricks placed between the modules to ensure correct gear meshing during tests.

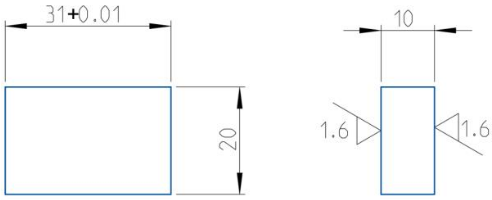


Figure 28: Construction drawing of distance bricks.

To ensure a precise interlocking of the teeth at the desired gear meshing distance $a_w = r_{w1} + r_{w2}$, see Figure 5. Multiple bricks were constructed, facilitating a more straightforward and accurate assembly of the modules, see Figure 27, 28 and 29.

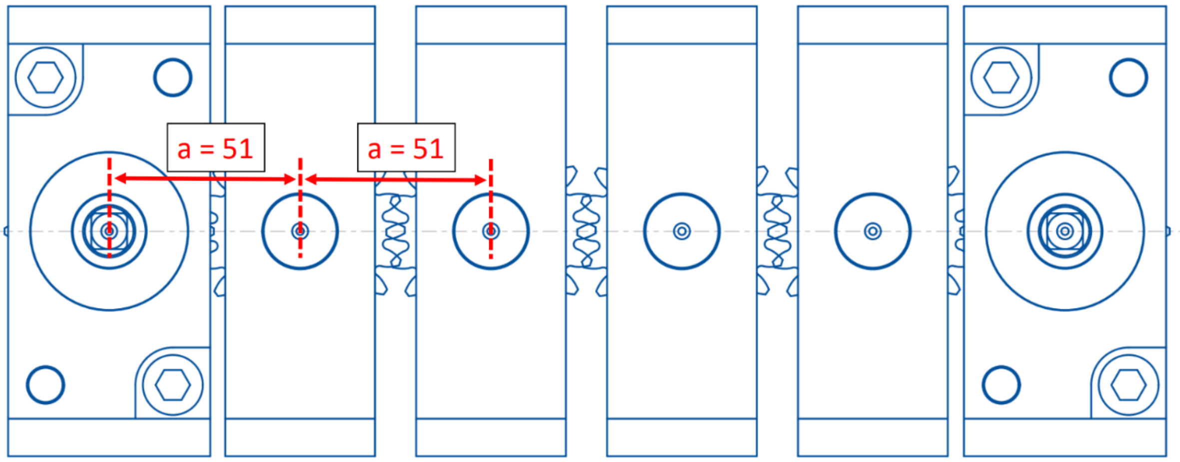


Figure 29: Gear module teeth interlocking distance.

After integrating all hardware components into the test rig system, the subsequent step involved programming the fixtured nutrunner software to regulate the output torque which will be generated by the tool. The controller/drive, see Figure 25, has an associated software which enables tool programming for various tightening programs and regulations of tightening parameters. The controller program was set up to make the tool generate constant spinning with 40 rpm velocity. Additionally, another essential software setup was for the DEWE software test arrangement. This software is linked to the IRTT transducers, allowing logging of test data. The DEWE software was specifically programmed to record input and output torque as well as the angle.

3.2.3. Risk Analysis

After completing the integration of both hardware and software into the GFA test rig, the next crucial step before initiating the testing phase was to identify potential risks associated with operating the test rig. A risk analysis was conducted and approved by Atlas Copco's safety department, see Table 2. The risk levels are defined by a scale 1-5 where P = Probability and C = Consequence. The risk factor (RF) is the product of the probability and consequence, $P \cdot C = RF$. To avoid potential risks that may occur while operating the test rig it is important to evaluate and execute preventive measures and actions before starting the test phase.

Risk event	Consequence	P 1-5	C 1-5	RF	Mitigation Actions
When power is applied to the modules rotation occurs in gears and shaft.	Risk of pinch hazards and hair getting stuck in the rotation of gears and shaft.	3	3	9	Install plexiglass on the rig to minimize the risk of hair or fingers getting stuck between gears. If the operator has long hair it is recommended to have pinned-up hair or hair net.
Heavy components needs to be removed, added or adjusted while changing gear steps.	Risk of dropping heavy components on floor or body, such heavy components are for example the brake, controller, steel plates and tool which can cause pinch hazards, injury and hearing impairment.	2	3	6	Wear safety gadgets such as steel-toe shoes, protective clothes, safety glasses and hearing protection earmuffs.
Sharp edges on parts and components that needs to be handled.	Risk of cut wound.	1	2	2	Smooth out any sharp edges through grinding. Wear safety gloves and clothes.
Wrong controller software program uploaded to the fixture nutrunner QST tool.	Risk of damaging gears and modules due to wrong program parameters uploaded to the tool. Risk of injury.	2	2	4	Ensure that there is an emergency stop close to the operator while running test to minimize potential module damage or operator injury.
Wrongfully mounted or assembled components and parts.	Risk of injury or component damage if assembly is not correctly mounted.	2	2	4	Install plexiglass to ensure that parts do not fall outside of the test rig. Start test with low torque and velocity before starting high torque to minimize risk of damaging components.
Handling of high voltages.	Risk of getting an electric shock due to that the controller has a three-phase power supply.	1	3	3	Ensure that all cables are intact and functional.
Moving the test rig.	Risk of pinch hazards and injury when moving the test rig due to very heavy rig components.	2	2	4	Have a dedicated place where the test rig can be stationed and avoid moving it too much if not necessary. Wear safety gadgets.

Table 2: Risk factor analysis and mitigation actions.

3.3. The Test Phase

The third and last phase of the project was to verify the test rig construction, ensuring that the gear train test rig meets Atlas Copco's requirements and needs. Unnecessary noise was filtered to smooth and enhance the clarity and interpretation of the test results. The test logging software (DEWE soft) recorded data for input torque, output torque, input angle, and output angle. Each test was conducted within a 10-second timeframe to minimize unnecessary wear on the gears. A smoothing function was devised to calculate a moving average over every 50 data points in the torque column, effectively mitigating noise and simplifying plot analysis, see formula 1.5 and Figure 30. This noise-filtering function was uniformly applied to all torque data.

$$Moving\ Average = \frac{A_1 + A_2 + \cdots + A_n}{n} \tag{1.5}$$

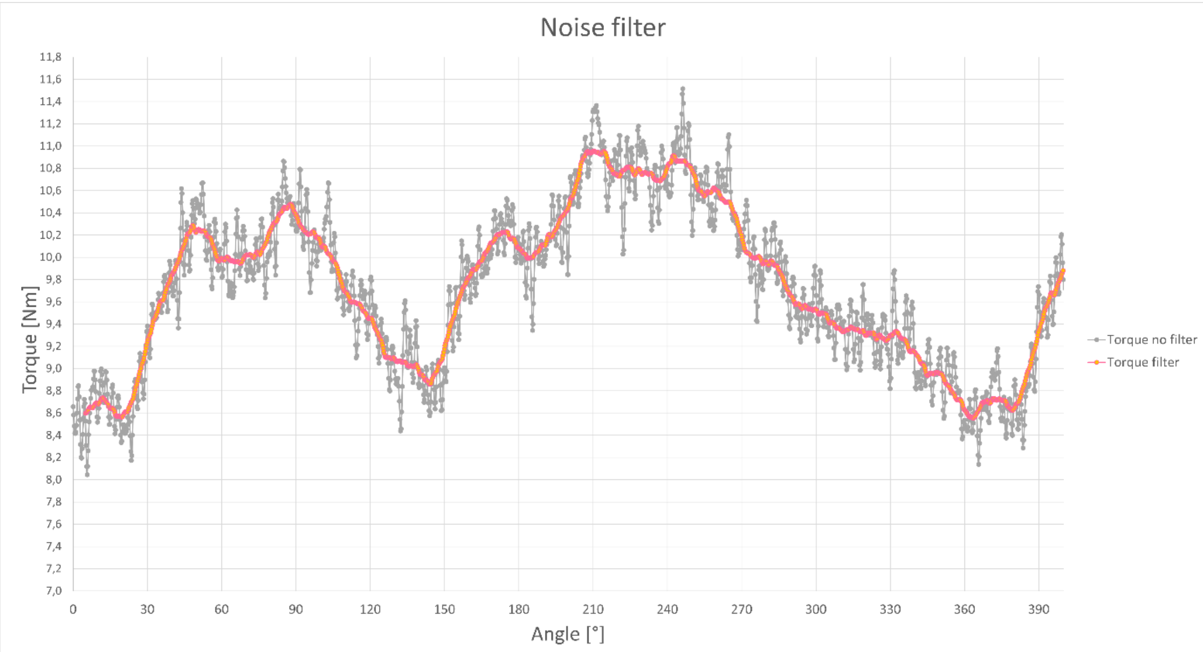


Figure 30: Moving average applied to smooth the interpretation of the test results.

The logging software did not record the angle with starting point 0˚. This made it difficult to interpret the gear angle position. To make the angle read easier an angle converting formula was implemented. This formula converted the recorded angle counting with 0˚as starting point. The implementation of the angle converting formula makes it possible to read the gear rotating position making it easier to compare test results.

3.3.1. Test Case Performance

The overall goal was to verify the efficiency capacity of the constructed test rig. Figure 32 show the logged data and the efficiency losses occurring in the rig during testing. The figure illustrates efficiency losses in the test rig. The earlier theory chapter in the report identifies certain causes of efficiency loss, such as friction during the gear meshing process. Additional factors that may contributing to efficiency losses will be further discussed in the upcoming Conclusion and Discussion chapter.

The following tests were conducted with two gear steps, one test case was conducted without grease and the other two tests was conducted with two different grease brands.

1. **Dry run** (no grease applied to gears)
    - 10 Nm test (TEST 1)
    - 12 Nm test (TEST 2)
2. **Molykote Longterm 2 plus**
    - 11 Nm test (TEST 1)
    - 20 Nm test (TEST 2)
3. **Atlas Copco Gear Grease 270**
    - 11 Nm test (TEST 1)
    - 20 Nm test (TEST 2)

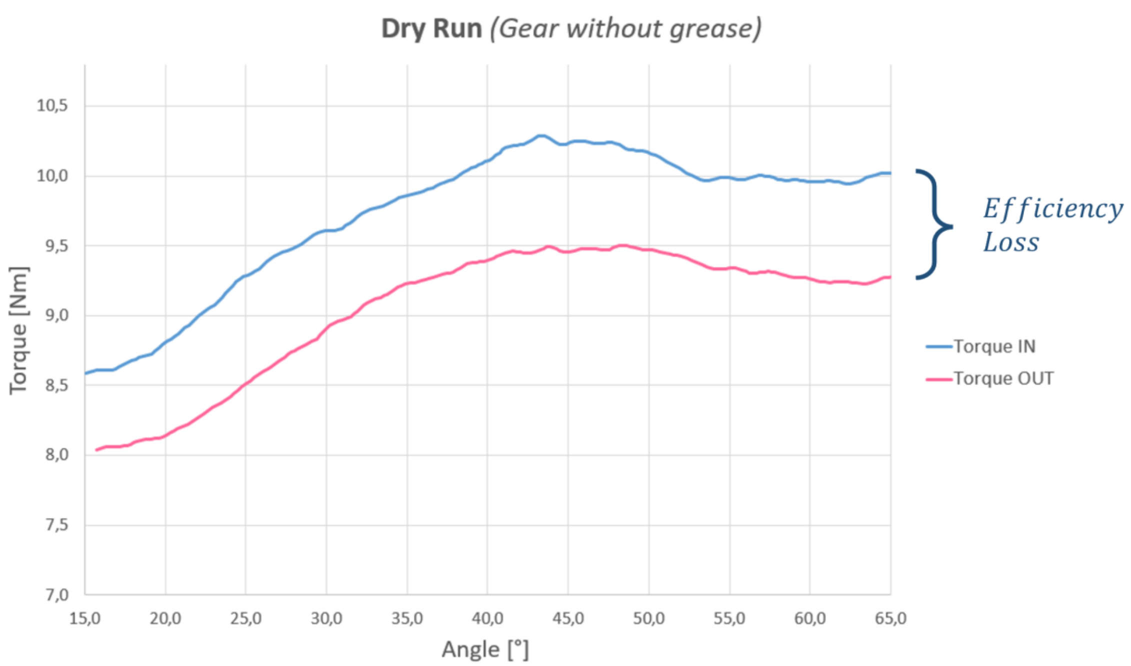


Figure 31: Close up plot of efficiency loss.

3.3.2. Test Procedure and Execution

The gears were prepared according to either test case 1, 2 or 3. If test case 1 was performed there were no grease applied to the gears. If test case 2 or 3 was executed, grease was applied to all gear modules. After applying the grease, the test rig was operated for a period to ensure an even distribution of the lubricant and to achieve an optimal grease layer on the gears.

The next step was to clamp all the gear modules to the T-slot aluminium plate with the distance a = 51 mm between each gear step. The distance bricks were put between the modules, ensuring that the distance was set correctly to achieve optimal gear meshing position while operating the test rig.

When the modules were clamped to the aluminium plate the next step was to prepare the motor controlling software (Tools Talk). The rotation was set to 40 rpm and the angle was set to rotate for 360 000°. The high angle can be adjusted if necessary. In this case a high angle was used to ensure that the test rig was rotating constantly. The test rig operator will end the test run when enough logged test data has been recorded.

After the motor has been programmed accordingly, the last step before starting the test procedure was to regulate the pneumatic brake. The brake will control the torque applied to the system and was regulated with the pressure regulator. The desired torque was attained by monitoring the data logging software and adjusting the pressure until the target torque was reached. When all the above steps were completed the gear train test rig was ready for testing.

Each test case was recorded with a logging data software (DEWE software) which has a DEWE 43 hardware and two transducers. One of the transducers was connected to the input shaft and the other transducer was connected to the output shaft. The test rig operator started data logging recording and then started the motor. After 10 seconds the motor was turned off and the recording was stopped. All logged data files were stored and organized in their respective folders for each test case - 1, 2, or 3. When reviewing the data plot results, three gear rotations were selected for further analysis.

3.3.3. Test Case Results

The test case results reveal the efficiency losses observed in each test. The plot from each test case illustrates the relationship between input torque, output torque, and the position of gear rotation, see Figure 32. The efficiency was calculated with formula 1.3 which can be found in the theory chapter. An average was computed using the gathered input and output torque data, see Table 3, 4 and 5.

1. Dry run result

DRY RUN	TEST 1		TEST 2	
Average Torque IN	9,666 *Nm*		12,64 *Nm*	
Average Torque OUT	9,052 *Nm*		11,87 *Nm*	
Efficiency	0,936	**93,6 %**	0,939	**93,9 %**

Table 3: Dry run result with average and efficiency calculations.

2. Molykote Longterm 2 plus

MOLYKOTE	TEST 1		TEST 2	
Average Torque IN	11,42 *Nm*		20,83 *Nm*	
Average Torque OUT	10,78 *Nm*		19,74 *Nm*	
Efficiency	0,944	**94,4 %**	0,948	**94,8 %**

Table 4: Molykote Longterm 2 plus result with average and efficiency calculations.

3. Atlas Copco Gear Grease 270

ATLAS COPCO	TEST 1		TEST 2	
Average Torque IN	11,50 *Nm*		20,08 *Nm*	
Average Torque OUT	10,87 *Nm*		19,04 *Nm*	
Efficiency	0,945	**94,5 %**	0,948	**94,8 %**

Table 5: Atlas Copco Gear Grease 270 result with average and efficiency calculations.

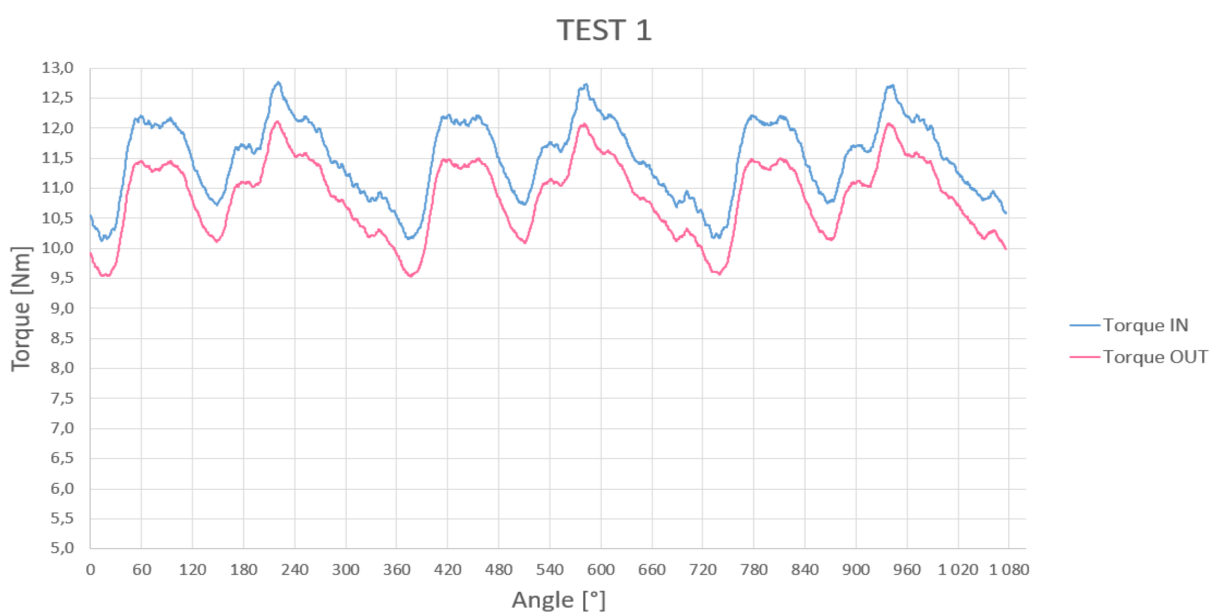


Figure 32: Plot of input torque and output torque during the Atlas Copco Gear Grease test.

4. Results

The mechanical design and construction of the gear train test rig have been validated for functionality through the conducted tests 1, 2 and 3. Comparison between the two greases (Molykote Longterm 2 plus and Atlas Copco Gear Grase 270) show no significant efficiency difference according to Table 6.

No Grease

DRY RUN	TEST 1
Efficiency	**93,6 %**
Efficiency loss	**6,4 %**

Grease

MOLYKOTE	TEST 2
Efficiency	**94,8 %**
Efficiency loss	**5,2 %**

Grease

ATLAS COPCO	TEST 2
Efficiency	**94,8 %**
Efficiency loss	**5,2 %**

Table 6: Efficiency loss comparison.

$$Improved\ Efficency = \frac{No\ Grease\ efficiency\ loss - Grese\ efficiency\ loss}{No\ Grease\ efficiency\ loss} = \frac{6{,}4 - 5{,}2}{6{,}4} \approx 0{,}1875 \ldots$$

$$Improved\ Efficency \approx 19\ \%$$

The company can utilize the gear train test rig to conduct and assess test cases depending on how many gear steps the test case requires. The module construction and design entails that the rig will be able to provide flexibility depending on what test case the company wants to perform.
The verification of the test rig functionality involves analysing efficiency performance with the implementation of two gear steps. During two-gear-step test cases, the gear train test rig achieves an efficiency of approximately 95 %. Applying grease to the gears will enhance the test rig efficiency by approximately 19 %.

4.1. Grease Comparison

The result of comparing the two different greases show that there is not a significant difference with regards to input torque comparison, see Figure 33. The Atlas Copco Gear Grease 270 have 0,1% higher efficiency compared to the Molykote Longterm 2 plus grease. However, when plotting an efficiency comparison graph the Molykote grease has more variation in efficiency compared to the Atlas Copco grease. Higher peaks in efficiency indicate a superior performance at that specific gear ratio position. However, achieving a consistently efficient system with minimal variations in lower efficiency performances is preferable. In Figure 34 the Molykote grease performs with higher variation compared to the Atlas Copco grease. The Atlas Copco grease demonstrates a more consistent efficiency performance.

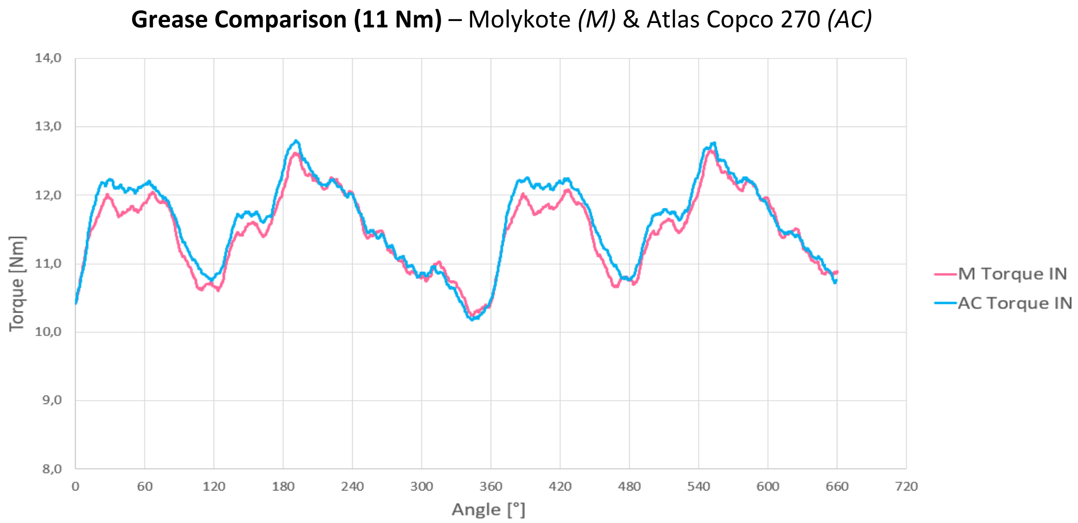


Figure 33: Plot of input torque grease comparison.

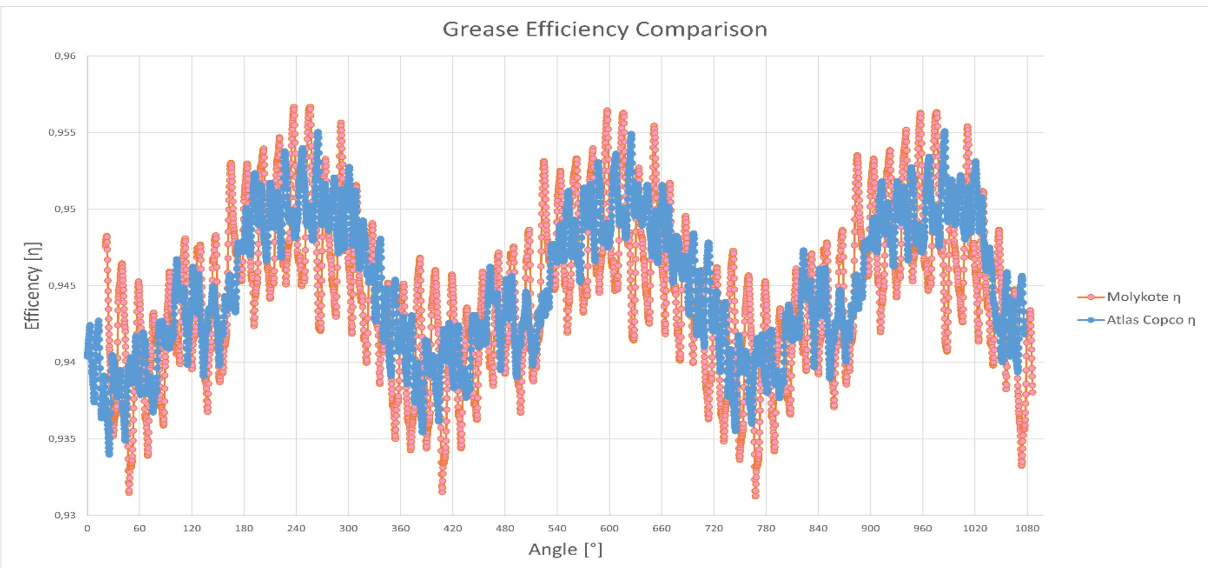


Figure 34: Plot of efficiency grease comparison.

5. Conclusions

Atlas Copco desired a test rig to perform gear accuracy and efficiency tests on, with the goal to potentially improve their future GFA tool tightening solutions. The modular design, illustrated in Figure 35, represents the GFA gear structure, making it possible to evaluate gear steps performance depending on what type of tests the company desires to analyse. The complete assembled test rig, shown in Figure 36, has successfully executed two-gear-step test cases to validate the construction functionality.

Figure 35: Rendering of gear train modules.

Figure 36: Assembled test rig with two gear steps.

5.1. Future Test Rig Improvements

There are some improvements that could enhance the efficiency and the overall performance of the gear train test rig. The torque plot in Figure 37 shows a variation in torque performance depending on the position of the gear during one gear rotation. In the plot it is shown that the highest torque performance occurs when the gear wheel has rotated approximately 75°. During one full gear rotation (360°), the highest torque is approximately 20,4 Nm and the lowest torque is approximately 18,3 Nm. To enhance the test rig performance, it would be preferable to attain a more consistent torque during one full gear rotation.

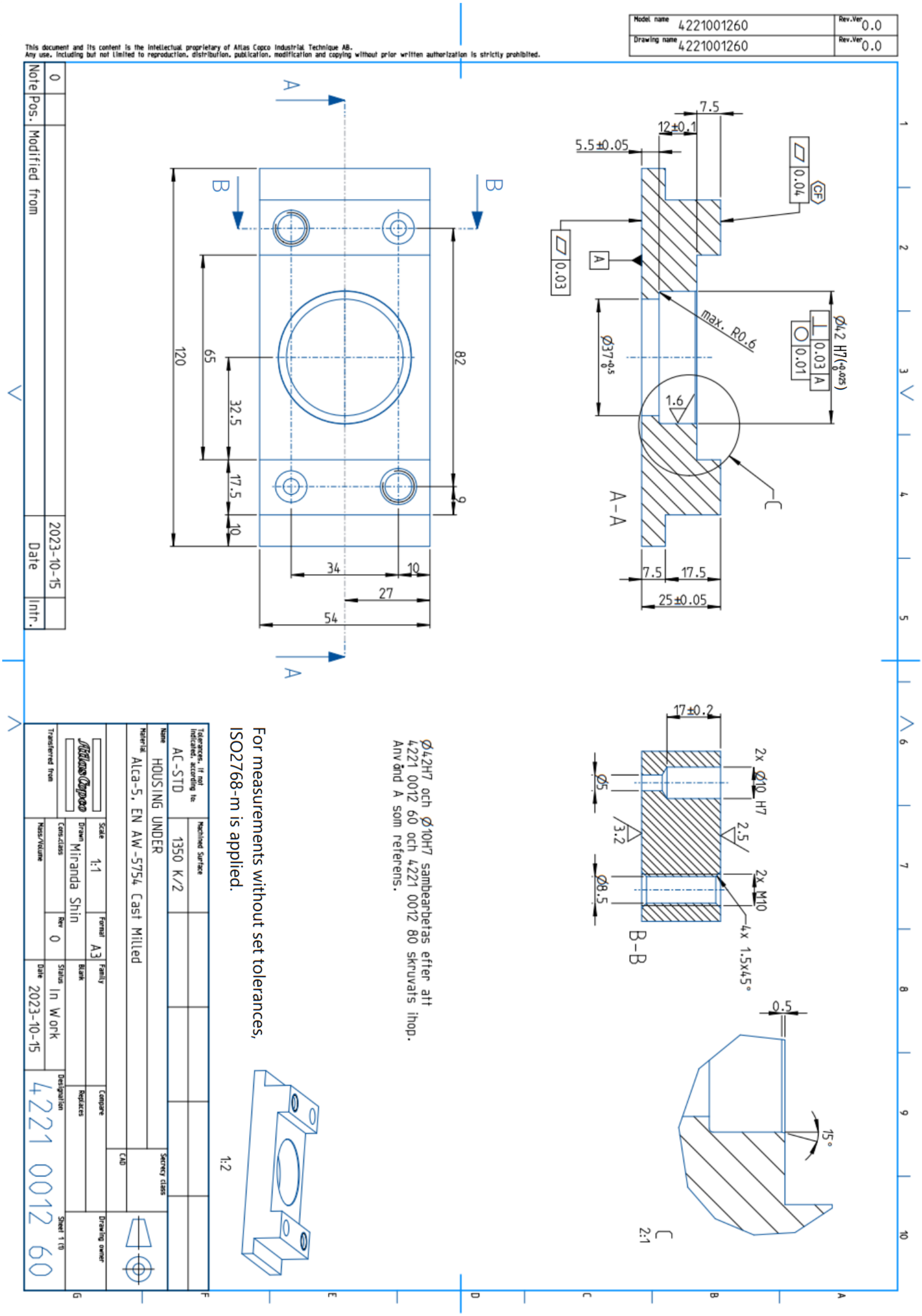
Figure 37: Plot of one full gear rotation.

The torque variation could also occur because of the suspension caused by the pneumatic brake. An improvement could be to use a different brake sort, for example a hydraulic brake. Ensuring the test rig assembly is well connected to all necessary components. Another improvement could be to reposition the input shaft to be placed closer to the input module. During the test phase the input shaft appeared a bit wobbling which indicates that the shaft is not perfectly centred. It would also be preferable to place the input shaft as close as possible to the input module to minimize the wobbling effect during shaft rotation. Although, when performing two gear steps test cases, it will not be possible to shorten the input shaft due to the motor and brake geometry. Due to the overall shorter gear train module in the two-gear-step test cases, the brake and motor will collide if poisoned next to each other. Due to the collision, either the brake or the motor must be repositioned to a different height level. In this case, this entails elevating the motor. Conducting test cases with multiple gear steps would involve a longer gear train, allowing for the motor to be positioned closer to the input module. This minimizes potential shaft wobbling, resulting in a more efficient performance of the test rig.

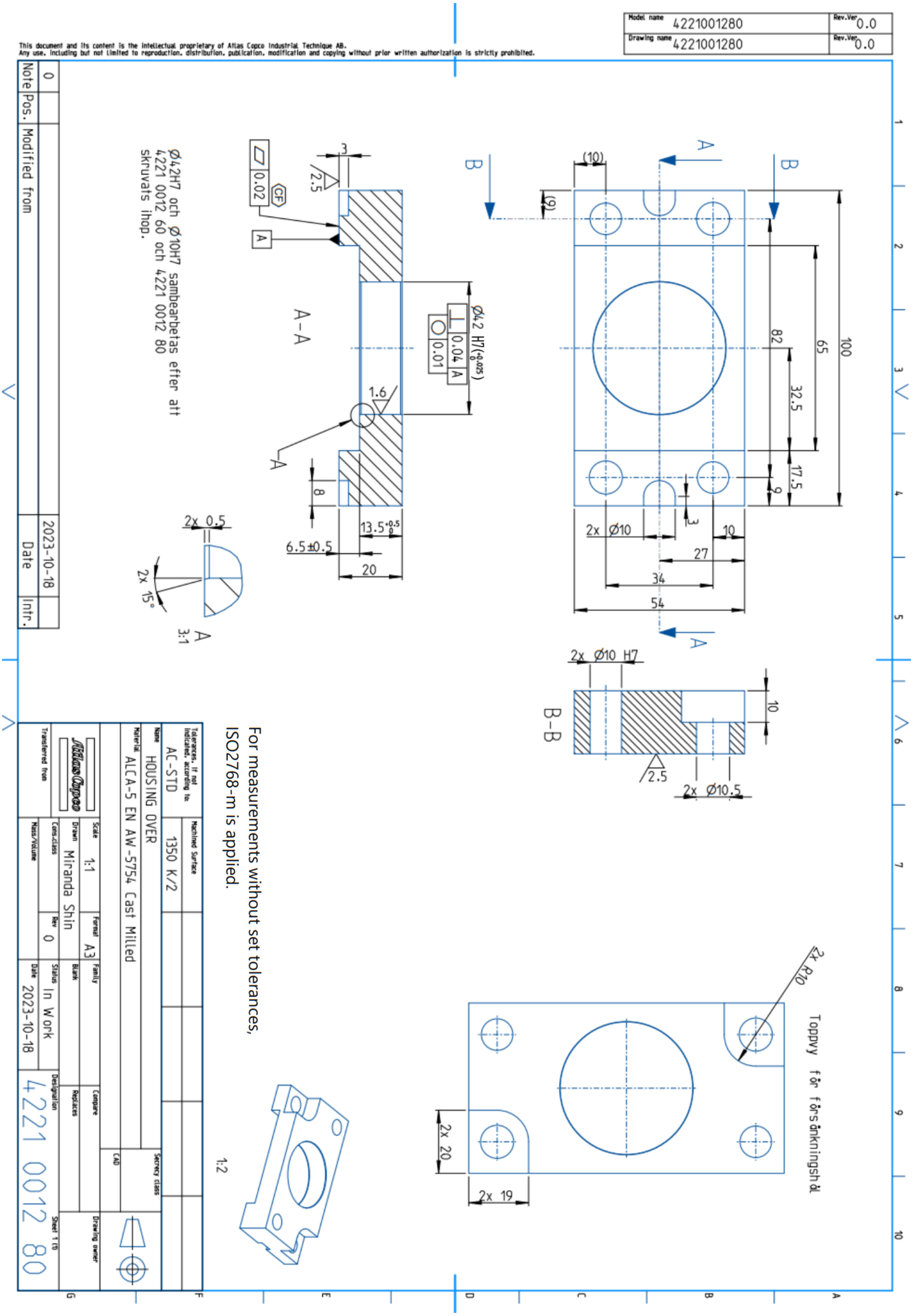
Appendix

Part drawings of module components sent to manufacturing.

A1

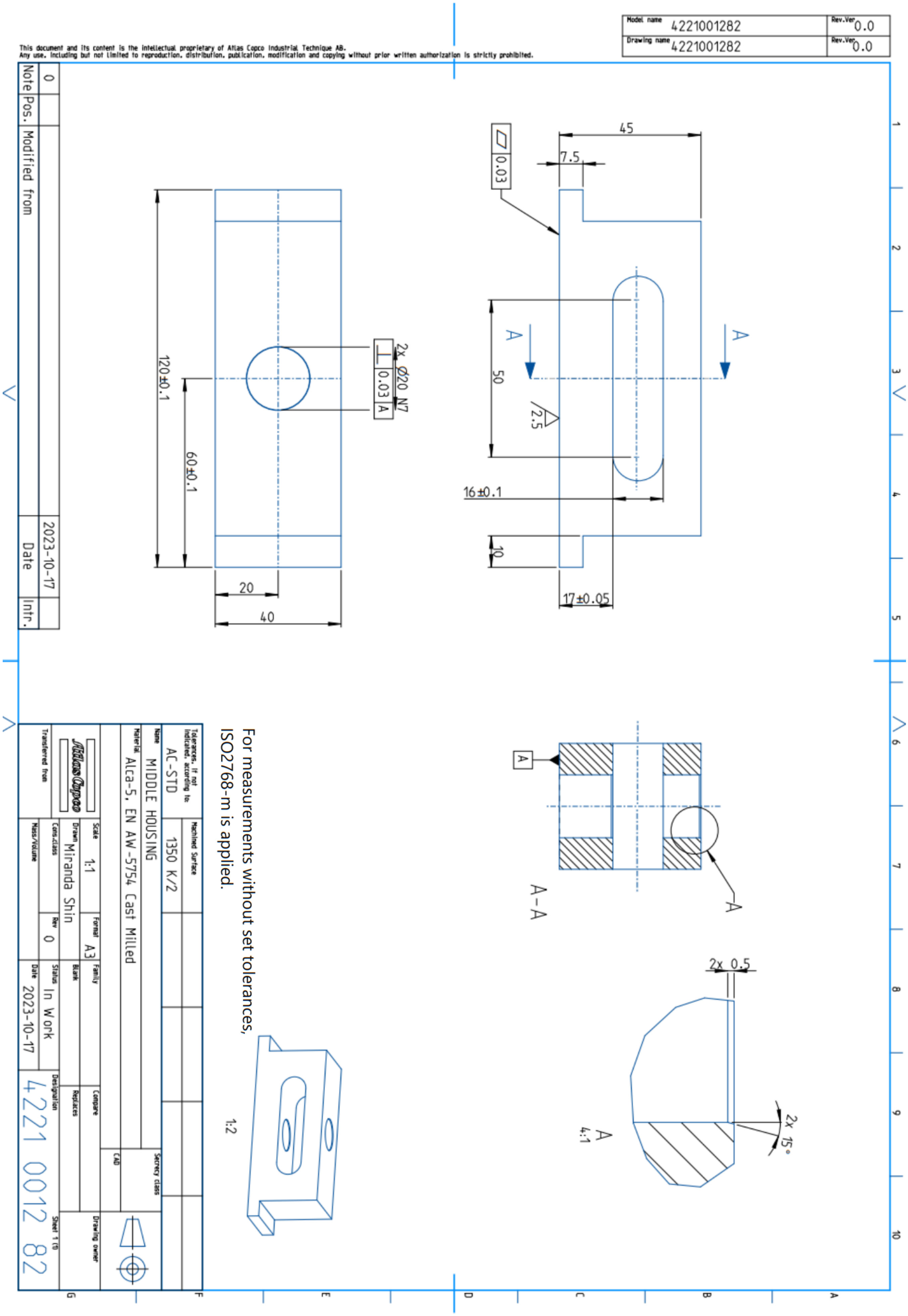

Model name 4221001260 Rev.Ver 0.0
Drawing name 4221001260 Rev.Ver 0.0
This document and its content is the intellectual proprietary of Atlas Copco Industrial Technique AB.
Any use, including but not limited to reproduction, distribution, publication, modification and copying without prior written authorization is strictly prohibited.
Note Pos. Modified from Date Intr.
0 2023-10-15
A-A
B-B
C
2:1
1:2
Ø42H7 och Ø10H7 sambearbetas efter att 4221 0012 60 och 4221 0012 80 skruvats ihop.
Använd A som referens.
For measurements without set tolerances, ISO2768-m is applied.
Tolerances, if not indicated, according to AC-STD
Machined Surface 1350 K/2
Name HOUSING UNDER
Material Alca-5, EN AW-5754 Cast Milled
Scale 1:1
Format A3
Drawn Miranda Shin
Rev 0
Status In Work
Date 2023-10-15
Designation 4221 0012 60

A2



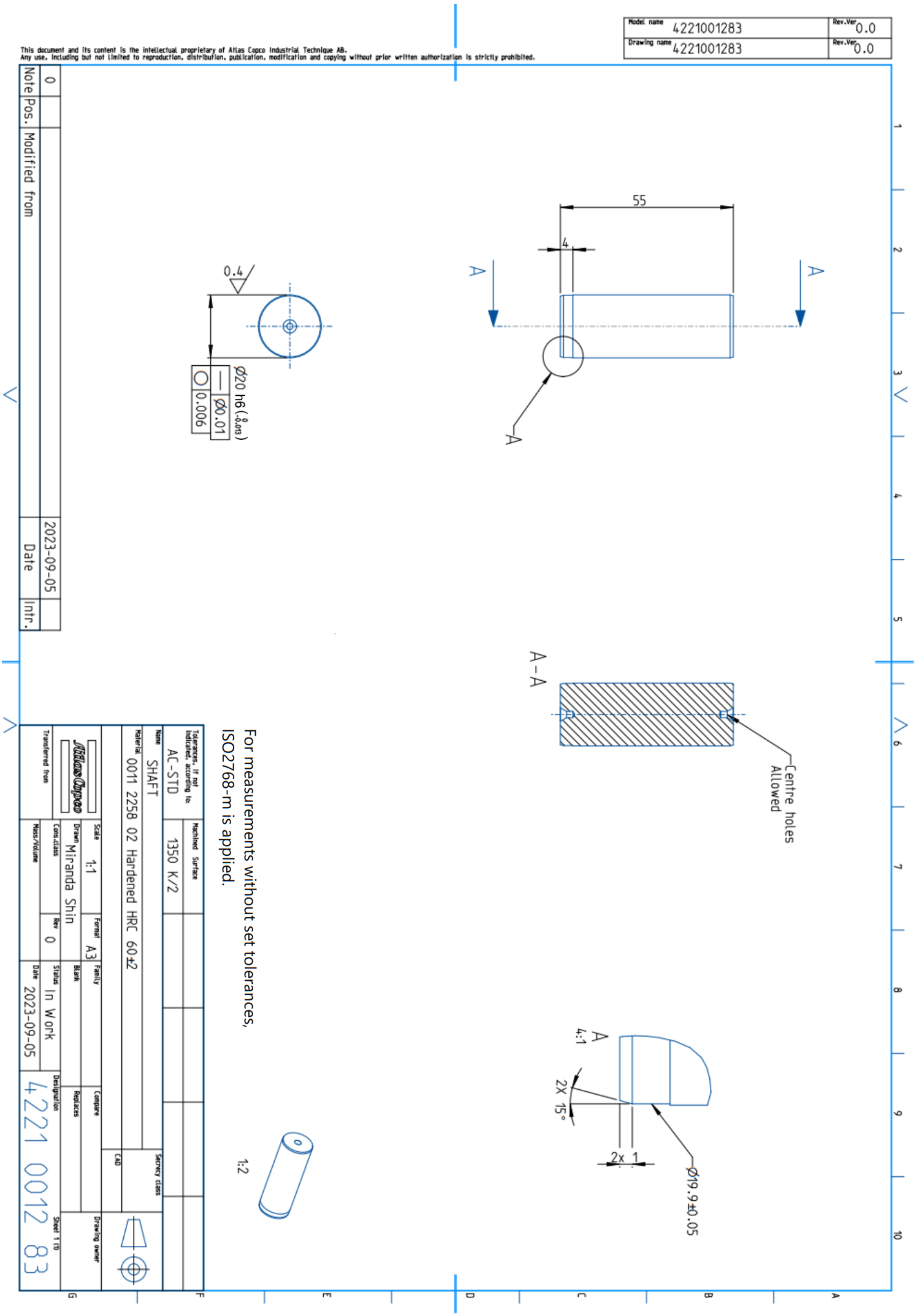
Model name 4221001280
Rev.Ver 0.0
Drawing name 4221001280
Rev.Ver 0.0
This document and its content is the intellectual proprietary of Atlas Copco Industrial Technique AB.
Any use, including but not limited to reproduction, distribution, publication, modification and copying without prior written authorization is strictly prohibited.
A-A
B-B
Ø42H7 och Ø10H7 sambearbetas efter att
4221 0012 60 och 4221 0012 80
skruvats ihop.
Toppvy för försänkningshål
For measurements without set tolerances,
ISO2768-m is applied.
Note
Pos.
Modified from
Date
Intr.
0
2023-10-18
Tolerances, if not indicated, according to: AC-STD
Machined Surface 1350 K/2
Name HOUSING OVER
Material ALCA-5 EN AW-5754 Cast Milled
Scale 1:1
Format A3
Drawn Miranda Shin
Rev 0
Status In Work
Date 2023-10-18
Designation 4221 0012 80
Atlas Copco

A3



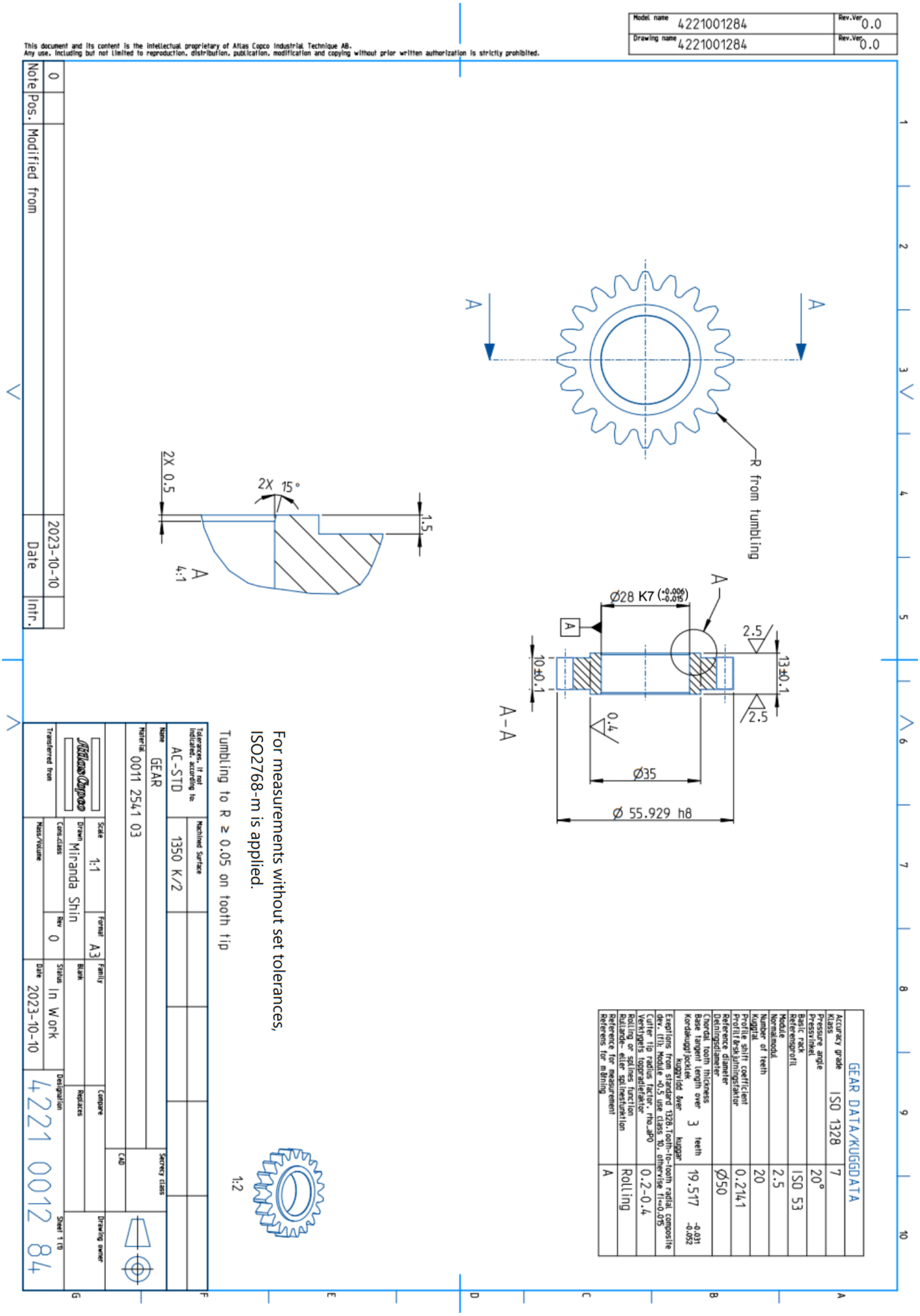
Model name 4221001282 Rev.Ver 0.0
Drawing name 4221001282 Rev.Ver 0.0
This document and its content is the intellectual proprietary of Atlas Copco Industrial Technique AB. Any use, including but not limited to reproduction, distribution, publication, modification and copying without prior written authorization is strictly prohibited.
Note Pos. Modified from Date Infr.
0 2023-10-17
For measurements without set tolerances, ISO2768-m is applied.
1:2
A-A
A 4:1
2x 0.5
2x 15°
2x Ø20 N7
120±0.1
60±0.1
20
40
45
7.5
50
16±0.1
10
17±0.05
Tolerances, if not indicated, according to: AC-STD
Machined Surface 1350 K/2
Name MIDDLE HOUSING
Material AlCa-5, EN AW-5754 Cast Milled
Scale 1:1 Format A3
Drawn Miranda Shin
Rev 0
Status In Work
Date 2023-10-17
4221 0012 82

A4

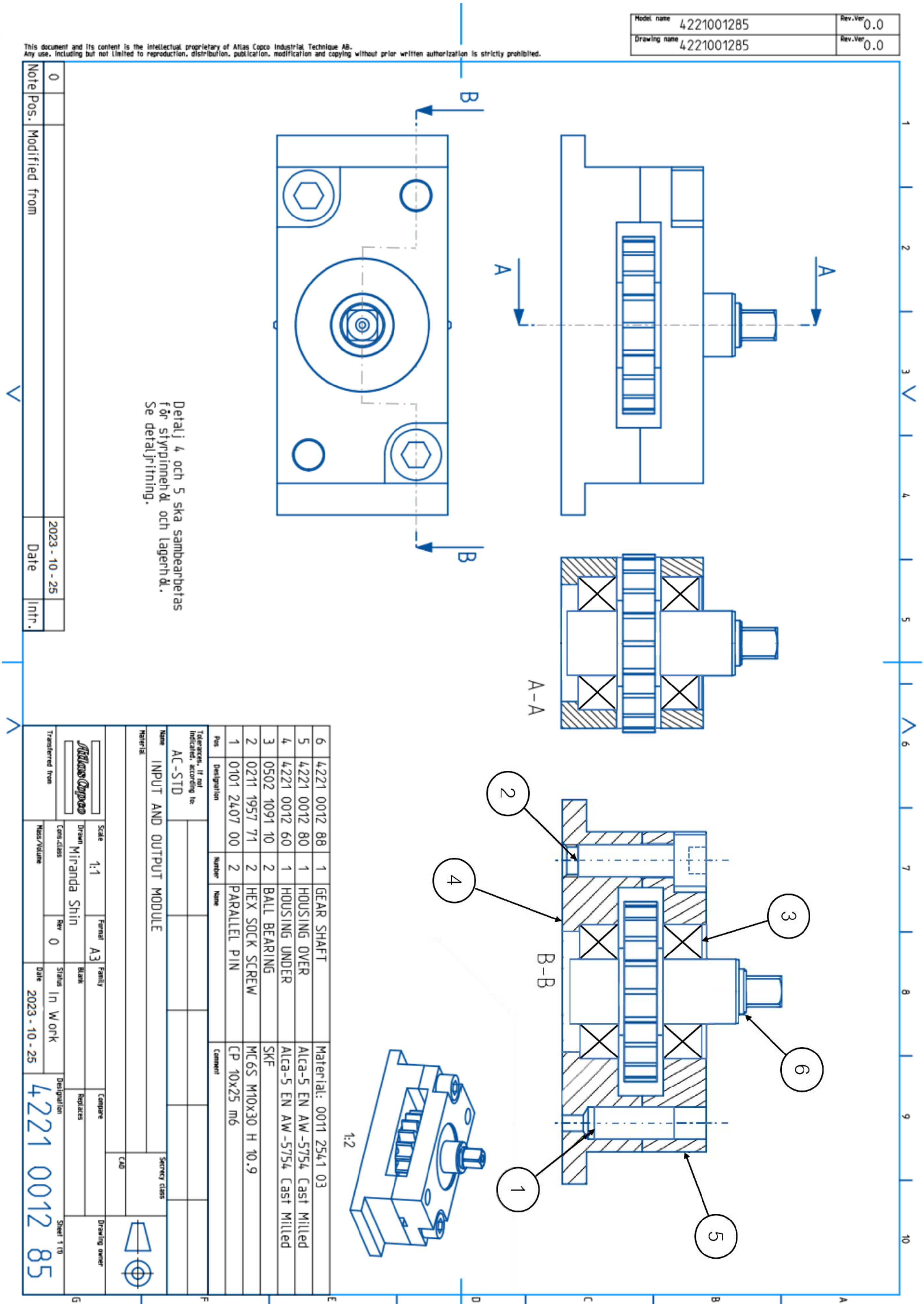


Model name 4221001283
Rev.Ver 0.0
Drawing name 4221001283
Rev.Ver 0.0
This document and its content is the intellectual proprietary of Atlas Copco Industrial Technique AB.
Any use, including but not limited to reproduction, distribution, publication, modification and copying without prior written authorization is strictly prohibited.
Note
Pos.
Modified from
Date
Intr.
0
2023-09-05
55
4
A
A
A
0.4
Ø20 h6(-0.013)
Ø0.01
0.006
A-A
Centre holes Allowed
A 4:1
2X 15°
2x 1
Ø19.9±0.05
1:2
For measurements without set tolerances, ISO2768-m is applied.
Tolerances, if not indicated, according to:
AC-STD
Machined Surface
1350 K/2
Name
SHAFT
Material
0011 2258 02 Hardened HRC 60±2
Secrecy class
CAD
Transferred from
Scale 1:1
Format A3
Family
Compare
Drawing owner
Drawn Miranda Shin
Blank
Replaces
Cons.class
Rev 0
Status In Work
Sheet 1 (1)
Mass/Volume
Date 2023-09-05
Designation
4221 0012 83

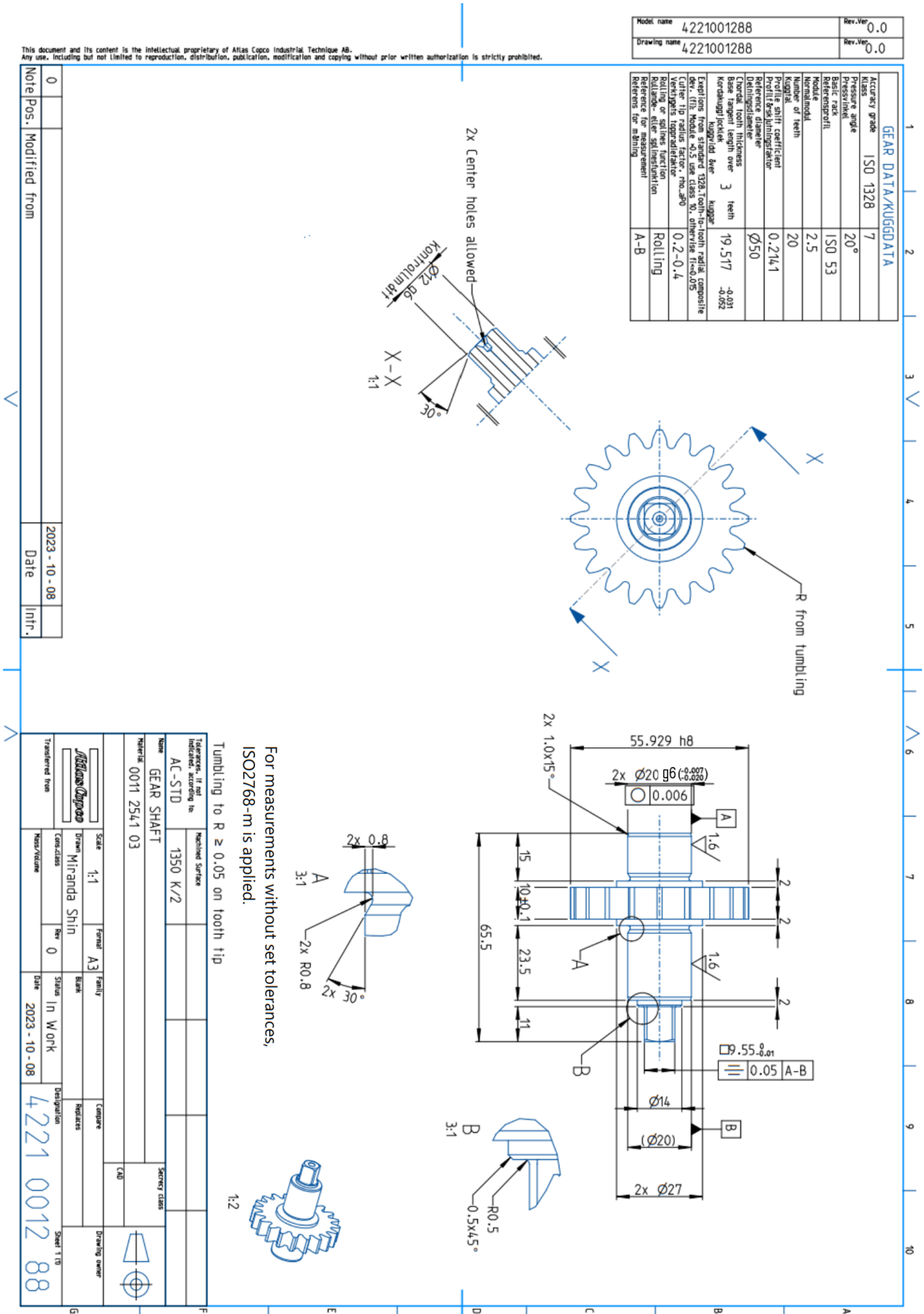
A5


Model name 4221001284 Rev.Ver 0.0
Drawing name 4221001284 Rev.Ver 0.0
This document and its content is the intellectual proprietary of Atlas Copco Industrial Technique AB. Any use, including but not limited to reproduction, distribution, publication, modification and copying without prior written authorization is strictly prohibited.
R from tumbling
A-A
Ø28 K7 (+0.006 -0.015)
13±0.1
10±0.1
2.5
0.4
Ø35
Ø 55.929 h8
1.5
2X 15°
2X 0.5
A 4:1
GEAR DATA/KUGGDATA
Accuracy grade Klass ISO 1328 7
Pressure angle Pressvinkel 20°
Basic rack Referensprofil ISO 53
Module Normalmodul 2.5
Number of teeth Kuggtal 20
Profile shift coefficient Profilförskjutningsfaktor 0.2141
Reference diameter Delningsdiameter Ø50
Chordal tooth thickness Base tangent length over 3 teeth Kordakuggtjocklek kuggvidd över kuggar 19.517 -0.031 -0.052
Exeptions from standard 1328.Tooth-to-tooth radial composite dev. (fi): Module >0.5 use class 10, otherwise fi<=0.015
Cutter tip radius factor, rho_aP0 Verktygets toppradiefaktor 0.2-0.4
Rolling or splines function Rullande- eller splinesfunktion Rolling
Reference for measurement Referens for mätning A
For measurements without set tolerances,
ISO2768-m is applied.
Tumbling to R ≥ 0.05 on tooth tip
1:2
Tolerances, if not indicated, according to: AC-STD
Machined Surface 1350 K/2
Name GEAR
Material 0011 2541 03
Secrecy class
CAD
Scale 1:1
Format A3
Family
Compare
Drawing owner
Drawn Miranda Shin
Blank
Replaces
Cons.class
Rev 0
Status In Work
Designation 4221 0012 84
Sheet 1 (1)
Transferred from
Mass/Volume
Date 2023-10-10
0 2023-10-10
Note Pos. Modified from Date Intr.

A6

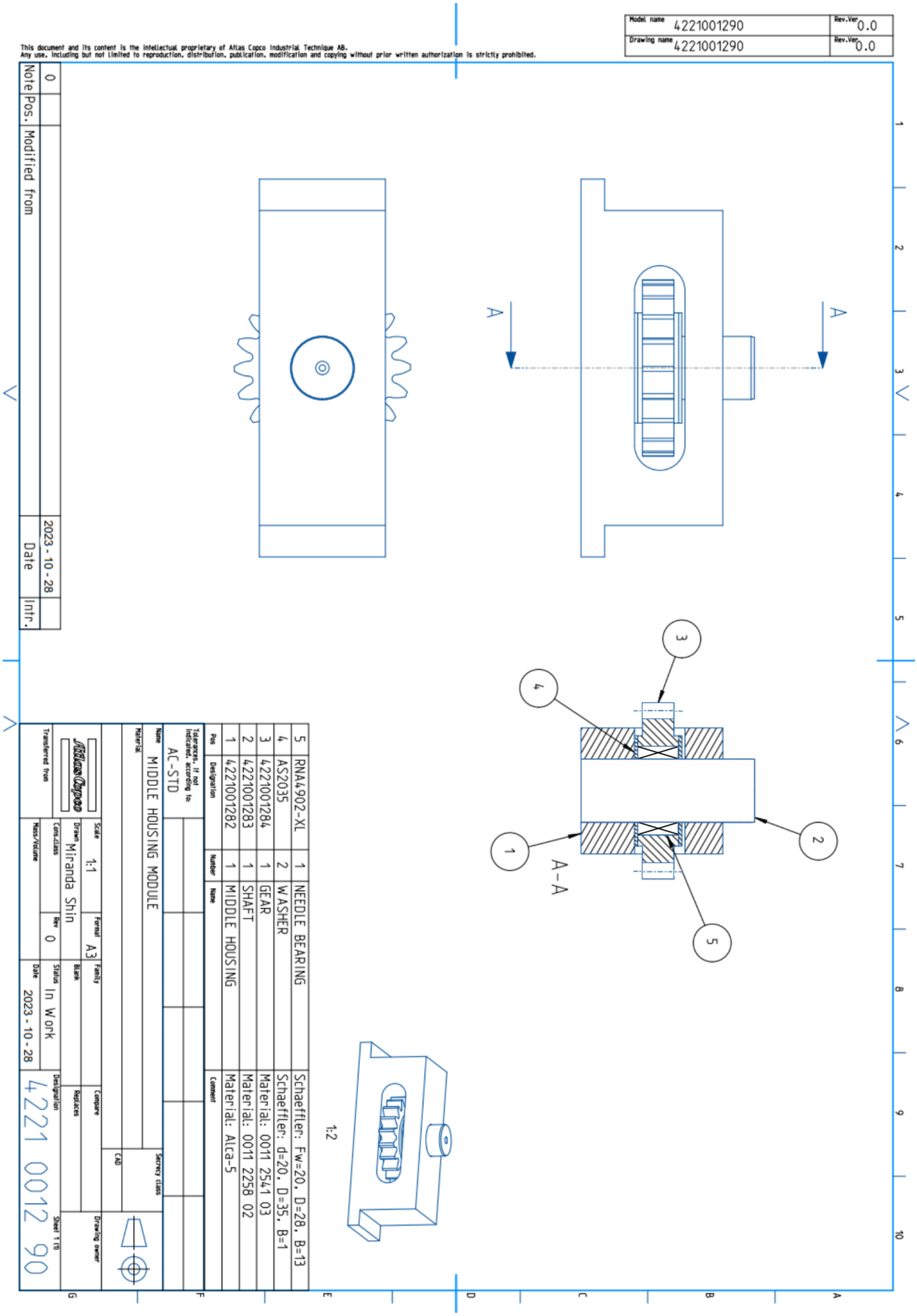

Model name 4221001285 Rev.Ver 0.0
Drawing name 4221001285 Rev.Ver 0.0
This document and its content is the intellectual proprietary of Atlas Copco Industrial Technique AB.
Any use, including but not limited to reproduction, distribution, publication, modification and copying without prior written authorization is strictly prohibited.
A
A
A-A
B
B
B-B
1
2
3
4
5
6
1:2
Detalj 4 och 5 ska sambearbetas
för styrpinnehål och lagerhål.
Se detaljritning.
6 4221 0012 88 1 GEAR SHAFT Material: 0011 2541 03
5 4221 0012 80 1 HOUSING OVER Alca-5 EN AW-5754 Cast Milled
4 4221 0012 60 1 HOUSING UNDER Alca-5 EN AW-5754 Cast Milled
3 0502 1091 10 2 BALL BEARING SKF
2 0211 1957 71 2 HEX SOCK SCREW MC6S M10x30 H 10.9
1 0101 2407 00 2 PARALLEL PIN CP 10x25 m6
Pos Designation Number Name Comment
Tolerances, if not indicated, according to: AC-STD
Name INPUT AND OUTPUT MODULE
Material
Secrecy class
CAD
Scale 1:1
Format A3
Family
Compare
Drawing owner
Drawn Miranda Shin
Blank
Replaces
Cons.class
Rev 0
Status In Work
Designation
Sheet 1 (1)
Transferred from
Mass/Volume
Date 2023-10-25
4221 0012 85
0 2023-10-25
Note Pos. Modified from Date Intr.

A7



This document and its content is the intellectual proprietary of Atlas Copco Industrial Technique AB. Any use, including but not limited to reproduction, distribution, publication, modification and copying without prior written authorization is strictly prohibited.
Model name 4221001288 Rev.Ver 0.0
Drawing name 4221001288 Rev.Ver 0.0
GEAR DATA/KUGGDATA
Accuracy grade Klass ISO 1328 7
Pressure angle Pressvinkel 20°
Basic rack Referensprofil ISO 53
Module Normalmodul 2.5
Number of teeth Kuggtal 20
Profile shift coefficient Profilförskjutningsfaktor 0.2141
Reference diameter Delningsdiameter Ø50
Chordal tooth thickness
Base tangent length over 3 teeth Kordakuggtjocklek kuggvidd över kuggar 19.517 -0.031 -0.052
Exeptions from standard 1328. Tooth-to-tooth radial composite dev. (fi). Module <0.5 use class 10, otherwise fi<=0.015
Cutter tip radius factor, rho_aP0 Verktygets toppradiefaktor 0.2-0.4
Rolling or splines function Rullande- eller splinesfunktion Rolling
Reference for measurement Referens för mätning A-B
2x Center holes allowed
Kontrollmått Ø12 g6
30°
X-X 1:1
X
R from tumbling
55.929 h8
2x 1.0x15°
2x Ø20 g6 (-0.007 -0.020)
0.006
A
1.6
15
10±0.1
65.5
23.5
11
2
A
B
9.55 0 -0.01
0.05 A-B
Ø14
(Ø20)
B
2x Ø27
2x 0.8
A 3:1
2x R0.8
2x 30°
B 3:1
R0.5
0.5x45°
For measurements without set tolerances, ISO2768-m is applied.
Tumbling to R ≥ 0.05 on tooth tip
1:2
Tolerances, if not indicated, according to: AC-STD
Machined Surface 1350 K/2
Name GEAR SHAFT
Material 0011 2541 03
Secrecy class
CAD
Scale 1:1
Format A3
Drawn Miranda Shin
Rev 0
Status In Work
Date 2023-10-08
Designation 4221 0012 88
Sheet 1 (1)
Note Pos. Modified from
0
2023-10-08
Date Infr.

A8


This document and its content is the intellectual proprietary of Atlas Copco Industrial Technique AB.
Any use, including but not limited to reproduction, distribution, publication, modification and copying without prior written authorization is strictly prohibited.
Model name 4221001290
Rev.Ver 0.0
Drawing name 4221001290
Rev.Ver 0.0
Note Pos. Modified from
0
Date 2023-10-28
Intr.
A
A
A-A
1:2
5 RNA4902-XL 1 NEEDLE BEARING Schaeffler: Fw=20, D=28, B=13
4 AS2035 2 WASHER Schaeffler: d=20, D=35, B=1
3 4221001284 1 GEAR Material: 0011 2541 03
2 4221001283 1 SHAFT Material: 0011 2258 02
1 4221001282 1 MIDDLE HOUSING Material: Alca-5
Pos Designation Number Name Comment
Tolerances, if not indicated, according to: AC-STD
Name MIDDLE HOUSING MODULE
Material
Secrecy class
CAD
Scale 1:1
Format A3
Family
Compare
Drawing owner
Drawn Miranda Shin
Blank
Replaces
Cons.class
Rev 0
Status In Work
Mass/Volume
Date 2023-10-28
Designation 4221 0012 90
Sheet 1 (1)
Transferred from
Atlas Copco

References

Alumeco Group. (n.d.). EN AW-5754 Cast Milled. https://www.alumeco.se/aluminium/plaat/saagad-plaat/en-aw-5754-cast-milled/20-x-1520-x-3020-mm/p/10001600/10143077

Atlas Copco. (n.d.2). Rendering of a GFA extension. Retrieved from employee at Atlas Copco

Atlas Copco. (n.d.1). GFA attached to tightening tool. Geared Front Attachments (GFA) An introduction (atlascopco.com)

Atlas Copco. (2020) ITBA-Presentation-2020_37034. Retrieved from employee at Atlas Copco

Atlas Copco. (2023). IRTT-B 75-10. Atlas Copco. https://www.atlascopco.com/en-us/itba/products/assembly-solutions/quality-assurance-in-tightening-and-fastening/transducers/irtt-b-75-10-sku8059094225 (viewed mm)

Atlas Copco. (2023). Fixtured Nutrunner QST Unique speed capabilities for high-torque applications https://www.atlascopco.com/en-us/itba/products/assembly-solutions/fixtured-assembly-solutions/qst-fixtured-nutrunner

Mägi, M., Melkersson, K., & Evertsson, E. (2017). Maskinelement. Studentlitteratur.

Richter, J. (2022). Continuous Feature. https://www.gdandtbasics.com/continuous-feature/

Schaeffler. (2023). RNA4902-XL Radial roller bearing. https://medias.schaeffler.de/en/product/rotary/rolling-and-plain-bearings/roller-bearings/needle-roller-bearings/machined-needle-roller-bearings/rna4902-xl/p/393476

SKF. (2018). Rolling bearings. SKF Group. https://cdn.skfmediahub.skf.com/api/public/0901d196802809de/pdf_preview_medium/0901d196802809de_pdf_preview_medium.pdf

SKF. (2023). 6004-2Z Deep groove ball bearing with seals or shields. https://www.skf.com/group/products/rolling-bearings/ball-bearings/deep-groove-ball-bearings/productid-6004-2Z

Westbroek, R., Leckner, J., & Olsson, J. (2023). Bevel gear grease: A sustainability case study. *NLGI Spokesman 87*(4) 26-51.

DEPARTMENT OF INDUSTRIAL AND
MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY