Study and mechanical improvement of the TUlip hip joint

DCT no.: DC 2012.067

Internship report
Eindhoven, September 2012.

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Abstract

A study is performed on the TUlip hip joint. This study is executed after backlash was noticed in the φ-axle of the hip joint. The second reason for the study was the lack of documentation on the hip joint. The study is performed on the 2011 TUlip.

Two different tests have been carried out to determine the range of motion and the backlash of the φ-axle hip joint. The actual range of motion of the hip joint is smaller than the documentation stated for the TUlip. While executing the test an additional problem was noticed. The linkages of the encoders that measure the angular displacement were hitting parts of the hip joint. This means measurements of the encoders differ from the real angular displacement in the extreme positions.

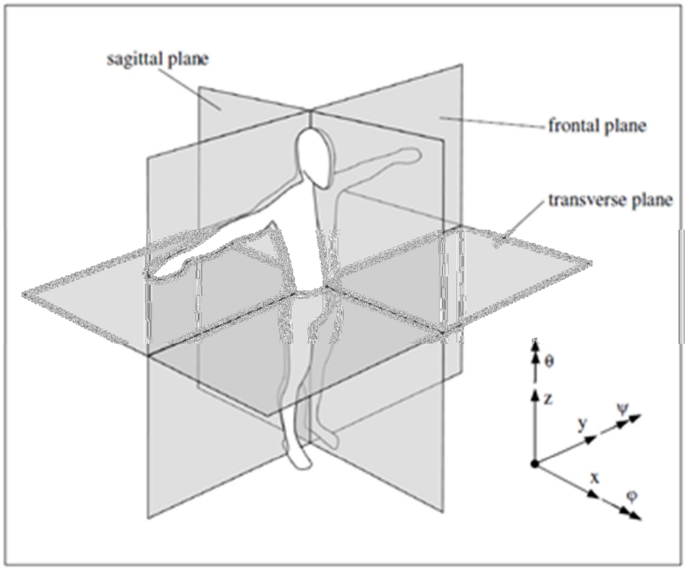
The measured radial play of the φ-axle is around 1.8 degree. The radial play of the Maxon motor-gearbox assembly is 2 degree. The difference between the measured and stated radial play by Maxon is due to the fact that, radial play stated by Maxon is the maximum allowable radial play on the motor-gearbox assembly.

To reduce the backlash in the φ-axle three concepts are developed:

- Editing a planetary gear set. For this concept, a few changes are necessary to implement it, the disadvantage is that the system is a custom design and it needs to be manufactured with a small tolerance.
- Using a harmonic drive as gearing. A harmonic drive has zero backlash. The disadvantage is the purchase price of a harmonic drive.
- Using the GP 42 Maxon gearbox. It has less backlash as the current gearbox. The disadvantage of this concept is that all the components that make up the φ-axle need to be altered to accommodate the larger GP 42 gearbox.

The harmonic drive is the ideal solution to reduce the backlash in the φ-axle hip joint, because it has no radial play. The disadvantages are: it is an expensive component, and the requirement stated for the concepts forces the harmonic drive to be placed in a certain position and this causes a complex installation.

Nomenclature



Abbreviations

DOF / DOF's	degree of freedom / degrees of freedom
ROM	range of motion
DC	direct current
PGS	planetary gear set

Table of Contents

1. Introduction

The research of the hip joint of the TUlip is carried out to get insight in the backlash of the φ-axle. During operation of the TUlip it was noticed that there was backlash on the φ-axle. Estimated was that the backlash caused an approximately 1 to 2 [cm] difference at the foot. There is no good documentation of the hip joint, therefore, a study of the model is needed. After the study of the joint, a recommendation is made about possible solutions to reduce the backlash.

The TUlip used in this research is the 2011 spec humanoid robot. In the rest of the report the robot will be denoted as TUlip. All the joints and measurements mentioned in this report refer to the hardware part of the 2011 spec Tulip.

The goal of this study is to get insight in the structure of the hip joint and its backlashes.

The recommendation gives a solution to reduce the backlash of the hip joint φ-axle.

The study contains information about the range of motion as is stated for the TUlip.

The kinematic structure of the TUlip is shown and the design of the hip joint is documented. The recommendation contains three concepts for reducing the backlash of the φ-axle. These concepts are designed with a few requirements in mind. These requirements are stated in the recommendation.

The report is devided in the following manner. The second chapter discusses the lay-out of the TUlip leg and the experiments executed on the hip joint. In the third chapter the results of the executed experiments are discussed. Chapter four describes the concepts to reduce radial play in the φ-axle hip joint and a comparison between the different concepts is made. In chapter five the conclusion and recommendations with respect to the hip joint are given.

2. Study of the hip joint

This section shows the structure of the hip joint and its performance in its range of motion. The study, performed on the hip joint of the TUlip, was executed because it had visible backlash during operation. The second reason to perform a study of the hip joint was a lack of documentation on the hip joint. In the past, research has been performed on the hip joint of the TUlip but small changes have been made since the concept was developed in 2011. The first section of the study shows the current configuration of the hip joint. The second section describes the tests that are carried out. The third section displays the results of these tests.

2.1 Configuration of the hip joint

In this section a brief description is given of the hip joint configuration. The different hardware components are described and the geometry of the joint is shown.

2.1.1. Geometry of the hip joint

The kinematic structure of the lower body is shown Figure 2-1. The upper body is represented by the torso. The lower body consists of an upper leg, a lower leg, and a foot. An individual leg has 6 degrees of freedom (DOF's). The hip joint in the kinematic structure contains 3 DOF's. Two are placed in the same plane. The third DOF is represented by an electronic motor placed at the side of the torso and is used for angular displacement about the ϴ-axle. The three DOF's imitate the human hip joint. The hip joint is the only joint in the TUlip that contains 3 DOF's. The hip joint is one of the most complex joints and its geometry is limited by the installation space.

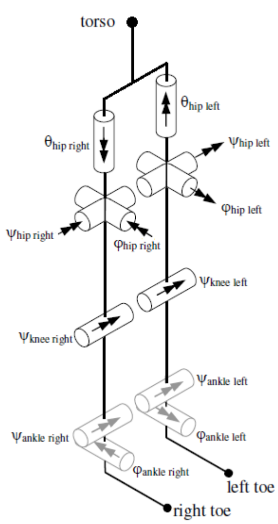


Figure 2-1: kinematic structure TUlip

In Figure 2-2 the overall layout of the hip joint is shown. The electric motor used for the angular movement about the φ-axle is placed inside the hip joint. The angular movement about the ψ-axle is realized by means of an electric motor placed in the upper leg. The upper leg is not shown in Figure 2-2. The electric motor is connected to the ψ-axle by means of a cable and pulley. The system to control the ψ-axle movement is not shown in Figure 2-2, only the hinge sections and connecting base to the upper leg are shown, to get an idea of the geometry of the hip joint. The hinge sections and the connecting base form the limitations in space for the geometry of the φ-axle. The dimensions of the hip joint are given in Appendix A: Dimensions hip joint 2011.

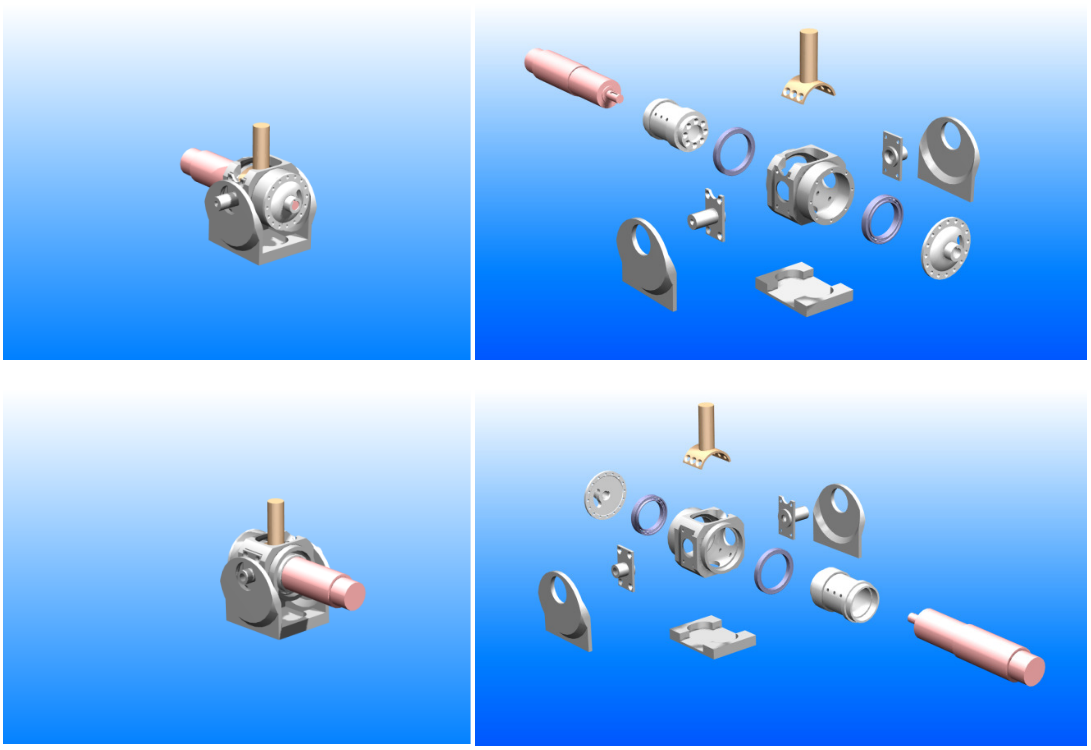


Figure 2-2 trisometric view of the hip joint

The motors and gearboxes used in the TUlip are produced by Maxon. The motors are brushed DC motors of the RE 35 series. The gearboxes used in the hip joint are of the planetary type of the GP 32 series. The encoders used in the hip joint are manufactured by two different companies. The encoders on the motors are produced by Maxon. The encoders placed on the joints are produced by Scancon. The Scancon encoder is used to measure the angular displacement of the joint. The specs of the motors, gearboxes and encoders that are used in the hip joint are shown in Appendix D: Specification of the electric components.

2.1.2. Theoretical range of motion

The range of motion as stated in earlier researches is shown in Table 2-1. The actual range of motion of the hip joint is stated in Chapter 3.

Table 2-1 human and TUlip range of motion [4, 5]

joint		Human			TUlip		
	Axle	min [°]	max [°]	range [°]	min [°]	max [°]	range [°]
waist	φ	-5	5	10	-	-	-
	Θ	-4	4	8	-	-	-
hip	φ	-20	45	65	-35	70	105
	ψ	-125	15	140	-135	45	180
leg	Θ	-45	45	90	-25	40	65
knee	ψ	0	135	135	0	135	135
ankle	φ	-30	20	50	20	20	40
	ψ	-20	45	65	-30	40	70
toe	ψ	-45	20	65	-	-	-

2.2 Experimental identification of the hip joint characteristics

In this section a description is given of the tests that are performed in the study of the TUlip hip joint. The following tests are performed to determine the backlash and the range of motion in the φ-axle. For testing, only the sensor part of the TUlip is active, the motoring part is not powered. The tests are executed while the robot hangs on a stand.

- *Range of motion test*: Moving one leg at a time by hand, from its neutral position to its maximum outer position and then to its maximum inner position. This is repeated a number of times.

The *Range of Motion test* is performed to see what the range of movement (ROM) is and if there are inconsistencies in the ROM.

- *Backlash test*: Moving one leg to a certain height. If the leg is at a certain height, the leg is released. Before letting go, it is made sure that the TUlip will not be damaged. This is repeated several times.

The backlash test is performed to see what the radial play is between the encoder en the measured position of the electric motor. At dead center of the swinging motion both the encoders have a static position. When the leg starts moving again a difference will be realized between the encoders, measuring backlash. For an accurate measurement of the backlash, the first swinging motion of the leg is not included.

3. Results

This chapter gives insight in the obtained results. For more information about the range of motion on the different joints of the TUlip see Appendix B: Testing results: data. For the actual testing results see Appendix C: Testing results: graphs.

3.1 Range of motion test

In this section the findings of the *range of motion test* will be displayed. The range of motion of both the hip joints is stated in Table 3-1. The ROM of the measurements differs from the state motion in 2.1.2.

Table 3-1 measured range of motion

	φ-axle hip joint		ψ-axle hip joint	
	left	right	left	right
Encoder				
max [°]	40,5	21	34	29,6
min [°]	-25,4	-40	-70,8	-82,5
range [°]	65,9	60,9	104,7	112,2
Motor				
max [°]	39,1	21,8	32,1	29,5
min [°]	-23,7	-36,4	-82,3	-83,8
range [°]	62,8	58,1	114,4	113,3
range difference [°]	3,1	2,8	-9,7	-1,1

An unforeseen issue has been noticed. Namely, the Scancon encoder linkage is hitting part of the hip joint. This is shown in Figure 3-1. This means that the angular displacement measured by the encoders of the φ -axle is larger than the actual angular displacement. If the encoder is used as a control signal, the leg will not reach the demanded angle, due to the larger angular displacement measured by the encoder. The hip joint ψ-axle has a similar problem. The placement of the encoder and its linkage is bound by the fact that the encoder has to work in a linear range for proper functioning of the software. Another thing that can be noticed is the difference between the range of motion of the left and the right hip joints. This difference is possibly due to the positioning of the Scancon encoders and/or the adjustments of the linkages that connect the encoder to the joint. Another possibility is wear on the motor-gearbox assemblies due to tests performed on the TUlip. For a better understanding a study has to be done on the position and adjustments of the Scancon encoders and the effects of repeatedly testing.

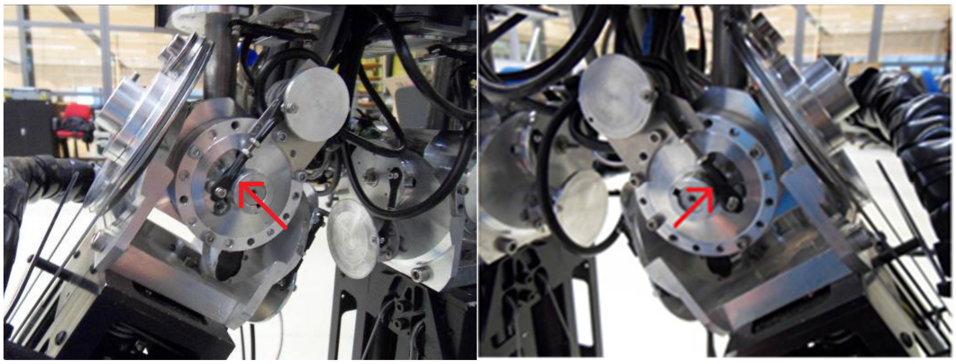


Figure 3-1 hitting of the encoder linkages of the φ -axle

3.2 Backlash test

In this section the findings of the *backlash test* will be discussed. The *backlash test* was used to determine the radial play in the joints.

During the test a few things were observed. First, in the initial position of the swinging motion a large difference in the measurements was noticed. This difference is due to the encoder hitting a part of the robot, as discussed in section 3.1. The initial swing of the leg is discarded. The measurements of backlash are shown in Table 3-2. For comparison of the backlash of the hip joint the ψ-axle of the knee was also tested.

Table 3-2 backlash in the hip and knee joints

	φ-axle hip joint		ψ-axle hip joint		ψ-axle knee joint
	left	right	left	right	left
deviation					
max [°]	1,77	3,59	1,79	2,17	2,86
min [°]	-1,75	-0,07	-1,21	-1,4	-0,43
range [°]	3,51	3,65	3	3,57	3,29
average deviation [°]	1,76	1,83	1,5	1,79	1,65

Table 3-3 Maxon specs on the motor-gearbox assembly

	φ-axle hip joint	ψ-axle hip joint
Serie (motor + gearbox)	RE 35 + GP 32 HP	RE 35 + GP 32 HP
Max radial play [°]	2,08	2,08

The backlash, as is stated by Maxon on the motor-gearbox assembly, is show in Table 3-3. For the backlash on the individual motor and gearbox see Appendix D: Specification of the electric components.

The backlash of the φ-axle hip joint as stated by Maxon is larger than the measured backlash, because the radial play stated by Maxon is the maximal allowed backlash. The φ-axle hip joint is configured without any additional gear sets or cables and pulley sets. Thus, the radial play of the φ-axle is solely caused by the backlash of the motor-gearbox assembly.

The radial play of the ψ-axle hip joint is smaller than the backlash stated in the documentation supplied by Maxon. The ψ-axle hip joint has a pulley-cable set to transfer the power of the motor-gearbox assembly to the hip joint. The disadvantages of using a cable to transfer a force and motion, is that a cable is subjected to deformation. A force can cause the cable to elongate. Tensioning the cable reduces the elongation during operating. The disadvantage of tensioning the cable is an increased friction on the pulleys. The ratio between the pulley and spindle drive makes the system stiffer. The used ratio causes the radial play in the ψ-axle hip joint to be smaller than the radial play stated by Maxon. The overall ratio ensures that the hip joint has a smaller radial play in the ψ-axle compared to the φ-axle.

4. Reduction of backlash in the φ-axle

In this section of the research of the TUlip hip joint, different concepts to reduce backlash are given. In the first section the requirements for the design are discussed. The second section shows the concepts that are developed to reduce the backlash. In the third section the advantages and disadvantages of the different designs are shown.

4.1 Design requirements

In this chapter the requirements for the design of the hip joint are stated. In the subtopic a short description is given of the calculations carried out to determine the parameters for the concepts.

The mean requirements are:

- The backlash must be reduced to a maximal radial play of 1.5 degrees
- The concepts must fit in the geometric limits of the TUlip
- The kinematic structure of the TUlip cannot be altered

Calculations

This section describes the method to compute the inertia matching. It is important to know the inertia matching. Inertia matching forms a benchmark in the functioning of the system. It gives insight in the speed that acts on the system during operation. Because little is known about the inertias of the leg, the following assumptions have been made: the center of mass of an assembly is located halfway the assembly, the leg is divided into three major assemblies (upper leg, lower leg, foot). For the calculation of the inertia of the leg of the TUlip the following formulas are used [2]:

$$J_l = \sum_n m_n * L_n{}^2 = \frac{J_m}{i^2}$$

$$\ddot{\varphi} = \frac{T_e}{J_m + \frac{J_l}{i^2}} = \frac{T_e}{J_m\left(1 + \frac{1}{i^4}\right)}$$

i : the cumulative of all ratio's acting on the system [-]
J_{load} : the inertia of the complete leg of the Tulip in [kg m^2]
J_{motor} : the inertia of the electrical motor in [kg m^2]
L_n : the distance between the axle of the joint and the center of mass in [m]
m_n : the mass in [kg]
T_e : Torque of the electric motor [Nm]
φ'' : the angular acceleration of the motor in [rad/s^2]

The radial play in a system is calculated by means of the formula stated below. The radial play is mainly caused by the manufacturing tolerances, therefore, the manufacturing specifications are used. If there are no manufacturing specifications available, the assumption is made that the system is backlash free, because the radial play has to be defined in further research.

$$\eta_{total} = \sum_{n} (i_1 * \ldots * i_{n-1}) \eta_n$$

η : the radial play of a specific component [rad]
i : the ratio between different components of a system [-]

4.2 Concepts

In this section the different concepts for reducing the radial play of the hip joint are described. A distinction can be made in the concepts; an addition ratio can be placed or a different gearing can be used, to reduce the backlash in the φ-axle. Three concepts are given: adding a planetary gear set (PGS), adding a harmonic drive and switching to a different gearbox with less backlash.

4.2.1 Planetary gear set

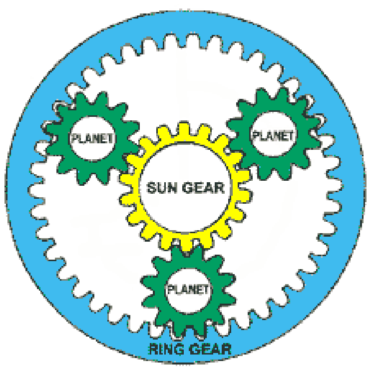


Figure 4-1 schematic planetary gear set

This concept is composed of adding additional PGS. The effect of the extra gear set is to reduce the backlash by means of the ratio used, as is described in section 4.1. The advantage of a PGS is the simplicity of applying it to the hip joint. A disadvantage is that a PGS has backlash, because of manufacturing tolerances and thereby contributes to the radial play of the joint [3]. The PGS is limited to two different layouts, because the outgoing shaft of the motor-gearbox assembly forms the sun-gear of the PGS. This is due to the fact that the outgoing gearbox shaft forms the center of where the PGS needs to be placed.

The following formula is used to calculate the ratio of a PGS:

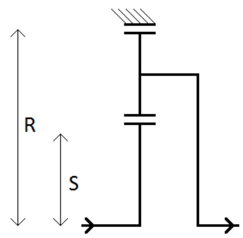
$$(R + S)\omega_P = R * \omega_R + S * \omega_S$$

$$i = \frac{\omega_{out}}{\omega_{in}}$$

i : the ratio of the planetary gear set [-]
R : the average radius of the ring-gear in [m]
S : the average radius of the sun-gear in [m]
ω_P : angular velocity of the planetary carrier in [rad/s]
ω_R : angular velocity of the ring-gear in [rad/s]
ω_S : angular velocity of the sun-gear in [rad/s]
ω_{in} : the angular velocity of the in-going shaft in [rad/s]

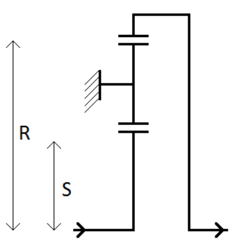
ω_{out} : the angular velocity of the out-going shaft in [rad/s]

Two different setups can be used for the PGS, depending on the available installation method. These are shown in Figure 4-2 and Figure 4-3. The overall calculation of the ratio is shown in the figures. When looking at the possibilities of the installation, the layout showed in Figure 4-3 is preferred. The planetary carrier can be fixed to the motor-gearbox housing and the ring-gear can be integrated in the cover, thereby creating the easiest installation and making optimal use of the available space.



$$\omega_R = 0$$
$$\omega_S = \omega_{in}$$
$$\omega_P = \omega_{out}$$
$$(R+S) * \omega_P = S * \omega_S$$
$$i = \frac{S}{R+S}$$

Figure 4-2 planetary gear set: ring-gear fixed



$$\omega_P = 0$$
$$\omega_S = \omega_{in}$$
$$\omega_P = \omega_{out}$$
$$R * \omega_R = -S * \omega_S$$
$$i = \frac{-S}{R}$$

Figure 4-3 planetary gear set: planetary carrier fixed

Concept 1: data

The implementation of the PGS influences the powertrain of the hip joint. Table 4-1 shows the information of the PGS. The inertia of the PGS is unknown because it is a custom design. The purchase price is determined by production methods and tolerances used to create the PGS. The costs will need to be determined on further notice. The radial play and inertia are unknown, because these can only be determined after fabrication due to the fact that it is a custom design.

Table 4-1 concept 1: planetary gear set

	concept 1
	planetary gear set
total radial play [°]	-
total ratio [-]	132
purchase price for transmission parts	-
weight [g]	42
inertia [gcm^2]	-
acceleration of the joint [rad/s^2]	-

Concept 1: Practice

The concept of adding a PGS can be carried out by changing the cover at the front of the φ-axle. A new cover needs to be fabricated to accommodate the PGS. Figure 4-4 shows the concept; the changes to the hip joint are colored light green and the parts of the PGS are colored red. The encoder needs to be relocated, due to the fact that the attachment point for the encoder cannot be used because the PGS occupies this location. The front cover is dimensioned to its maximum geometry where it will not hit any other part during operation. The issue with a PGS is the overall length of the teeth. The intermeshing teeth transfers the force, therefore the teeth must be able to cope with the stresses related to the force. To create more room, a small bit of the base that forms the connection to the upper part of the upper leg, is grinded down. The base is colored yellow in Figure 4-4. The base is the main obstruction that determines the shape of the φ-axle cover, which houses the PGS. The PGS is a custom design, therefore, there are no spare parts available. The problem with a custom PGS is the radial play. To reduce the overall backlash in the system, the radial play of the PGS needs to be minimized. Therefore, the custom design requires a high manufacturing accuracy, with high production costs as a consequence. The advantages of the PGS are: it is a compact design, it is easy to install, and it requires a minimal amount of alterations to implement. The disadvantages are: it has backlash because of manufacturing tolerances, and the manufacturing costs are high because it is a custom design. For the dimensions of the parts of the PGS concept see Appendix E: Planetary gear set.

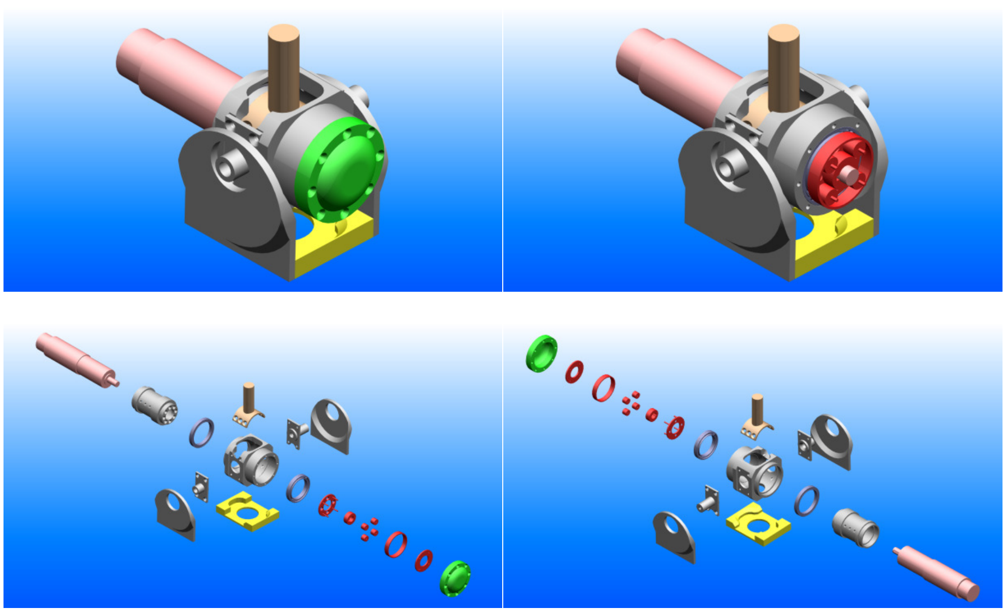


Figure 4-4 concept planetary gear set

4.2.2 aanHarmonic drive

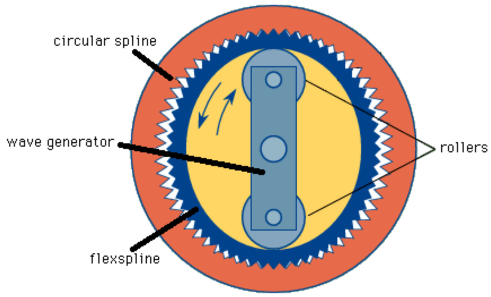


Figure 4-5 schematic harmonic drive

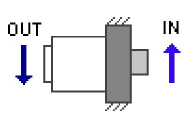
This concept is composed of replacing the gearing with a harmonic drive. A harmonic drive is a single stage gearing composed of three major components: the wave generator, flexspline and circular spline. The harmonic drive ratio is determined by the difference in teeth between the flexspline and the circular spline. Typical gearing ratios of commercial drivers range from 50:1 to 320:1 [1]. This is due to the configuration of the three major components. The advantages of the harmonic drive are: it has no backlash, it has high torque capacity, it causes an overall decrease in weight and it has a 30% teeth engagement and has a long life expectancy. The disadvantages are: the price of a harmonic drive is twice as high compared to a planetary gearbox (because its components need to be precision manufactured) and the installation is complex due to the layout of the harmonic drive. There are three basic harmonic drive layouts that can be used in the hip joint, these are shown in Figure 4-6 to Figure 4-8.

The following formula is used to calculate the ratio of the harmonic drive [4]:

$$\omega_{WG} = (i+1) * \omega_{CS} - i * \omega_{FS}$$

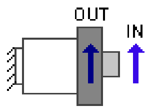
$$i = \frac{T_{FS}}{T_{CS} - T_{FS}}$$

i : the ratio of the harmonic driver [-]
T_{FS} : number of teeth of the flex spline
T_{CS} : number of teeth of the circular spline
ω_{WG} : angular velocity of the wave generator in [rad/s]
ω_{CS} : angular velocity of the circular spline in [rad/s]
ω_{FS} : angular velocity of the flex spline in [rad/s]



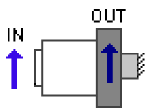
$$\omega_{CS} = 0$$
$$\omega_{WG} = \omega_{in}$$
$$\omega_{FS} = \omega_{out}$$
$$\omega_{WG} = -i * \omega_{FS}$$

Figure 4-6 harmonic drive, circular spline fixed



$$\omega_{FS} = 0$$
$$\omega_{WG} = \omega_{in}$$
$$\omega_{CS} = \omega_{out}$$
$$\omega_{WG} = (i+1) * \omega_{CS}$$

Figure 4-7 harmonic drive, flex spline fixed



$$\omega_{WG} = 0$$
$$\omega_{FS} = \omega_{in}$$
$$\omega_{CS} = \omega_{out}$$
$$(i+1) * \omega_{CS} = i * \omega_{FS}$$

Figure 4-8 harmonic drive, wave generator fixed

Concept 2: data

The implementation of the harmonic drive influences the lay-out of the powertrain. In Table 4-2 information is given about the harmonic drive. The major advantage of the harmonic drive is that it has zero radial play.

Table 4-2 concept 2: harmonic drive

	concept 2
	harmonic drive
total radial play [°]	0
total ratio [-]	81
purchase price for transmission parts	€ 514,00
weight [g]	90
inertia [gcm^2]	33
acceleration of the joint [rad/s^2]	1364,16

Concept 2: practice

The harmonic drive gearboxes produced are too large to fit in the hip joint. A components set is needed for this geometric limitation. Manufactures specify their component sets in different sizes. For this concept a size 14 component set can be used, colored red in Figure 4-9. The size 14 component set has an outer diameter of 50 [mm] and a torsion stiffness of 2 [Nm]. Such a component set is produced by Harmonic drive AG and is from the HFUC series [1]. It is assumed that the RE 35 electric motor will be used in this concept. The size 14 component set needs no changes to fit the motor. Because of the 50 [mm] diameter of the size 14 component set can only be connected in specific manner in the hip joint. The flex spline is fixed to the housing of the electric motor and forms the fixed part of the harmonic drive. The wave generator is coupled to the outgoing shaft of the motor and the circular spline is connected to the φ-axle housing, Figure 4-7 is the schematic representation of how the harmonic drive is installed. In Figure 4-9 the concept is shown. The parts that are colored green are newly machined parts. The φ-axle housing and the connection base to the upper part of the leg need to be grinded down to accommodate the new parts, these are colored yellow in Figure 4-9. An additional shaft is needed between the electric motor and the harmonic drive, because of the placement of the harmonic drive. For a better understanding see Appendix F: Harmonic drive. If attention is paid to the bearings, one thing can be noticed in this concept compared to the other concepts. The bearings are mounted from one side into the φ-axle housing. The size of the harmonic drive induced the relocation of one bearing. To accommodate the bearing the φ-axle housing needs to be grinded down. For the dimensions of the parts of the harmonic drive concept see Appendix F: Harmonic drive

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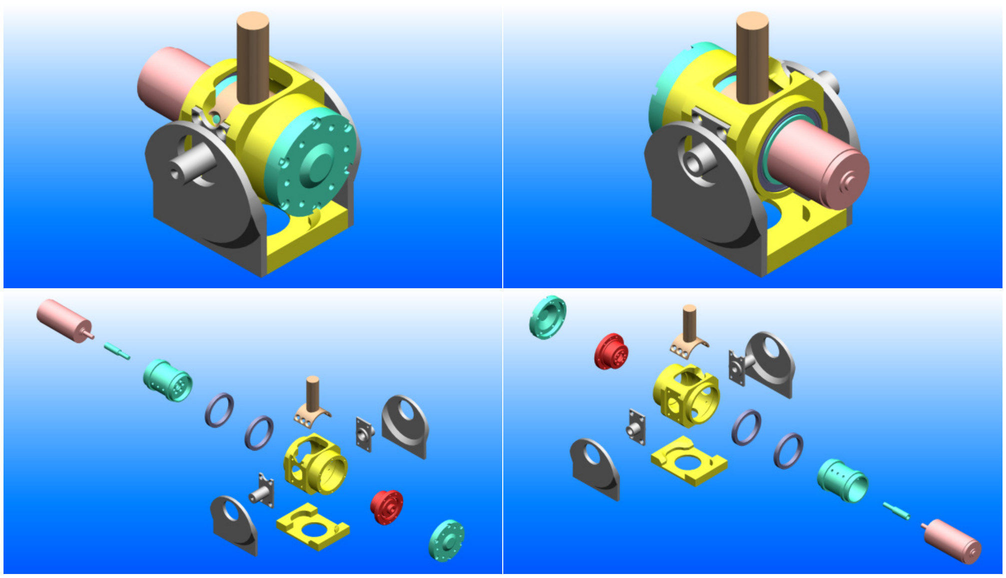

Figure 4-9 concept harmonic drive

4.2.3 GP 42 Maxon gearbox

Figure 4-10 Maxon gearbox

This concept is using a gearbox from different series. Different series of the Maxon gearboxes have different characteristics. The GP 32 series have a maximal radial play of 1.60 degree, while the GP 42 series have a maximal radial play of 0.57 degree. The gearboxes provided by Maxon are interchangeable and produced with a wide range of different ratios. The advantages of using a Maxon gearbox are: it perfectly fits onto the Maxon motor, it has a high torque capacity, has a long life expectancy and is a readily available part to order. The disadvantages are: the large GP 42 gearbox needs to be accommodated in the limitations of the geometry of the hip joint and therefore requires many parts to be altered, it has backlash due to manufacturing accuracy and it causes an overall increase in the weight of the joint. The GP 42 series has a gearbox with a 66:1 ratio that can be used (this is the same ratio as used in the original GP 32 gearbox).

Concept 3: data

Implementing a different Maxon gearbox influences the powertrain. In Table 4-3 GP42 Maxon gearbox, information is given about the concept.

Table 4-3 GP42 Maxon gearbox

	concept 3
	GP42 gearbox
total radial play [°]	0,57
total ratio [-]	66
purchase price for transmission parts	€ 216,40
weight [g]	460
inertia [gcm^2]	15
acceleration of the joint [rad/s^2]	945,29

Concept 3: practice

The Maxon gearboxes are interchangeable and are produced with compatible ratios. The issue with using the GP 42 series is the size of the gearbox. The GP 42 series has a diameter of 42 [mm], this is 10 [mm] large than the GP 32 gearbox. Most of the components of the hip joint are altered to accommodate the larger gearbox. In Figure 4-11 the concept is shown. The parts that are colored light green are the parts that are changed to implement the GP 42 gearbox. As visible in Figure 4-11, all the components that make up the φ-axle need to be altered. The bright green part is the motor-gearbox assembly composed with the GP 42 gearbox. The major disadvantage of implementing the GP 42 gearbox is that the components are larger and therefore heavier than in the existing hip joint.

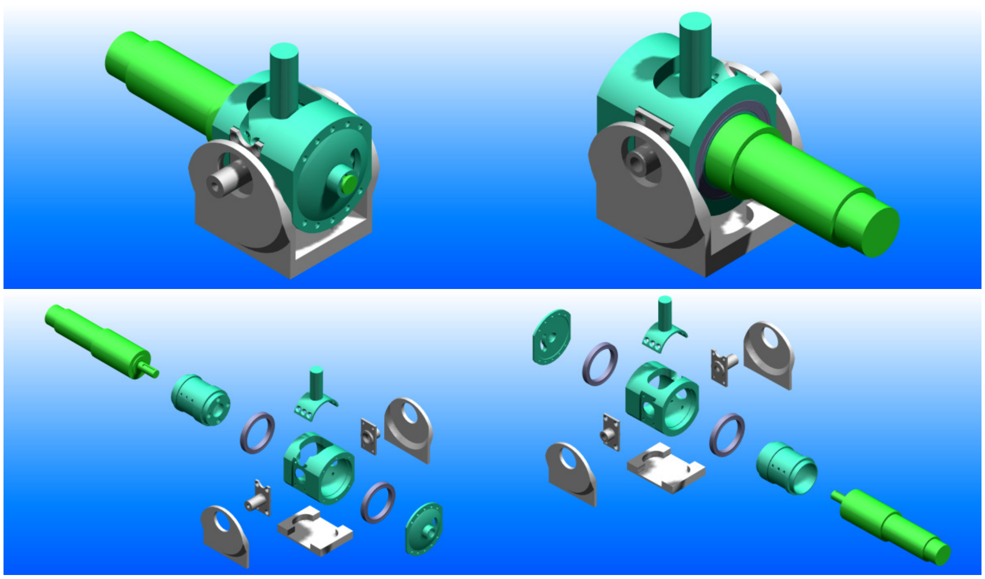

Figure 4-11 concept GP 42 gearbox

4.3 Comparison of the concepts

This section discusses the advantages and disadvantages of the different concepts. In Table 4-4 information about the current hip joint and the concepts are shown. Part of the information of the PGS is unknown, because of the custom design. The radial play and inertia of the PGS have to be determined when the PGS is manufactured.

Table 4-4 information parameters

	current configuration	concept 1	concept 2	concept 3
	GP32 gearbox	planetary gear set	harmonic drive	GP42 gearbox
Radial play of the transmission [°]	1,6	-	0	0,57
Total ratio [-]	66	132	81	66
Purchase price for transmission parts	€ 177,67	-	€ 514,00	€ 216,40
Weight [g]	213	42	90	460
Inertia [gcm^2]	1.5	-	33	15
Acceleration* [rad/s^2]	945,29	3077,70	1364,16	945,29

* Acceleration of the electronic motor

Table 4-5 shows to which extent a concept performs. The table is used as followed. Each characteristic is rated by means of a scale. The scale is constructed in the following manner:

++ : performance is excellent
+ : performance is average to better than average
- : performance is average to worse than average
-- : performance is bad

The characteristics used in the table are as follows:

- Radial play reduction: the extent to which the radial play is reduced.
- Overall costs: the extent to which the purchase price determines the budget needed for the implementation of the concept.
- Durability: the extent to which the system is able to cope with static and dynamic use.
- Manufacturability: the extent to which production is feasible, assumed that every part that cannot be purchased will be manufactured by a department of the Technical University of Eindhoven.
- Serviceability: the extent to which it is possible to carryout maintenance, with a small amount of experience.
- Retaining of the hip joint components: the amount of components that need to be altered to implement the concept, with ++ needing few alterations and -- needing a lot of alterations.
- Weight decrease: the extent to which the weight of the hip joint is decreased, by implementing the concept.

Table 4-5 decision schematics

	concept 1 planetary gear set	concept 2 harmonic drive	concept 3 GP42 gearbox
radial play reduction	-	++	+
Overall cost	*	--	+
durability	+	++	+
manufacturability	-	+	+
Serviceability	-	--**	++
Retaining of the hip joint components	++	+	--
Weight decrease	-	++	--

* The cost for the implementation of the PGS are unknown
** The serviceability for concept 2 performs badly because the placement of the harmonic drive. It is installed in such a way that many steps are required to remove the part

As Table 4-5 shows, the implementation harmonic drive stands out as the best option to reduce the radial play. The disadvantage of the harmonic drive concept is the serviceability. The placement of the harmonic drive forces a complex installation procedure. The benefit of the harmonic drive is its durability and the expectation is that a few maintenance intervals are needed.

5. Conclusion and recommendations

This section discusses the findings of the 2011 spec TUlip hip joint. Furthermore, a recommendation for the reduction of the backlash is made.

Conclusion of the tests

This section discusses the findings of the study carried out on the hip joint of the 2011 TUlip humanoid. A study of the hip joint was carried out because excessive play was noticed in the φ-axle of the hip joint. The second reason for the study is a lack of documentation on the 2011 TUlip hip joint. Two tests were executed to determine the backlash and the range of motion of the hip joints.

A single hip joint contains three Degrees of freedom (DOF's). The TUlip hip joint has two DOF's in the same plane and one DOF represented by an electronic motor on the side of the torso of the TUlip, this resembles the human. The geometry of the hip joint is given in Appendix A: Dimensions hip joint 2011. The range of motion test showed that the true range of the TUlip hip joint is smaller than the stated range for a human and also smaller than the documentation states for the TUlip. Furthermore, the encoder linkages are hitting parts of the hip joint. The effect is that the encoders are not measuring the exact position of the hip joint. The range of motion of the hip joint is shown in Table 5-1.

Table 5-1 range of motion

	human	TUlip	TUlip measured	
			encoder	motor
	range [°]	range [°]	range [°]	range [°]
φ-axle hip joint	65	105	66	63
ψ-axle hip joint	140	180	105	114

The backlash test showed the radial play of the different axles of the hip joint. The test showed that the left φ-axle hip joint had a large radial play. Table 5-2 shows the radial play.

Table 5-2 backlash of the hip joint

	φ-axle hip joint		ψ-axle hip joint	
	left	right	left	right
measured radial play	1,76	1,83	1,5	1,79
Max stated radial play motor-gearbox assembly Maxon	2,08	2,08	2,08	2,08

The measured backlash of the φ-axle is smaller than the specs given by Maxon. This is because Maxon specifies the maximal radial play allowed. The measured backlash in the ψ-axle hip joint is also smaller than the stated backlash of Maxon due to the additional ratio, created by pulley and cable construction. A disadvantage of using a cable is that a cable can elongate due to forces and thereby could contribute to the backlash.

The radial play in the φ-axle is smaller than the manufacturing specification but is still noticeable during operation. The radial play in the ψ-axle is smaller than the manufacturer's specification. This is due to ratio created by the pulley spindle drive.

The minor differences in the measured backlashes can be due to wear of the individual motor-gearbox assemblies. Another cause of the minor differences is the use of extra components to transfer motion, like the cable used in the ψ-axle hip joint. To determine the amount of backlash created by an individual component, further research must be carried out.

Recommendations

In this section the recommendation with respect to the reduction of radial play of the φ-axle is made. To reduce the radial play, three concepts have been developed.

- Adding a planetary gear set to reduce the backlash by means of an additional ratio.
- Using a harmonic drive as gearing and thereby reducing the backlash that would otherwise be created by the gearing.
- The use of the Maxon GP 42 gearbox, this gearbox has a smaller radial play compared to the gearbox used in the hip joint.

In section 4.2 a description is given of these concepts and their layout. Each concept has its advantages and disadvantages, the most important ones are given in Table 5-3.

Table 5-3 major advantages and disadvantages

	Advantage	Disadvantage
Planetary gear set	Compact design	Contributes to the overall backlash
Harmonic drive	Zero backlash	Complex installation
GP 42 gearbox	Large reduction of backlash	A large part of the hip joint has to be altered

The harmonic drive concept is a great solution to reduce radial play in the φ-axle. The harmonic drive has no backlash. The electric motor is the only component that contributes to the backlash when using a harmonic drive. Although the harmonic drive is the ideal solution to reduce radial play, it is an expensive part and this could be a problem regarding the budget.

The GP 42 gearbox is a good runner up for the reduction of the radial play. There are uncertainties concerning the PGS. The radial play is determined by the manufacturing accuracies and therefore, the amount of radial play of the PGS is unknown. To implement the GP 42 gearbox all the parts that make up the φ-axle need to be altered.

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Appendix A: Dimensions hip joint 2011

The dimensions of the hip joint are drawn in Unigraphics NX 7.5. The drawings are digitally printed to a .pfd file. The 2011 spec TUlip hip joint begins with A1 as name of the different files.

1) Overall view

2) X-Y axle housing

3) X-axle housing

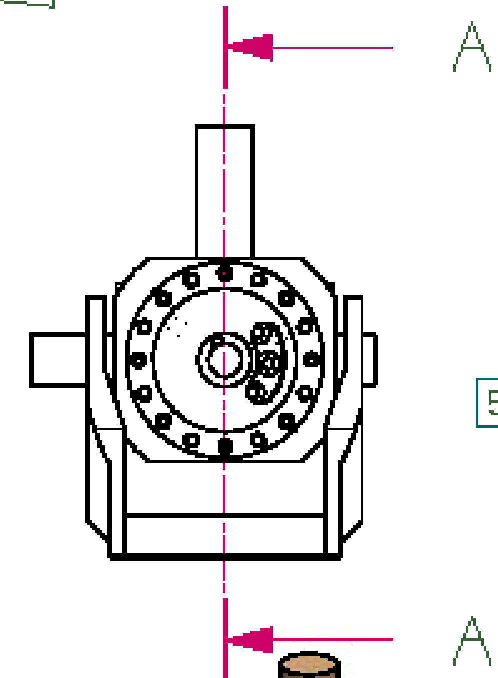
4) Cover

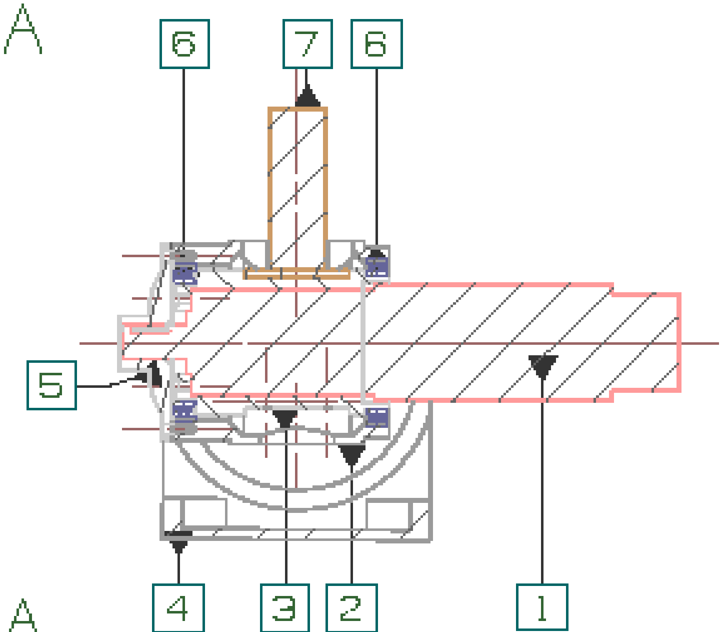
5) Z-axle bracket

6) Overall upper leg connecting base

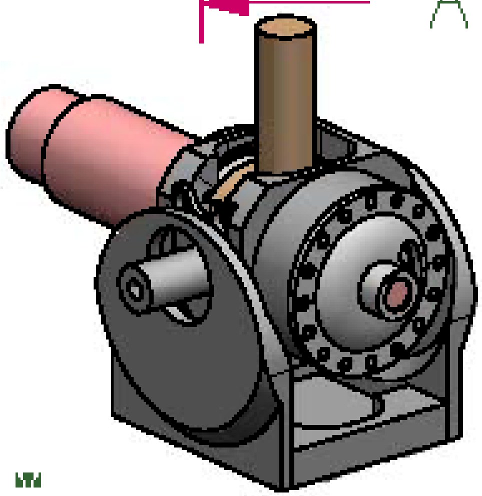
7) Y-axle right hinge bracket

8) Y-axle left hinge bracket





SECTION A-A



1	motor-gearbox assembly
2	X-Y axle housing
3	X-axle housing
4	upper leg connecting base
5	cover
6	bearing
7	Z-axle bracket

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

NX UGS The PLM Company

overview

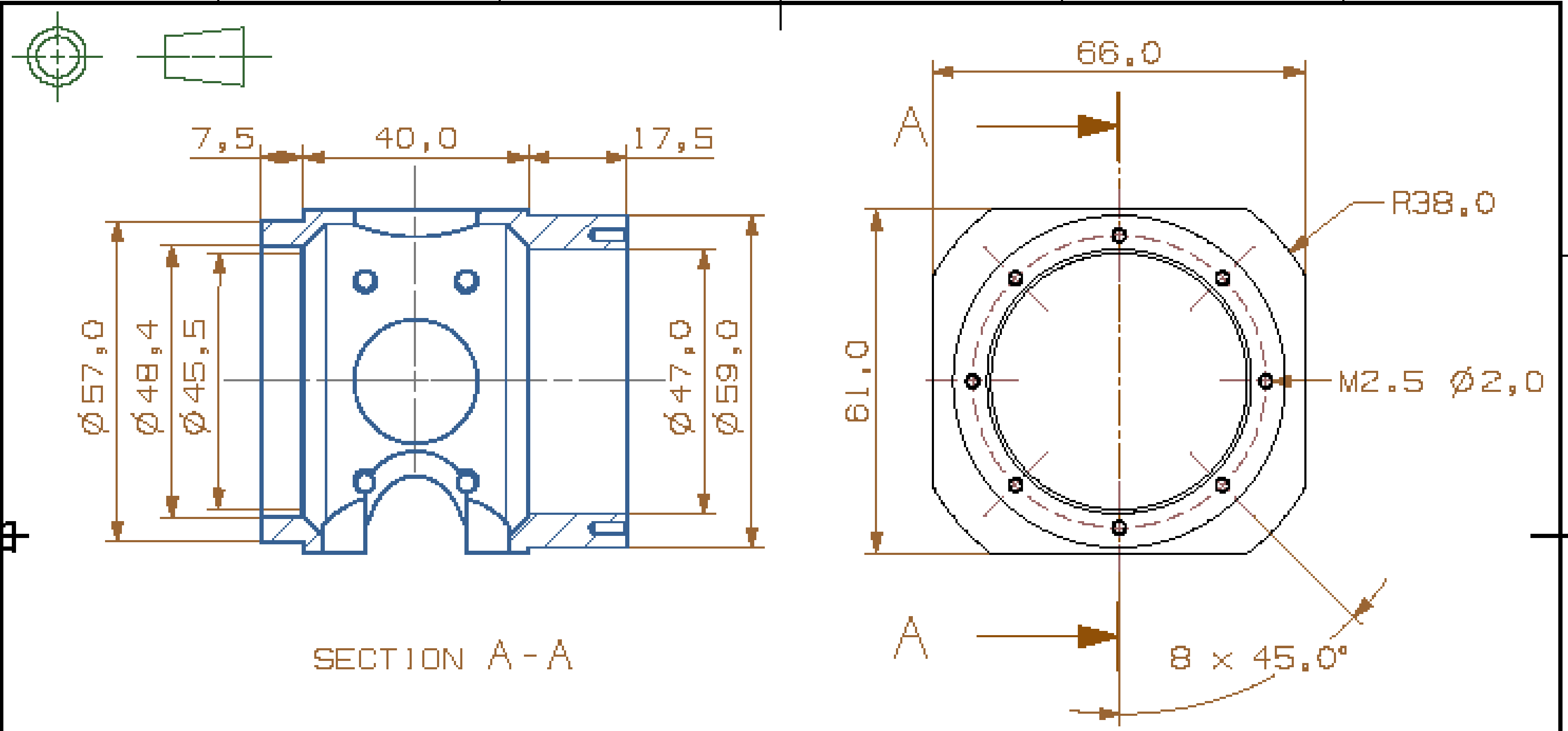
FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

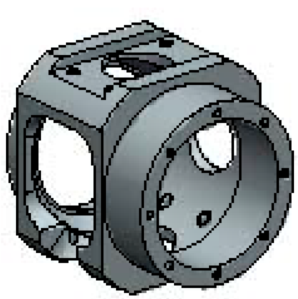
TITLE
TUlip right hip joint 2011 spec

SIZE	DWG NO.	REV.
A4	assembly heup R	

SCALE 1:2

SHEET 1 OF 1





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	overall geometry
FIRST ISSUED	TITLE
DRAWN BY	X-Y axle housing
CHECKED BY	
APPROVED BY	

SIZE	DWG NO.	REV.
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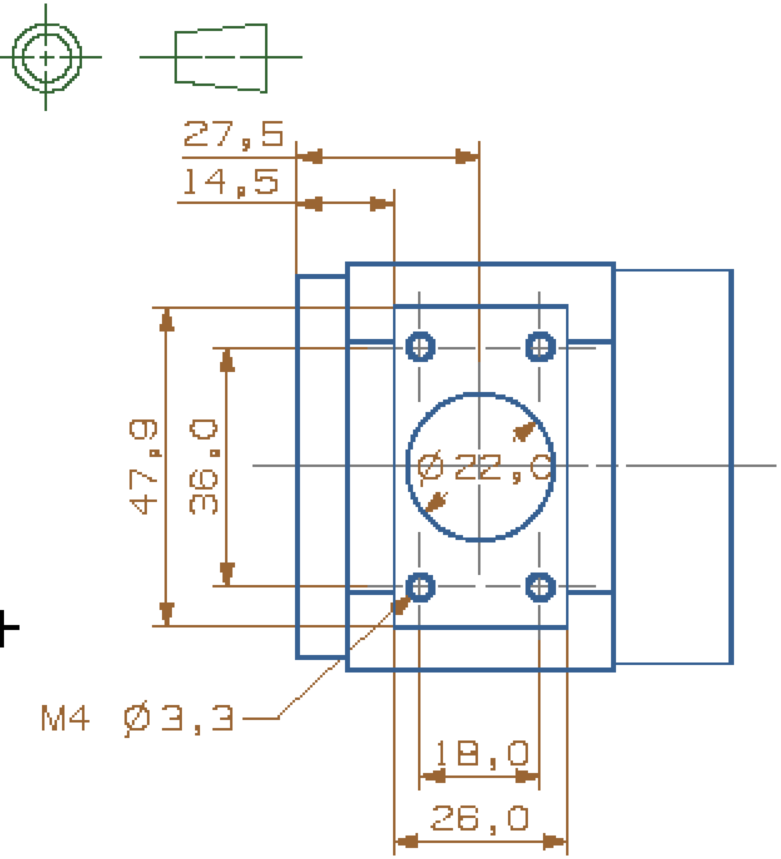
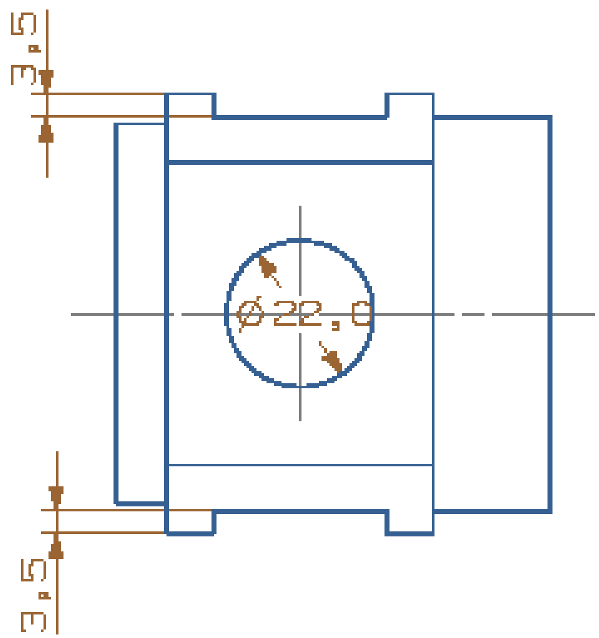
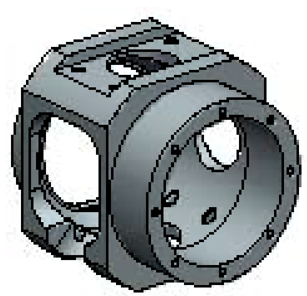
SCALE 1:1				SHEET 1 OF 3







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NX UGS The PLM Company		detailed view of connecting location of the Y-axle bracket, left and right side are the same
FIRST ISSUED		TITLE X-Y axle housing
DRAWN BY		
CHECKED BY		
APPROVED BY		SIZE A4 · DWG NO. X-Y AS behuizing_stp · REV.
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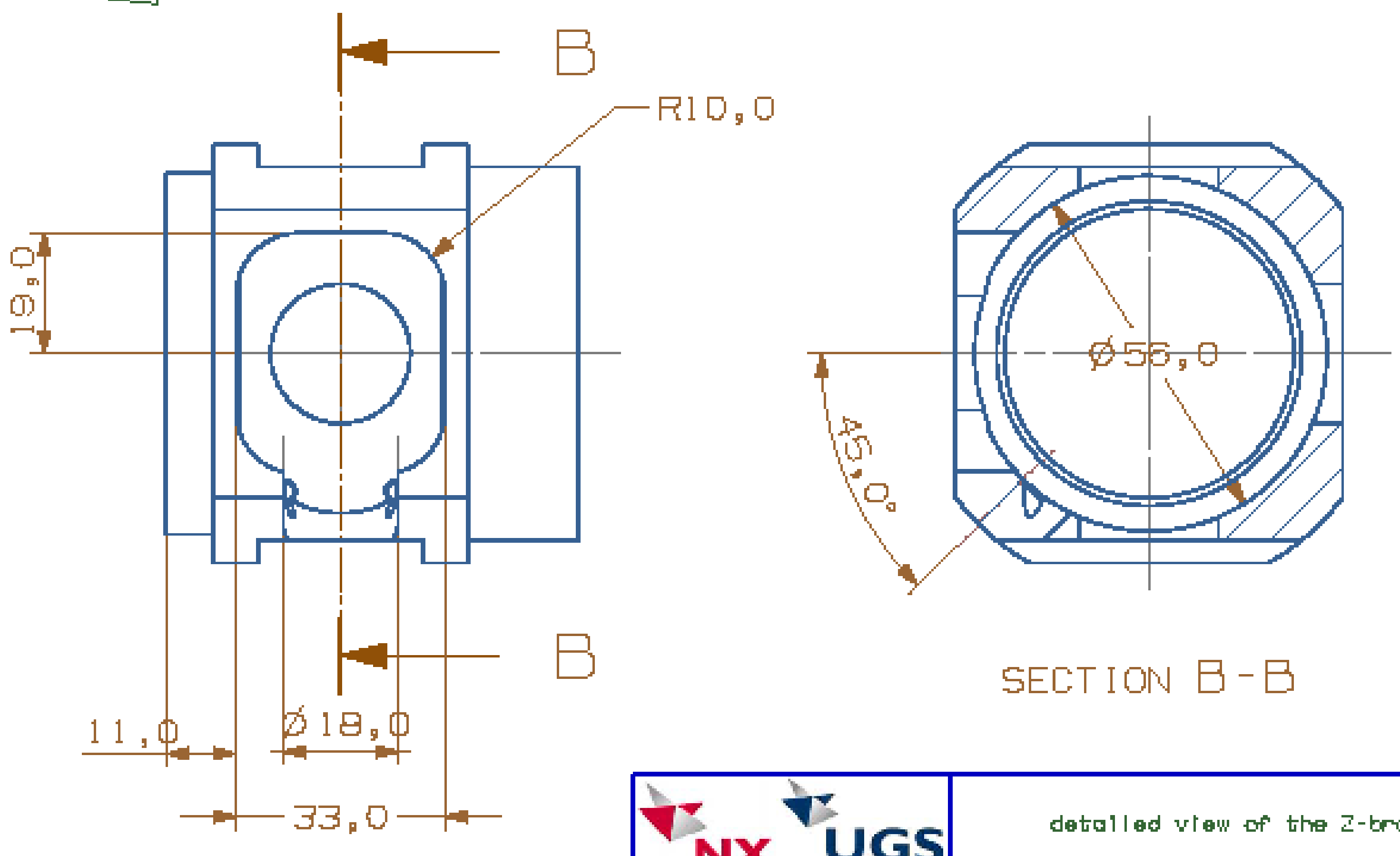

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3D CAD MASTER PART NAME: heup behuizing R1_MODEL31]

NX UGS The PLM Company

detailed view of the Z-bracket slot

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

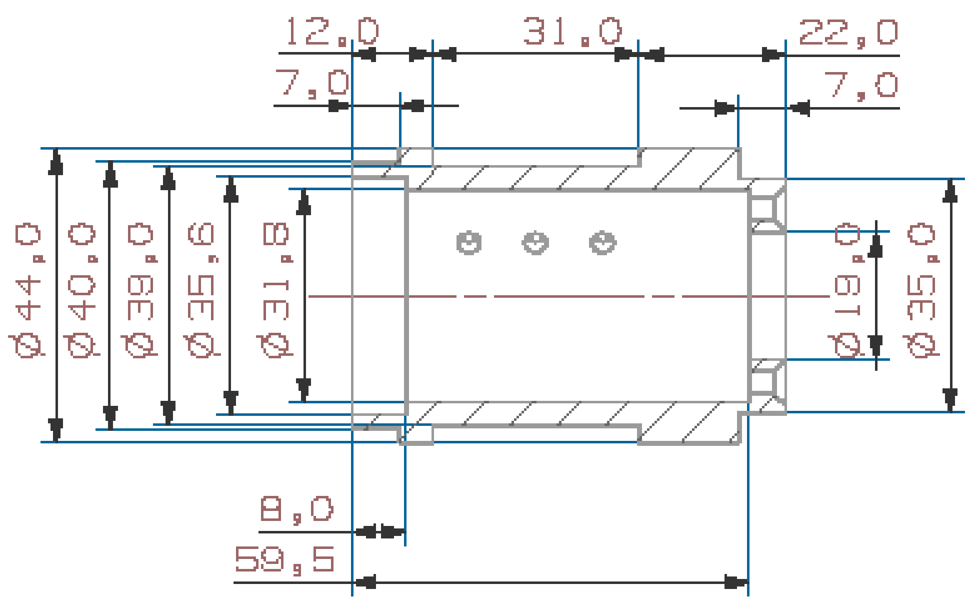
TITLE

X-Y axle housing

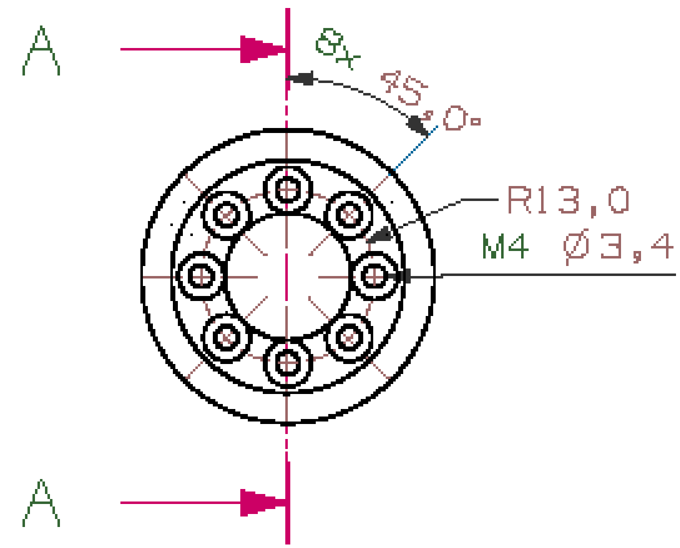
SIZE	DWG NO.	REV.
A4	X-Y AS behuizing_stp	

SCALE 1:1

SHEET 3 OF 3



SECTION A-A



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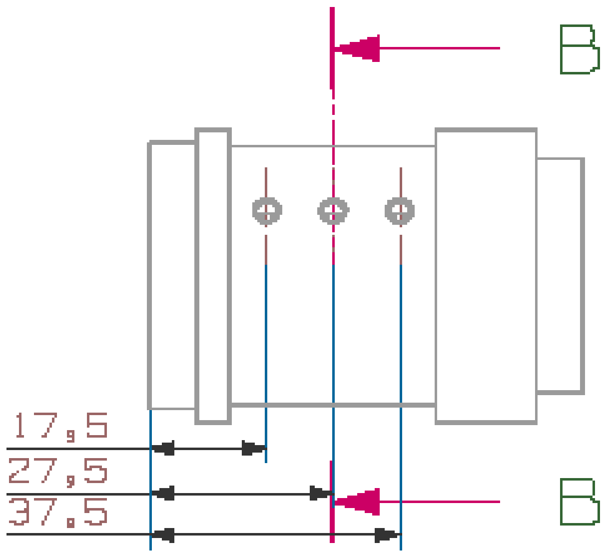
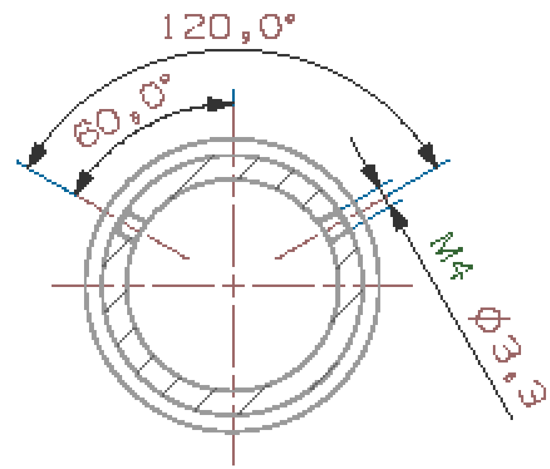
		SCALE 1:1		SHEET 1 OF 2





SECTION B-B

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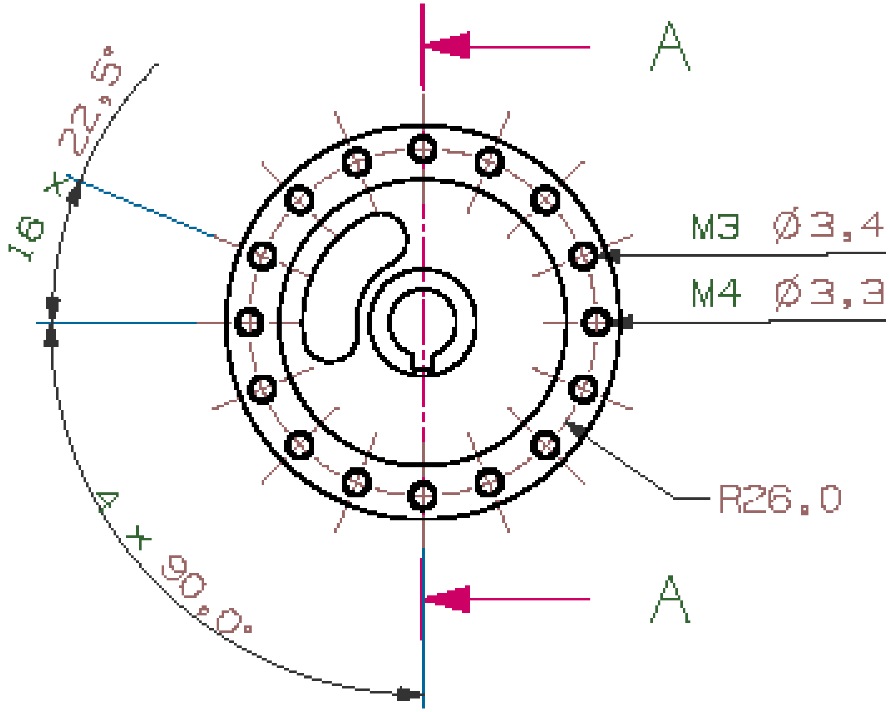
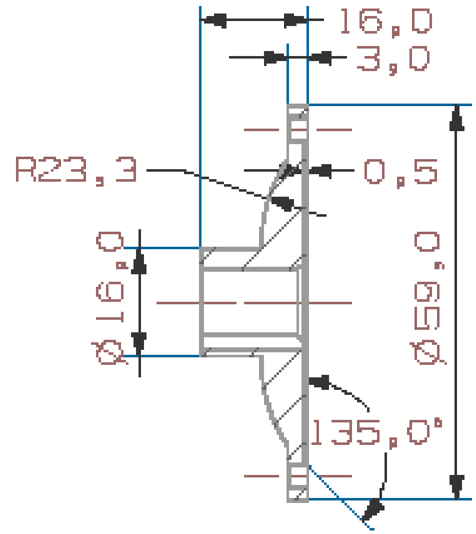
FIRST ISSUED	TITLE
DRAWN BY	motor-gearbox housing
CHECKED BY	
APPROVED BY	SIZE A4 · DWG NO. heup motorbehuizing · REV.
	SCALE 1:1 · SHEET 2 OF 2





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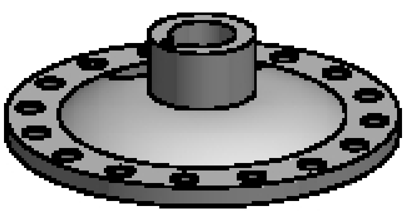

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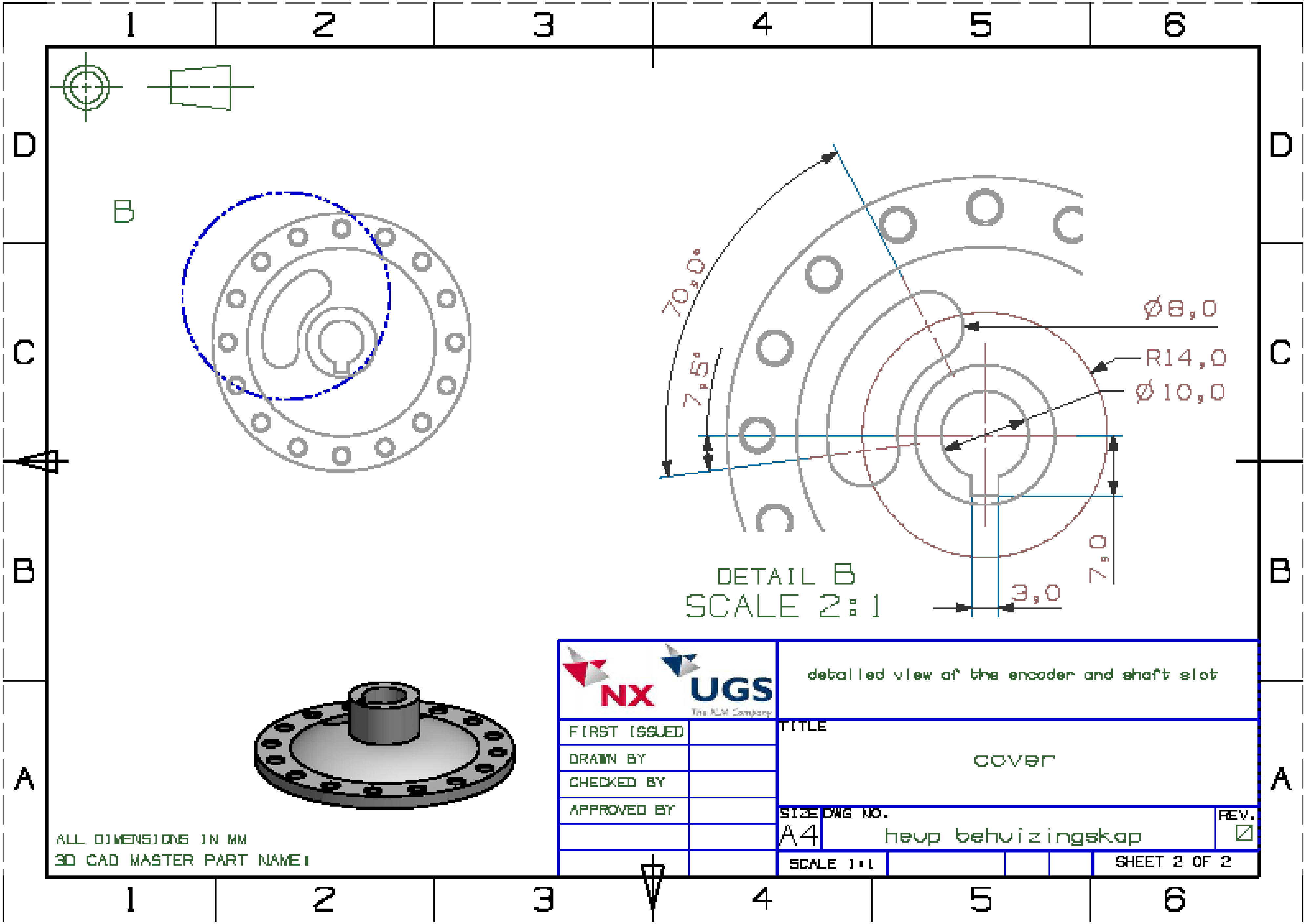
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7,5°
Ø8,0
R14,0
Ø10,0
7,0
3,0
DETAIL B
SCALE 2:1
NX
UGS
detailed view of the encoder and shaft slot
FIRST ISSUED
DRAWN BY
CHECKED BY
APPROVED BY
TITLE
cover
SIZE
A4
DWG NO.
heup behuizingskap
REV.
SCALE 1:1
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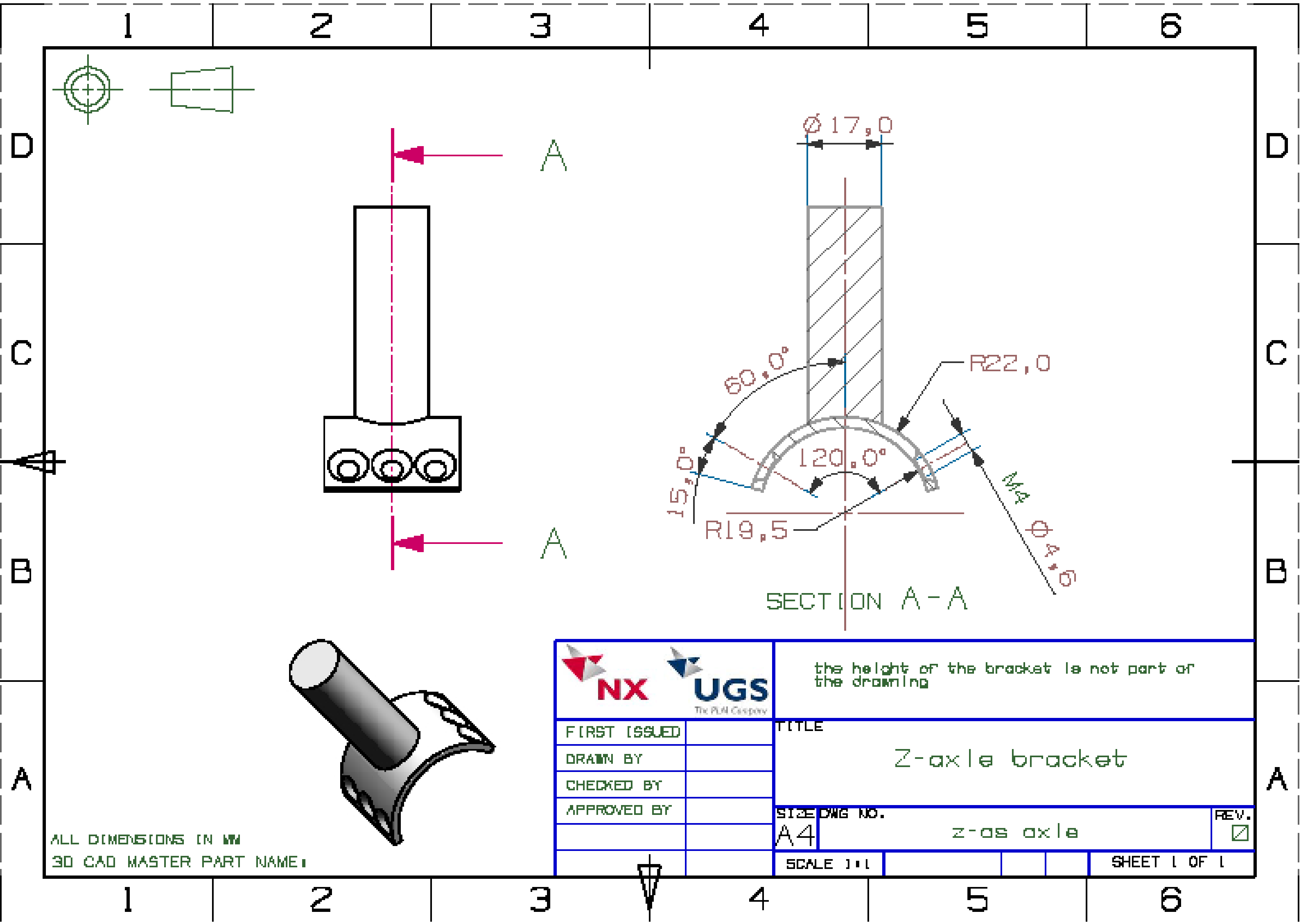

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R22,0
120,0°
15,0°
R19,5
M4 Φ4,6
SECTION A-A
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UGS
the height of the bracket is not part of the drawing
FIRST ISSUED
DRAWN BY
CHECKED BY
APPROVED BY
TITLE
Z-axle bracket
SIZE
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DWG NO.
z-as axle
REV.
SCALE 1:1
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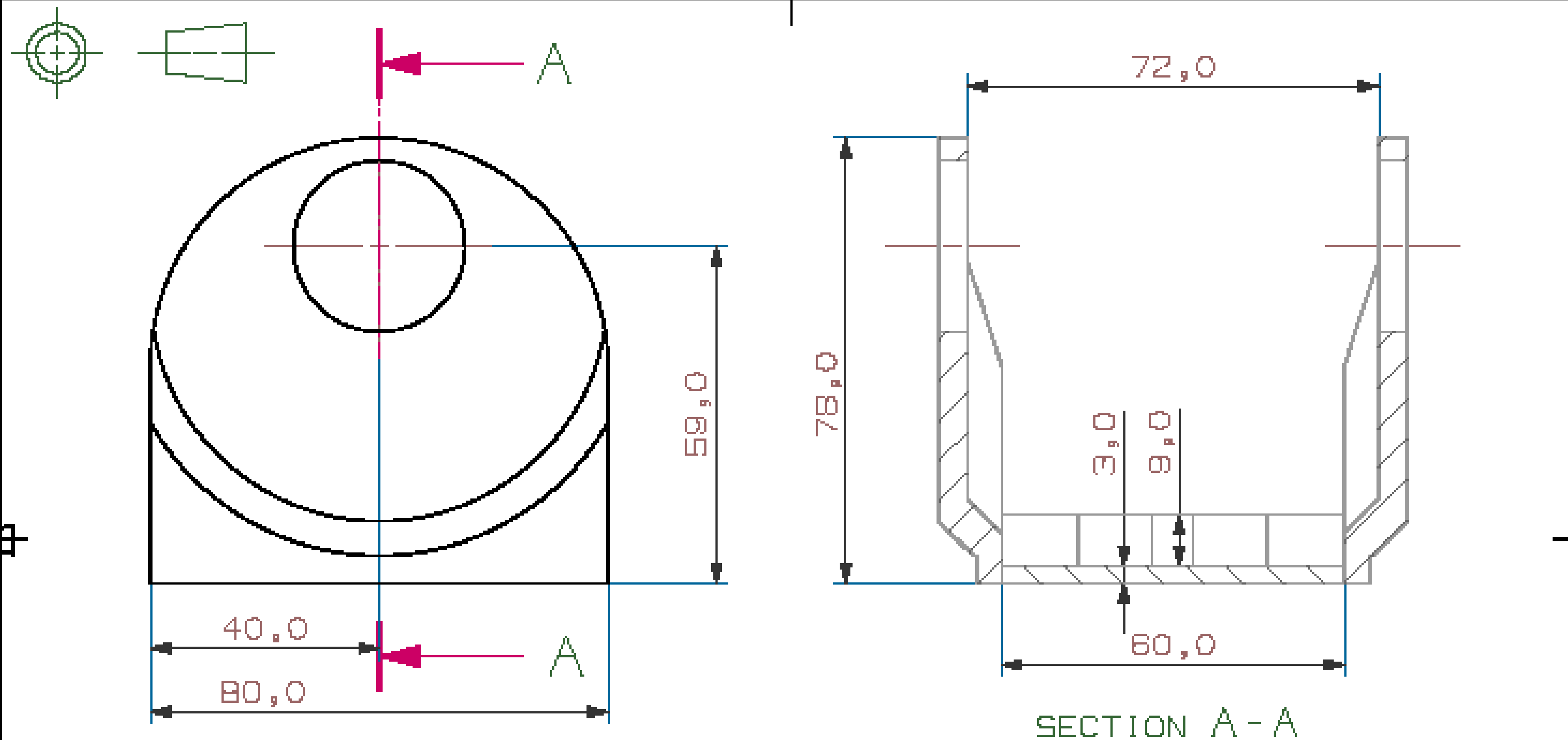

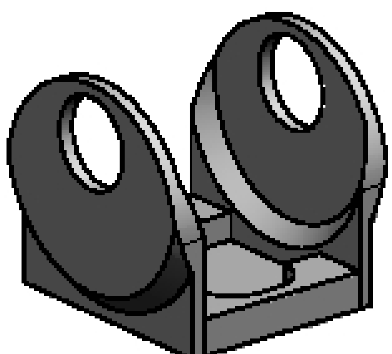

the general geometry of the Y-axle assembly forming the connection to the upper leg

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

TITLE

assembly:
Y-axle to upper leg

SIZE	DWG NO.	REV.
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SCALE 1:1

SHEET 1 OF 1

ALL DIMENSIONS IN MM

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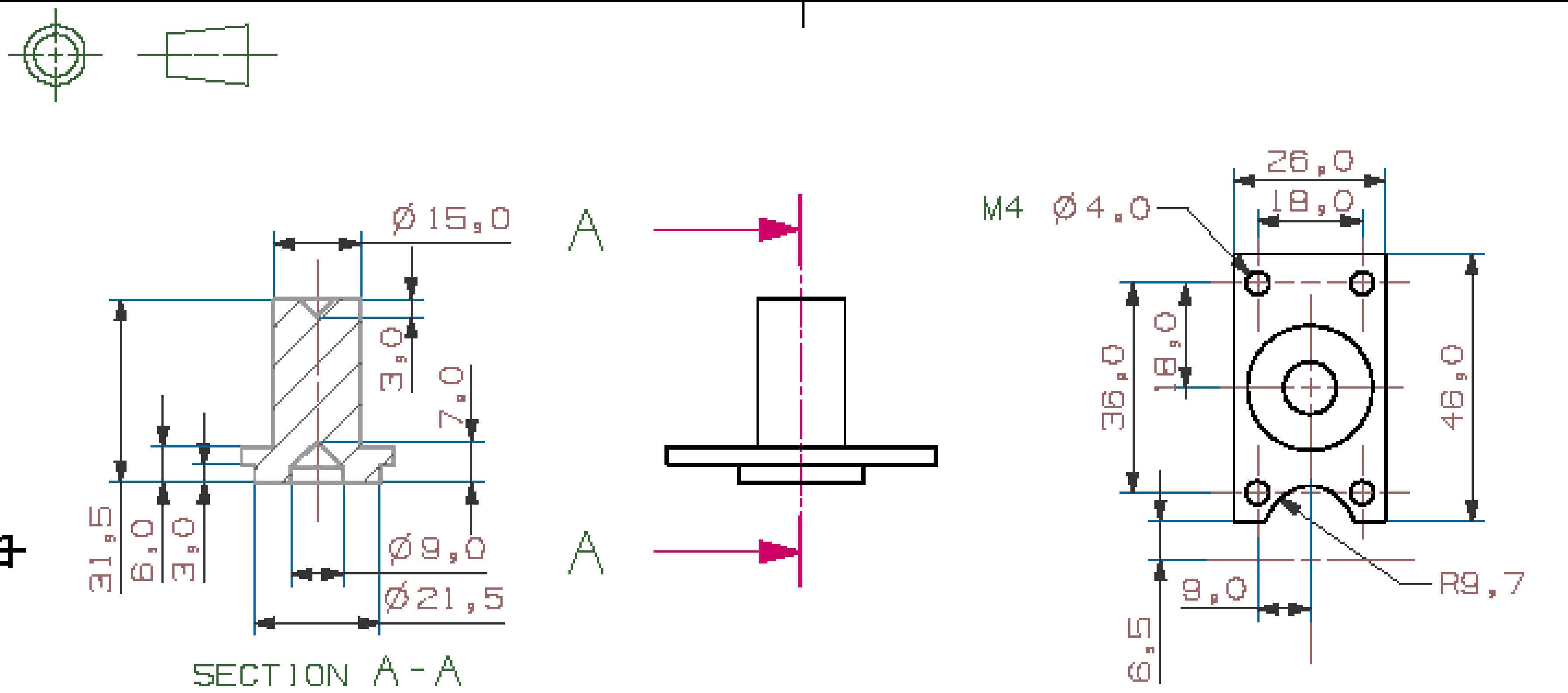

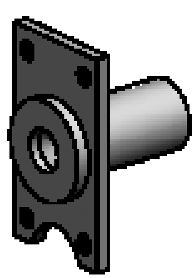

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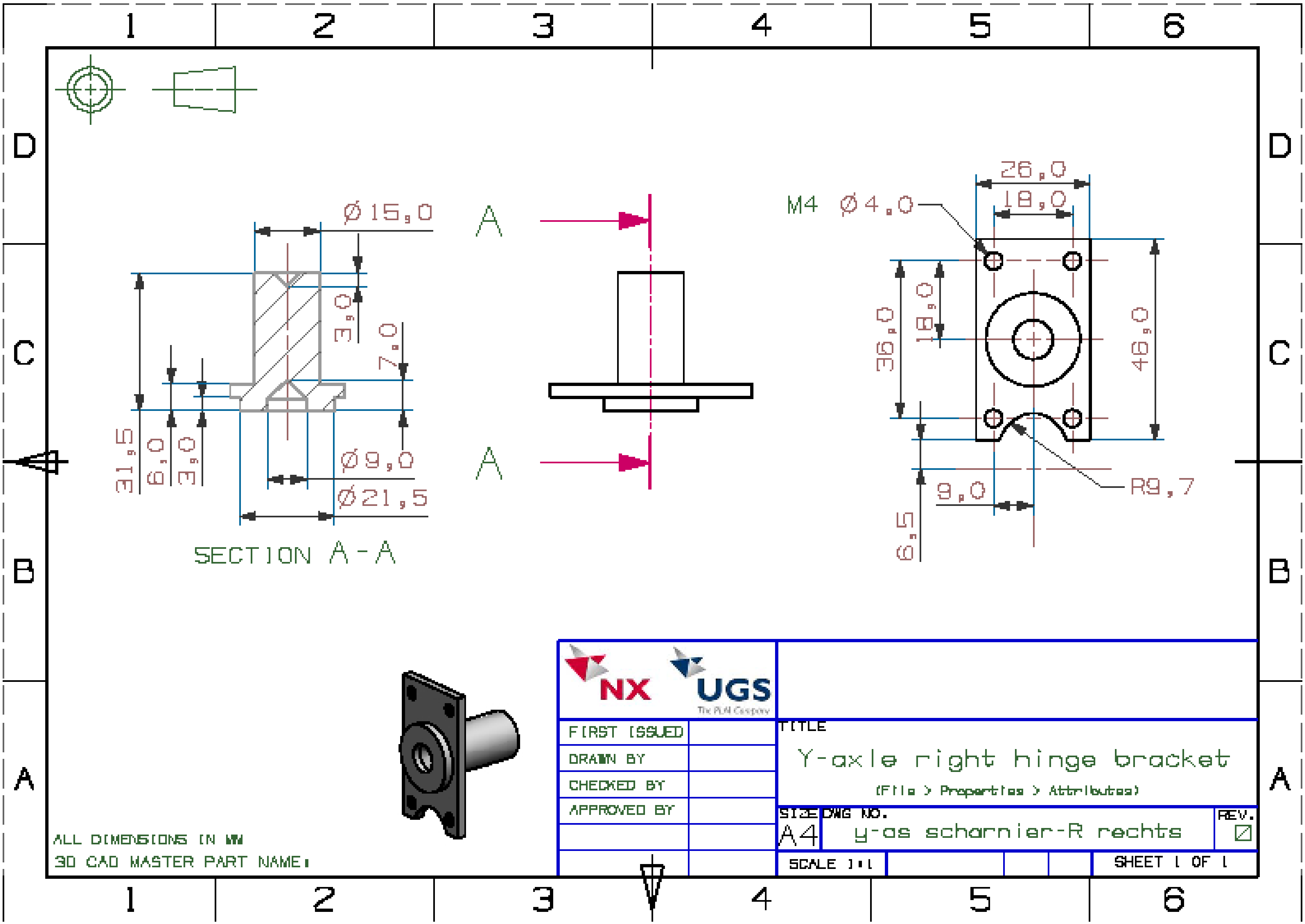
APPROVED BY	

TITLE
Y-axle right hinge bracket
(File > Properties > Attributes)

SIZE	DWG NO.	REV.
A4	y-as scharnier-R rechts	

SCALE 1:1 SHEET 1 OF 1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Ø9,0
Ø21,5
R9,7
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6,5
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APPROVED BY
TITLE
Y-axle right hinge bracket
(File > Properties > Attributes)
SIZE
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DWG NO.
y-as scharnier-R rechts
REV.
SCALE 1:1
SHEET 1 OF 1
ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME:

Appendix B: Testing results: data

Table B-1 stated in previous researches [4]

joint		human			TUlip		
	axle	min [°]	max [°]	range [°]	min [°]	max [°]	range [°]
waist	φ	-5	5	10	-	-	-
	ϴ	-4	4	8	-	-	-
hip	φ	-20	45	65	-35	70	105
	ψ	-125	15	140	-135	45	180
leg	ϴ	-45	45	90	-25	40	65
knee	ψ	0	135	135	0	135	135
ankle	φ	-30	20	50	20	20	40
	ψ	-20	45	65	-30	40	70
toe	ψ	-45	20	65	-	-	-

Table B-2 the measured TUlip joints

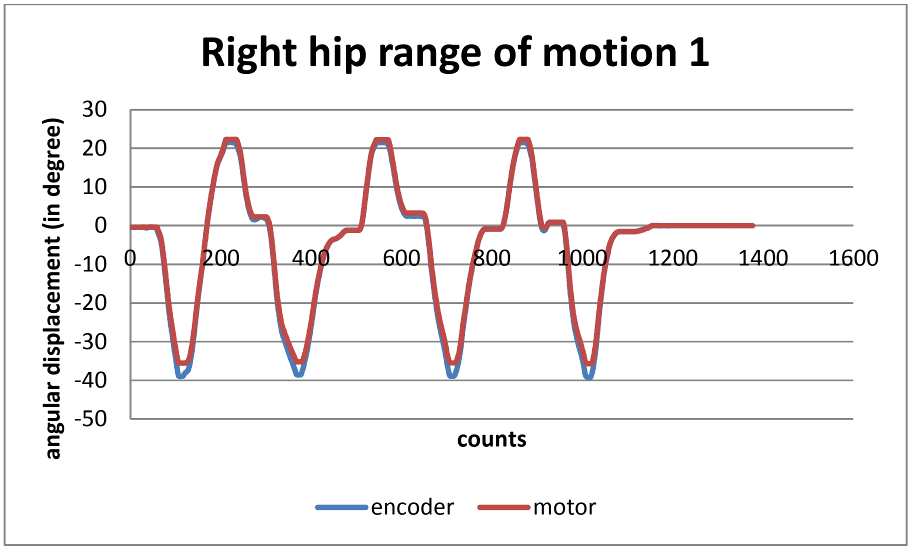
	φ-axle hip joint			**ψ-axle hip joint**		**ψ-axle knee joint****	**ϴ-axle torso joint**	
	left	left modified*	right	left	right	left	left	right
encoder								
max [°]	40,4	40,5	21,0	34,0	29,6	123,2	23,9	30,2
min [°]	-26,3	-25,4	-40,0	-70,8	-82,5	-4,1	-33,8	-27,0
range [°]	66,7	65,9	60,9	104,7	112,2	127,3	57,7	57,2
motor								
max [°]	37,4	39,1	21,8	32,1	29,5	127,1	22,8	33,7
min [°]	-24,3	-23,7	-36,4	-82,3	-83,8	-5,1	-35,6	-27,9
range [°]	61,7	62,8	58,1	114,4	113,3	132,2	58,4	61,6
range difference [°]	5,0	3,1	2,8	-9,7	-1,1	-4,9	-0,7	-4,4
deviation								
max [°]	2,15	1,77	3,59	1,79	2,17	2,86	0,3	4,3
min [°]	-3,82	-1,75	-0,07	-1,21	-1,40	-0,43	-1,9	-1,2
range [°]	5,97	3,51	3,65	3,00	3,57	3,29	2,2	5,5
average deviation [°]	2,99	1,76	1,83	1,50	1,79	1,65	1,1	2,8

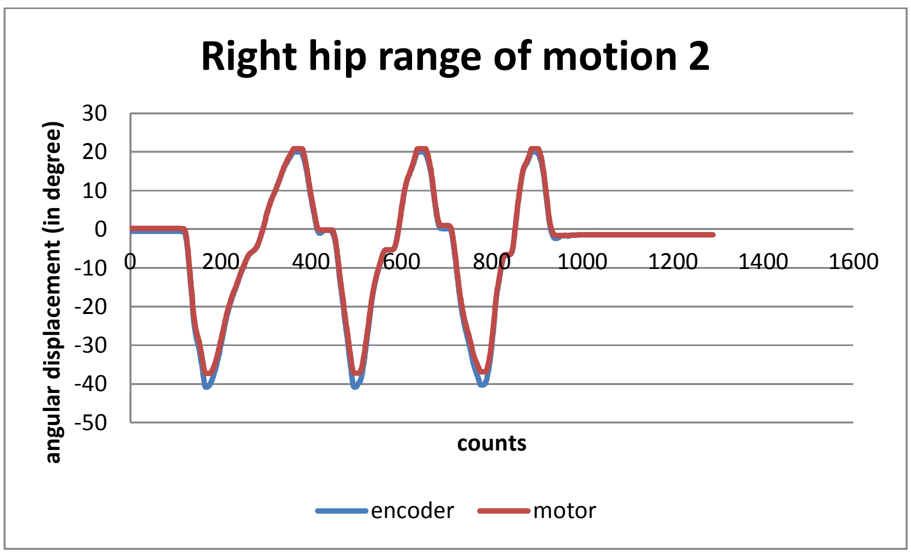
* Play in the motor-gearbox assembly affected the first measurements of the left φ-axle hip. That is why the series left modified was carried out, it shows the difference of a motor-gearbox assembly without play.
** Only the left knee joint could be tested, the right knee joint was not functioning properly at the time.

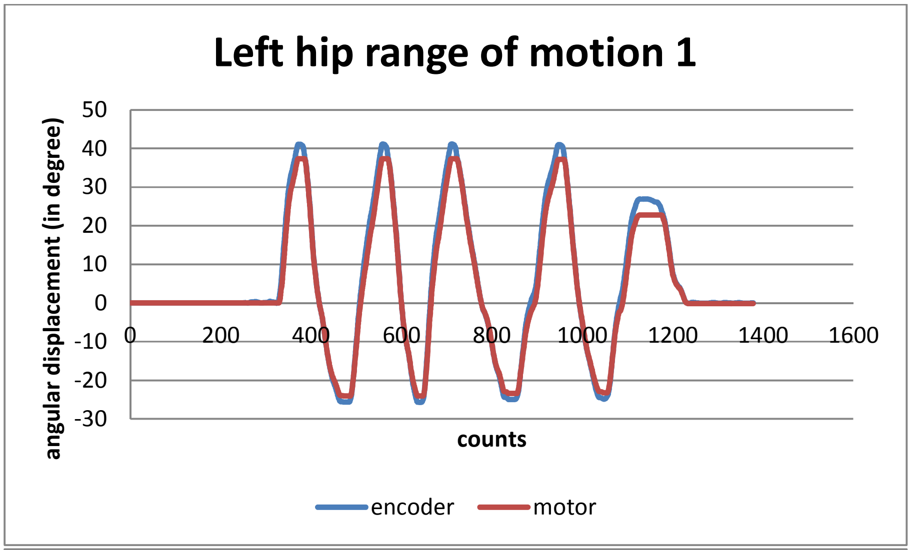
The backlash of the left φ-axle hip joint is due to slack between the motor and gearbox assembly. The assembly could be twisted by hand. The slack was caused by wear or loosening on the assembly itself. In the 'left modified' φ-axle hip joint there is no slack in the motor-gearbox assembly. A difference of 1.2 degrees was caused by the wear or loosening between the mounting point of the motor and gearbox.

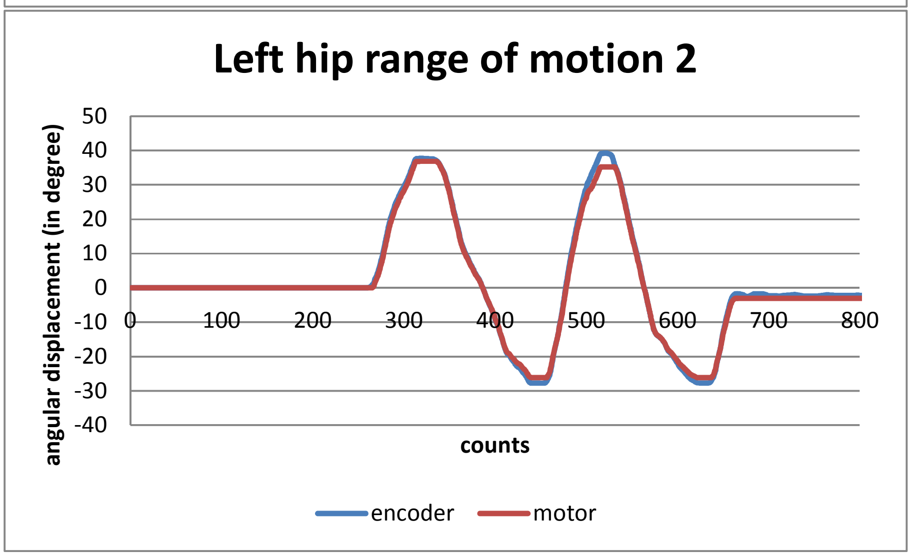
Appendix C: Testing results: graphs

Movement of the leg:



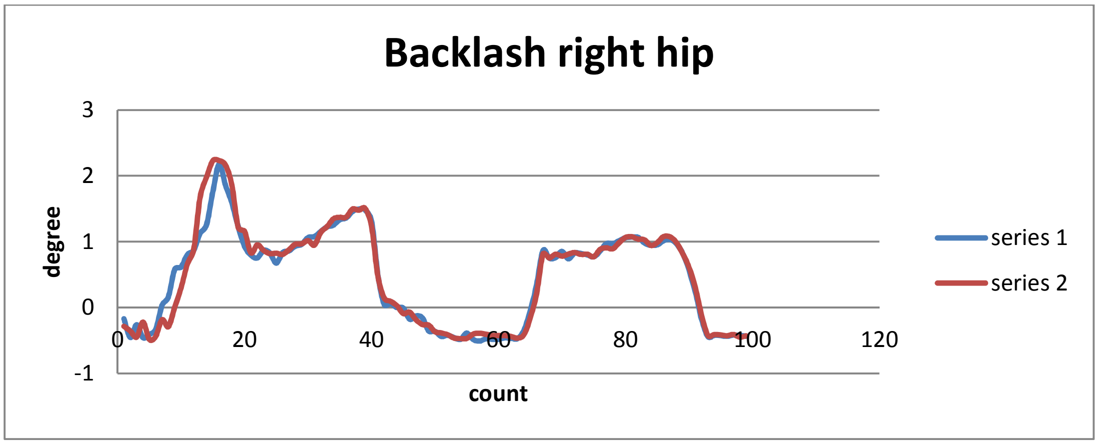


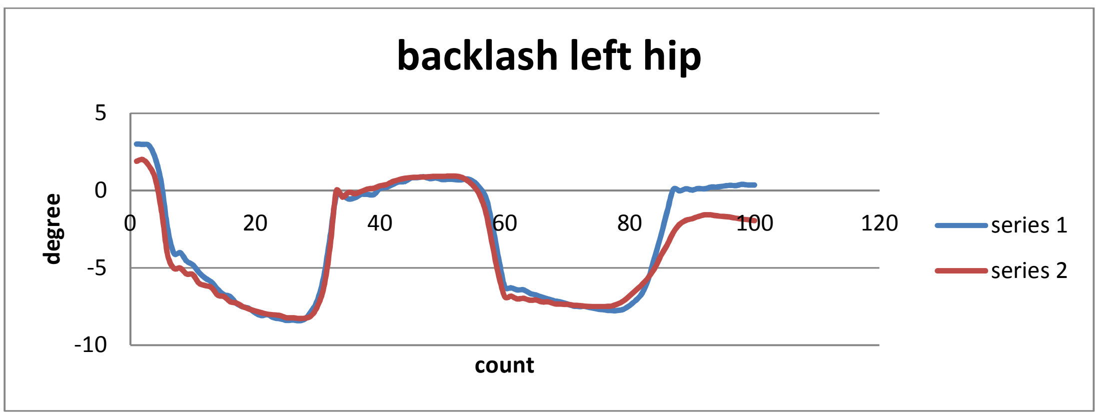

Left hip range of motion 1
angular displacement (in degree)
50
40
30
20
10
0
-10
-20
-30
0
200
400
600
800
1000
1200
1400
1600
counts
encoder
motor

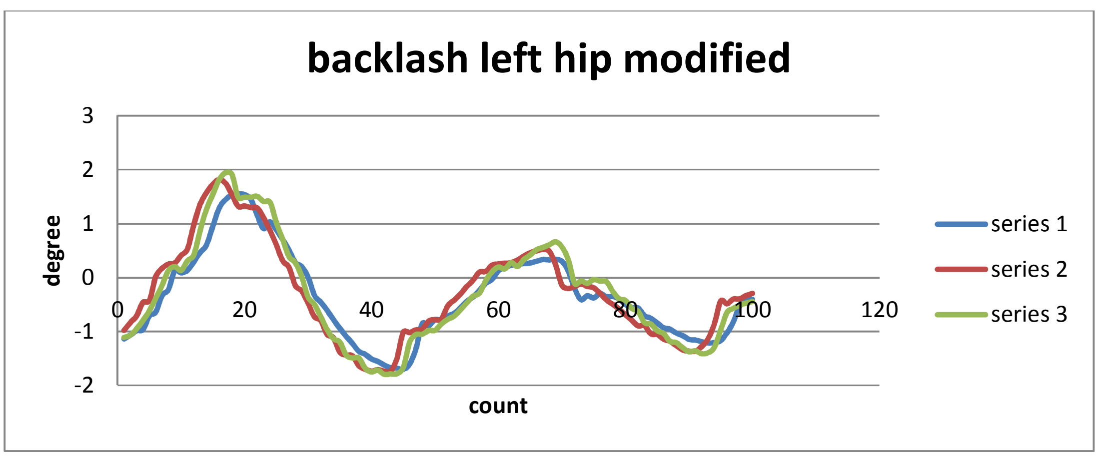

Left hip range of motion 2
angular displacement (in degree)
50
40
30
20
10
0
-10
-20
-30
-40
0
100
200
300
400
500
600
700
800
counts
encoder
motor

Swinging of the leg:

The initial swing of the leg is cut off, because the initial swing has an error. This error is caused by the encoder hitting part of the hip joint. The first peak of the swinging motion represents the backlash of the hip joint. The total backlash of the hip joint is given by the difference between the maximum and minimum degree difference.







Appendix D: Specification of the electric components

Table D-3 Maxon DC motor specs

position	φ-axle hip joint	ψ-axle hip joint
serie	RE 35	
order no.	323890	
power [W]	90	
mass [kg]	0.340	
η [%]	84	
stall torque [mNm]	1160	
max. velocity [rpm]	12000	
radial play [°]	0.4752	

Table D-4 Maxon gearbox specs

position	φ-axle hip joint	ψ-axle hip joint
serie	GP 32 HP	
on motor	RE 35	
order no.	326665	
ratio [-]	66:1	
mass [kg]	0.210	
η [%]	70	
nominal torque [Nm]	8	
stall torque	12	
radial play [°]	1.60	

Table D-5 encoders spec

manufacturer	Maxon	Scancon
position	motor	joint
serie	HED 5540	SCA24AN
counts/turn	500	1024

Appendix E: Planetary gear set

The dimensions of the hip joint are drawn in Unigraphics NX 7.5. The drawings are digitally printed to be a .pfd file. The 2011 spec TUlip hip joint begins with A1 as name of the different files. Only the parts that are altered are drawn. For parts that are not worked out in this appendix see appendix A

1) Overall view

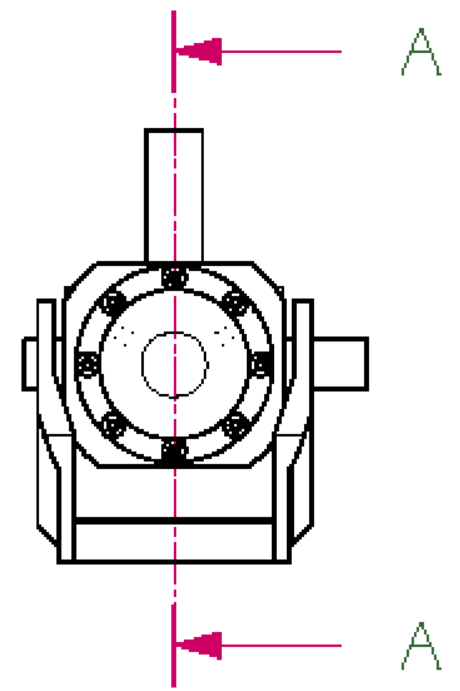
2) Cover

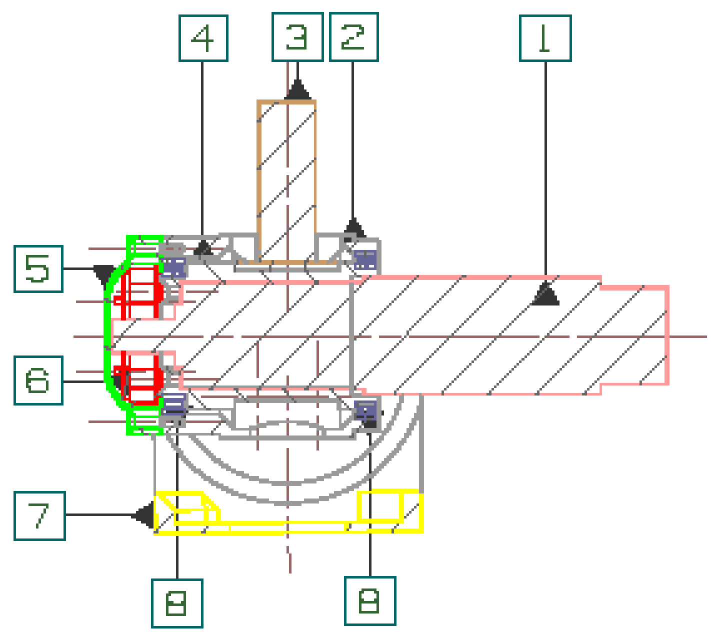
3) Overall planetary gear set geometry

4) Planetary carrier 1

5) Planetary carrier 2

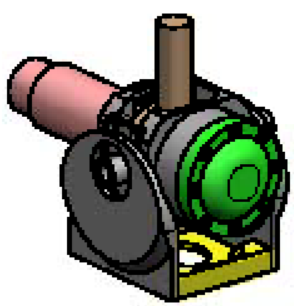
6) Upper leg connecting base





SECTION A-A

1	motor-gearbox assembly
2	X-Y axle housing
3	Z-axle bracket
4	X-axle housing
5	cover
6	planetary gear set
7	upper leg connecting base
8	bearing



NX UGS The PLM Company

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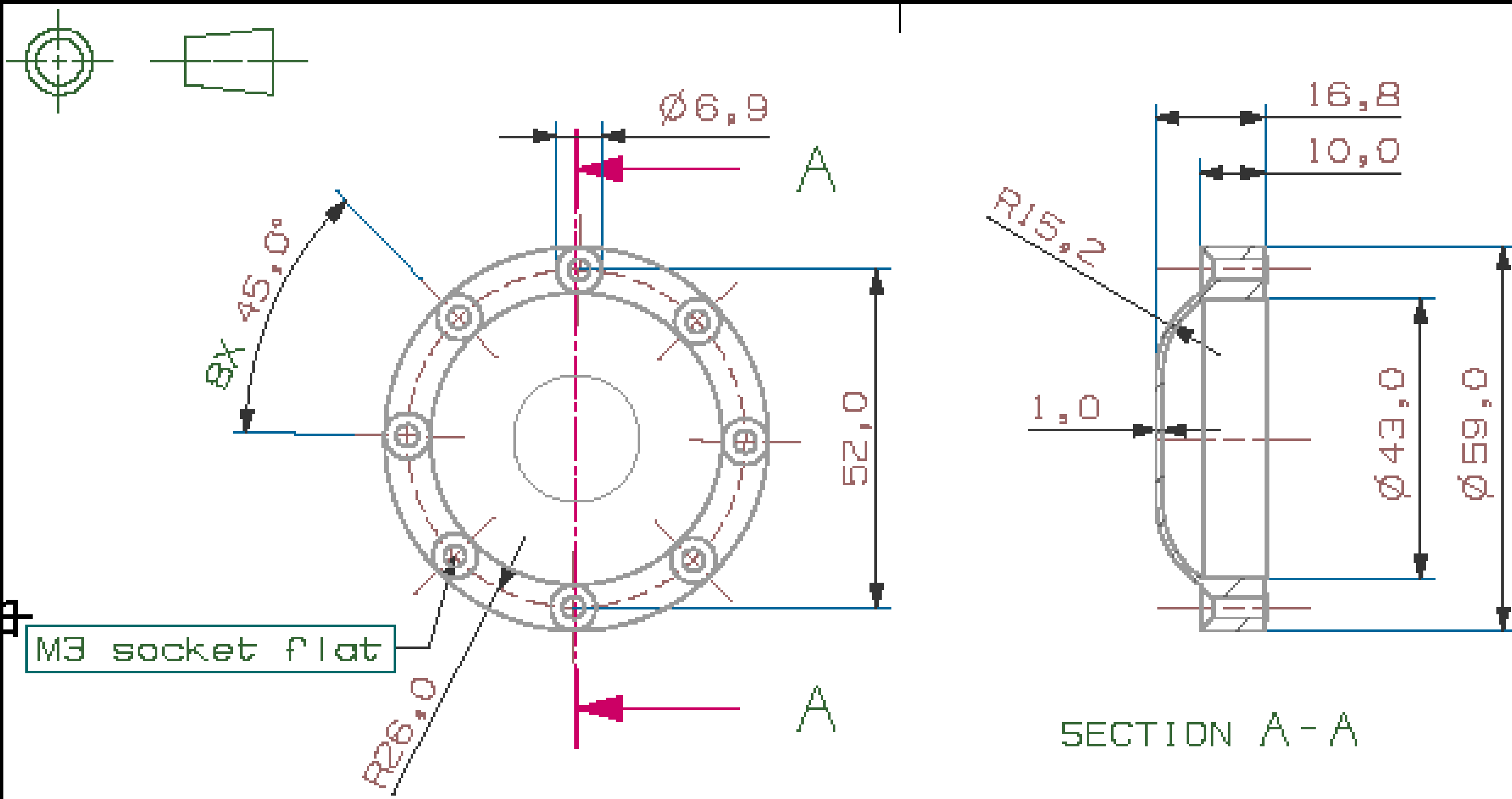
DRAWN BY	
CHECKED BY	
APPROVED BY	

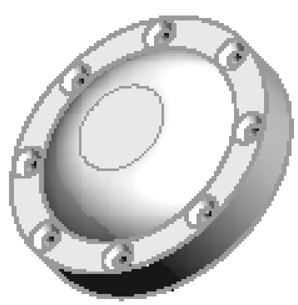
TITLE
concept: planetary gear set

SIZE	DWG NO.	REV.
A4	C1 assembly heup R	

SCALE 1:2 SHEET 1 OF 1

ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME:





ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

NX UGS

this cover can only be used if part of the base is grinded down. see DC 2012.087

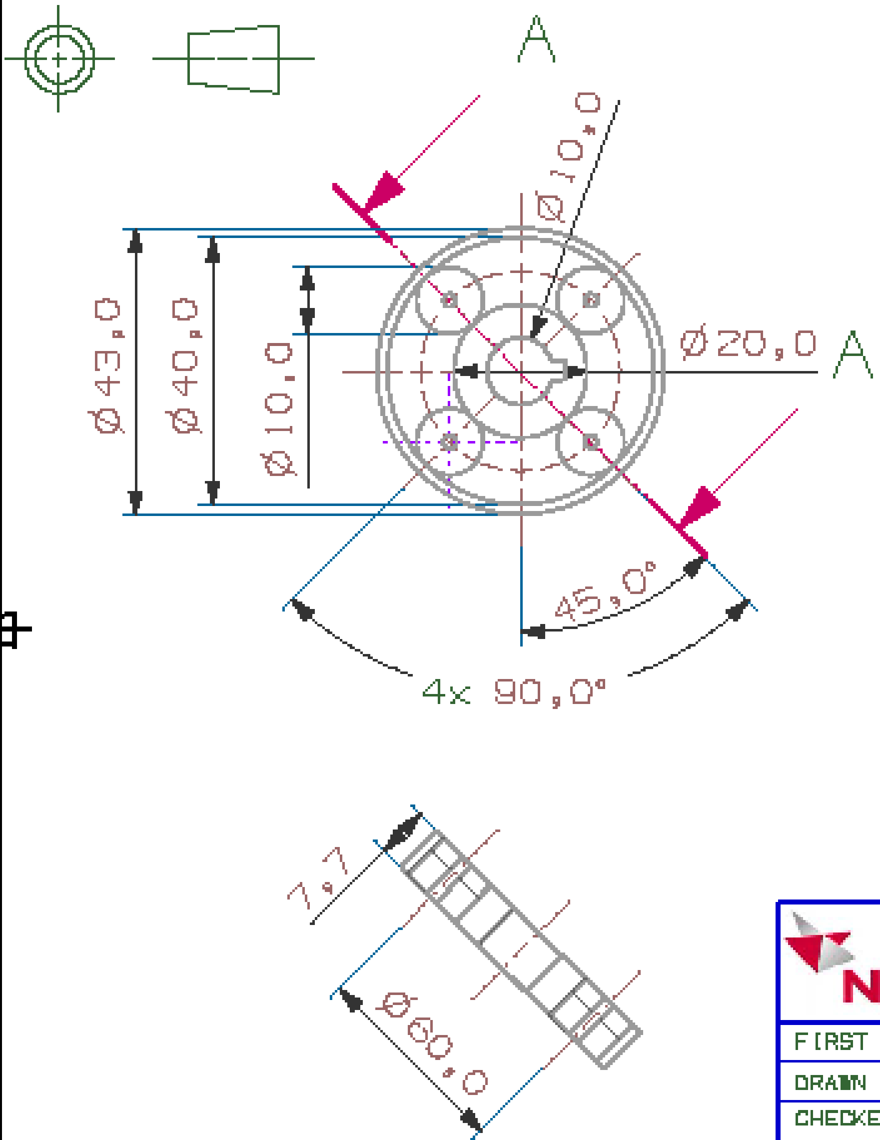
FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

TITLE

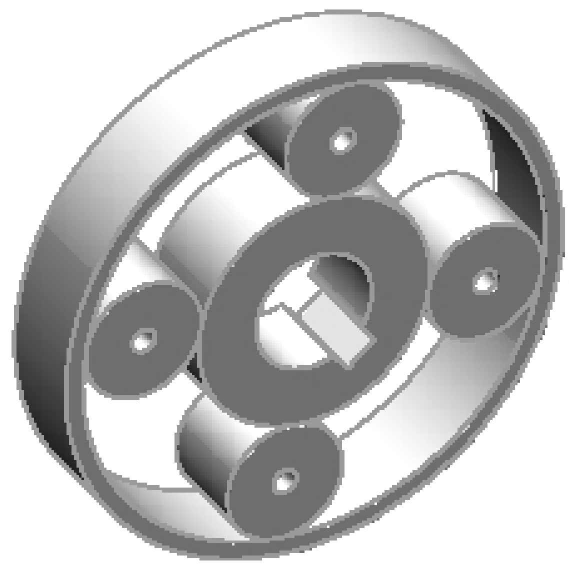
Planetary gear cover

SIZE A4 | DWG NO. heup behuizingskap C1.2 | REV.

SCALE 1:1 | SHEET 1 OF 1



SECTION A-A



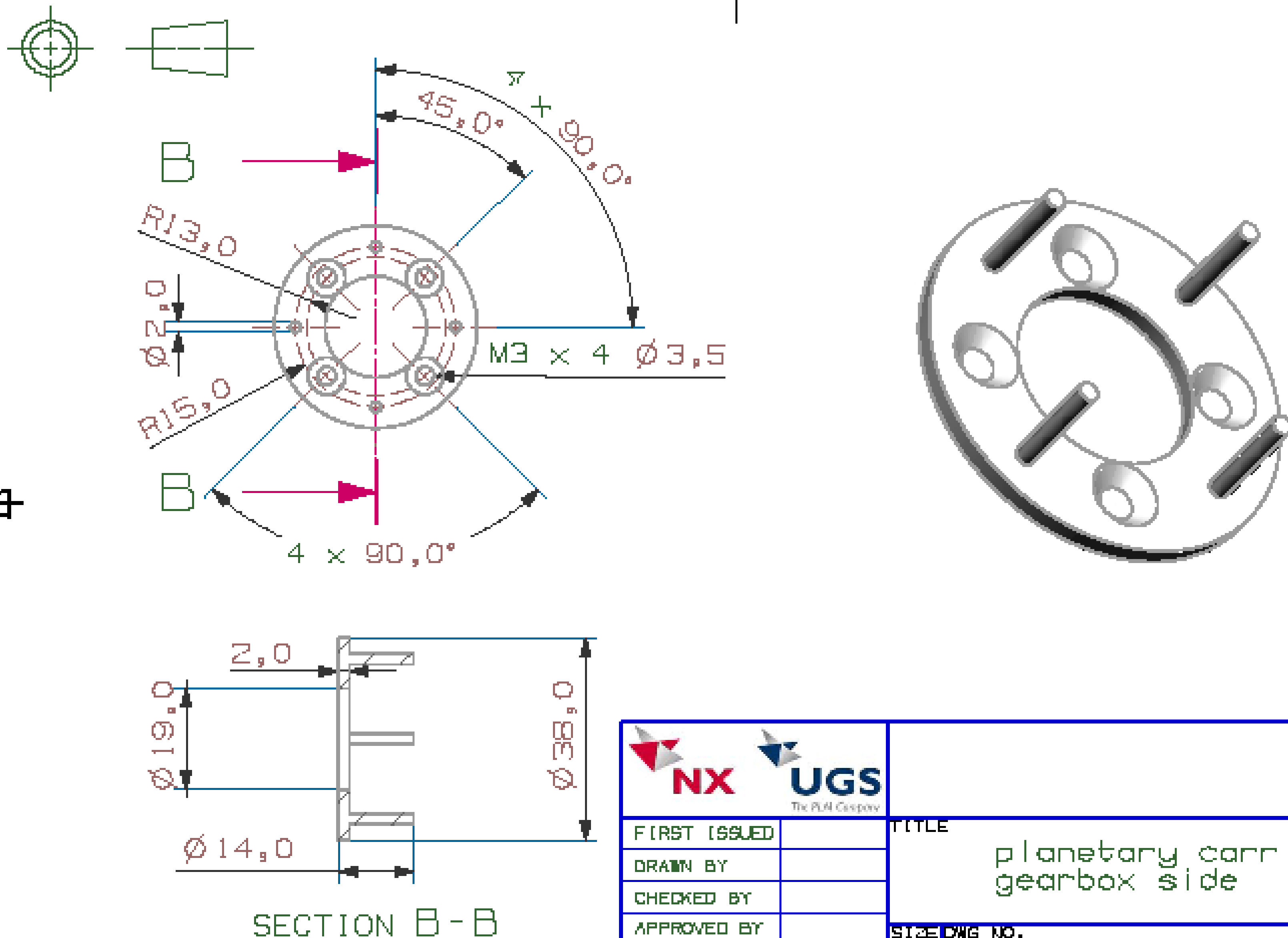
ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME:

NX UGS The PLM Company	the overall geometry planetary gear set is given, only the base circle is given
FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

TITLE
overall geometry of the planetary gear set

SIZE	DWG NO.	REV.
A4	C1 planetary gear set	

SCALE 1:1 | SHEET 1 OF 1



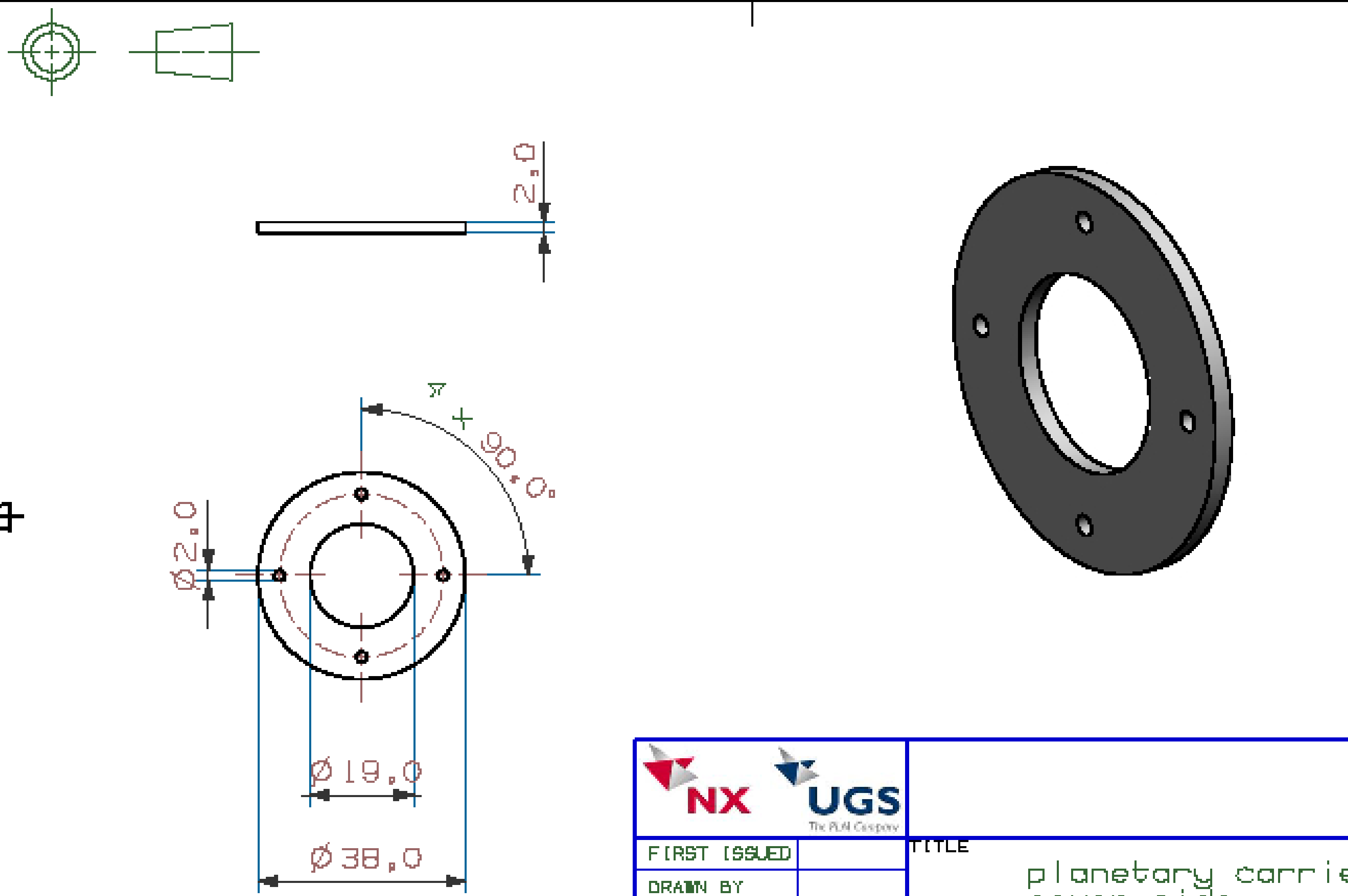
ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME:

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

TITLE
planetary carrier
gearbox side

SIZE	DWG NO.	REV.
A4	planetary carrier1	

SCALE 1:1 | SHEET 1 OF 1



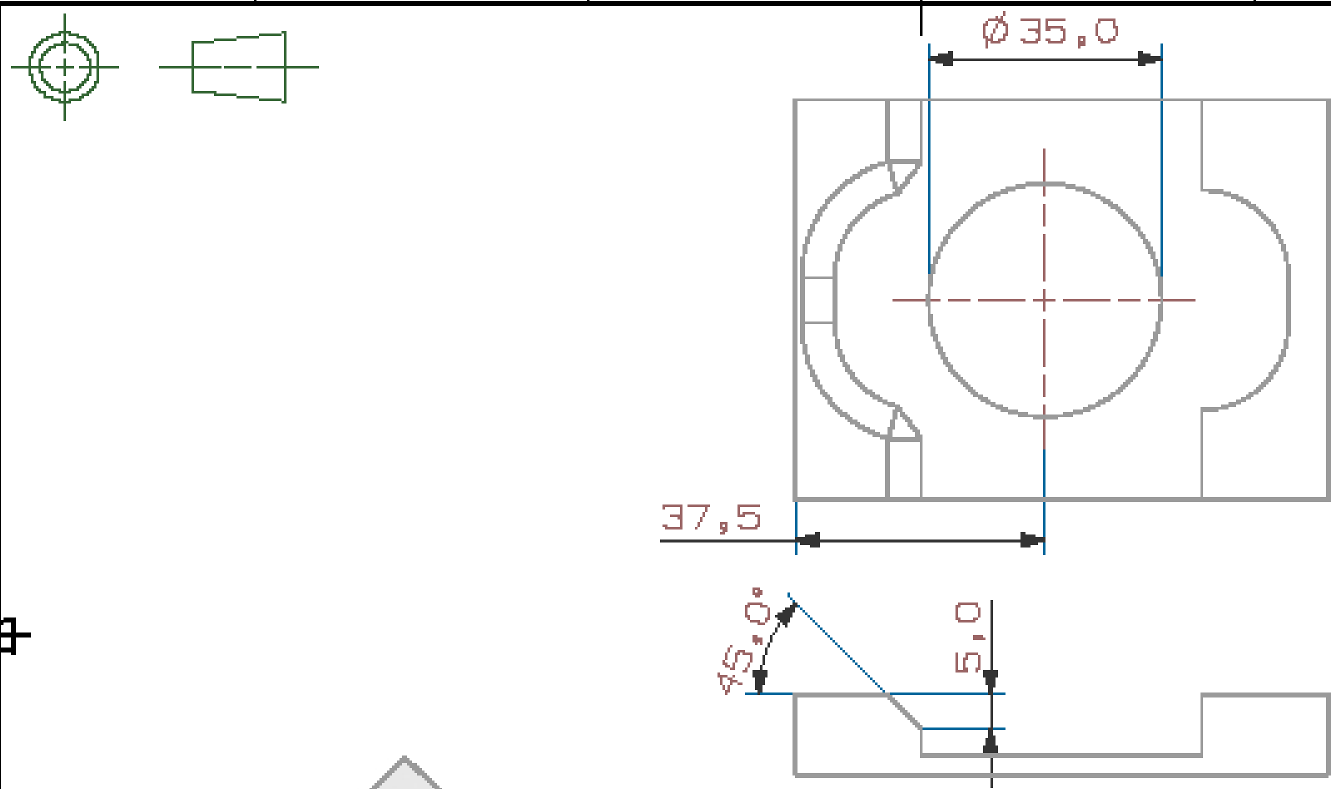
FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

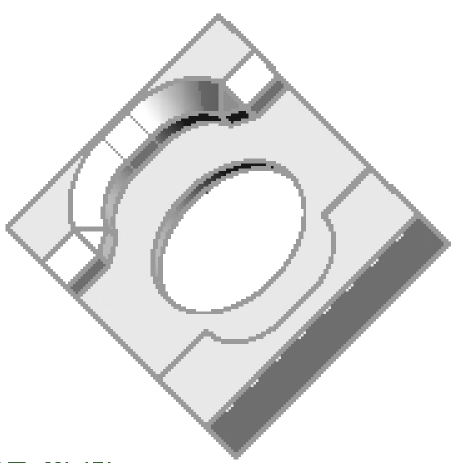
TITLE
planetary carrier
cover side

SIZE	DWG NO.	REV.
A4	planetary carrier	

SCALE 1:1 SHEET 1 OF 1

ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME:





the base of the 2011 spec TUlip is
grinded down to accomodate the large cover

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

TITLE

upper leg base

SIZE	DWG NO.	REV.
A4	Y-as base assembly C	

SCALE 1:1

SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

Appendix F: Harmonic drive

The dimensions of the hip joint are drawn in Unigraphics NX 7.5. The drawings are digitally printed to be a .pfd file. The 2011 spec TUlip hip joint begins with A1 as name of the different files. Only the parts that are altered are drawn. For parts that are not worked out in this appendix see appendix A

1) Overall view

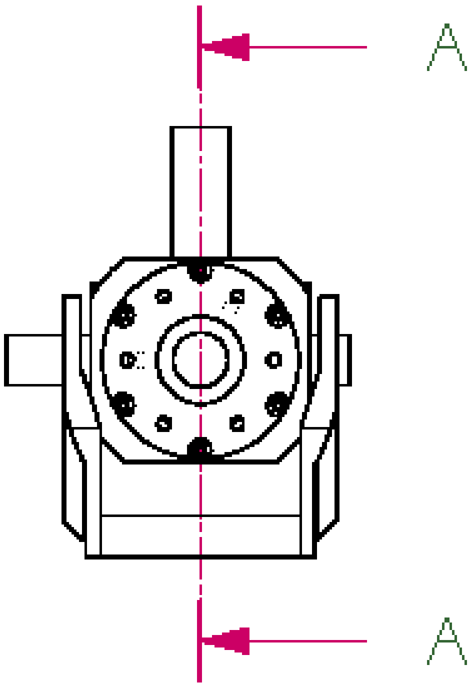
2) X-Y axle housing

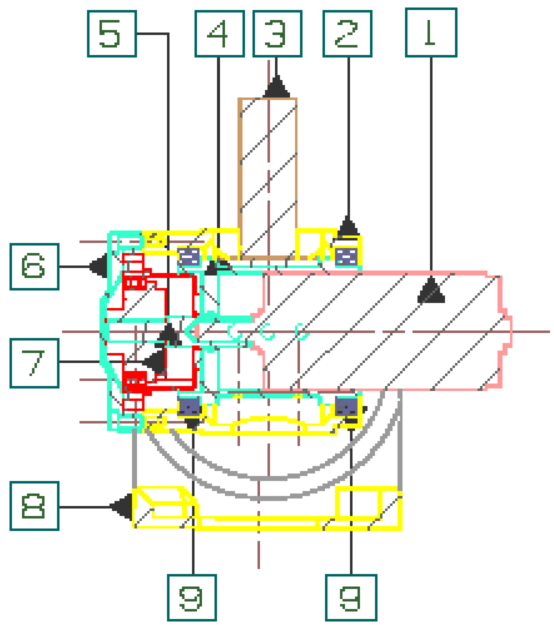
3) Cover

4) X-axle housing

5) Connecting shaft

6) Upper leg connecting base





SECTION A-A

1	motor
2	X-Y axle housing
3	Z-axle bracket
4	X-axle housing
5	connecting shaft
6	harmonic drive
7	cover
8	upper leg connecting base
9	bearing

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

NX UGS The PLM Company

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

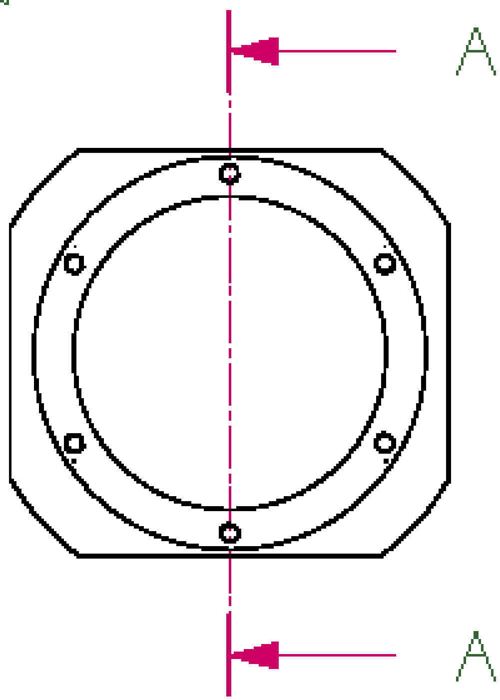
TITLE

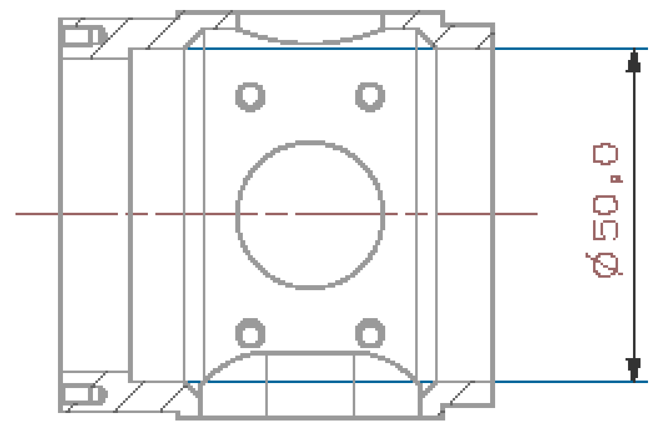
concept: harmonic drive

SIZE	DWG NO.	REV.
A4	C3 assembly heup R	

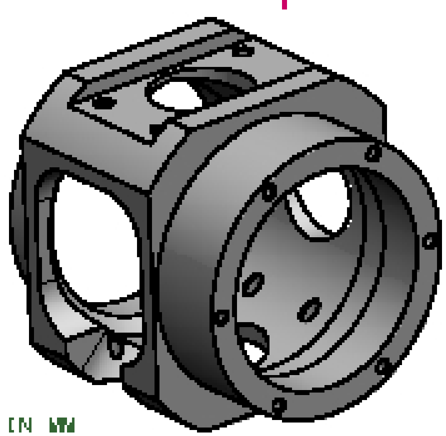
SCALE 1:2

SHEET 1 OF 1





SECTION A-A



ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

NX UGS The PLM Company

the interior is reamed to acommodate the motor-gearbox houzing, of the 2011 spec TUlip hip joint. the bearing will need to be installed via the right hand side

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

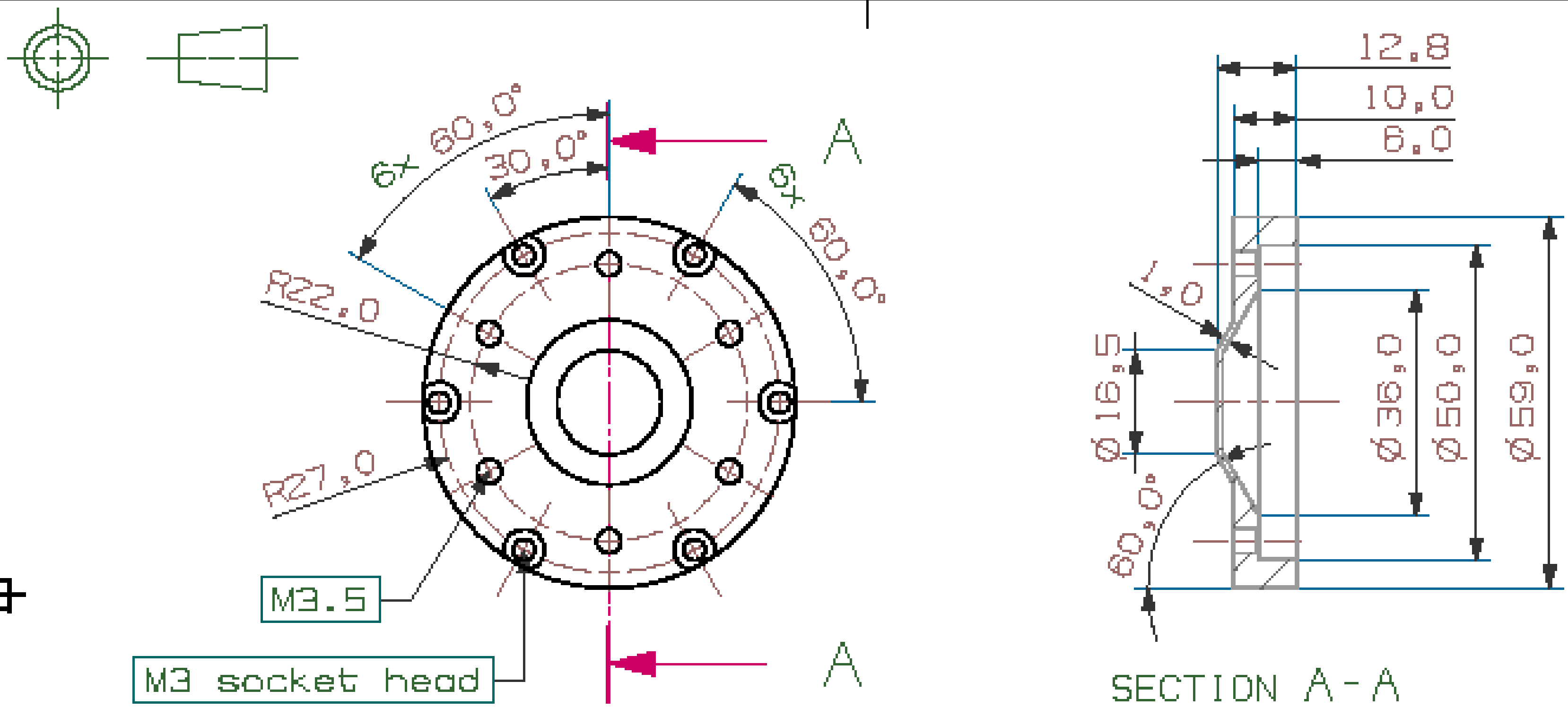
TITLE

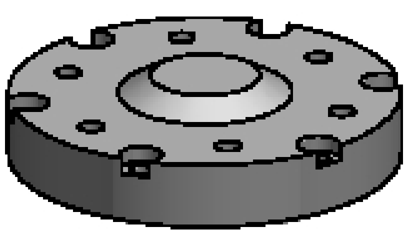
Y and X axle houzing

SIZE	DWG NO.	REV.
A4	C3 Y+X as frame	

SCALE 1:1

SHEET 1 OF 1

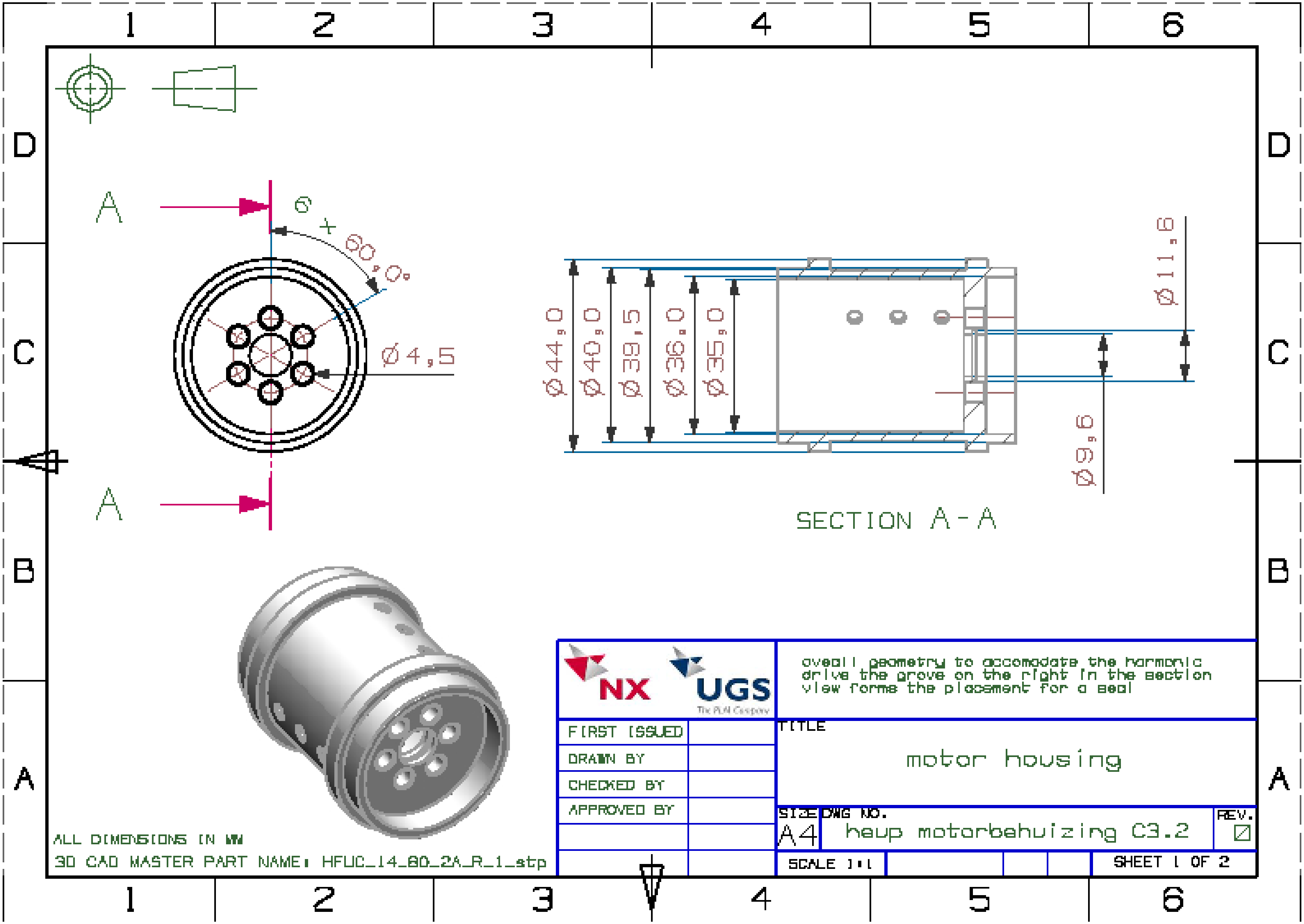




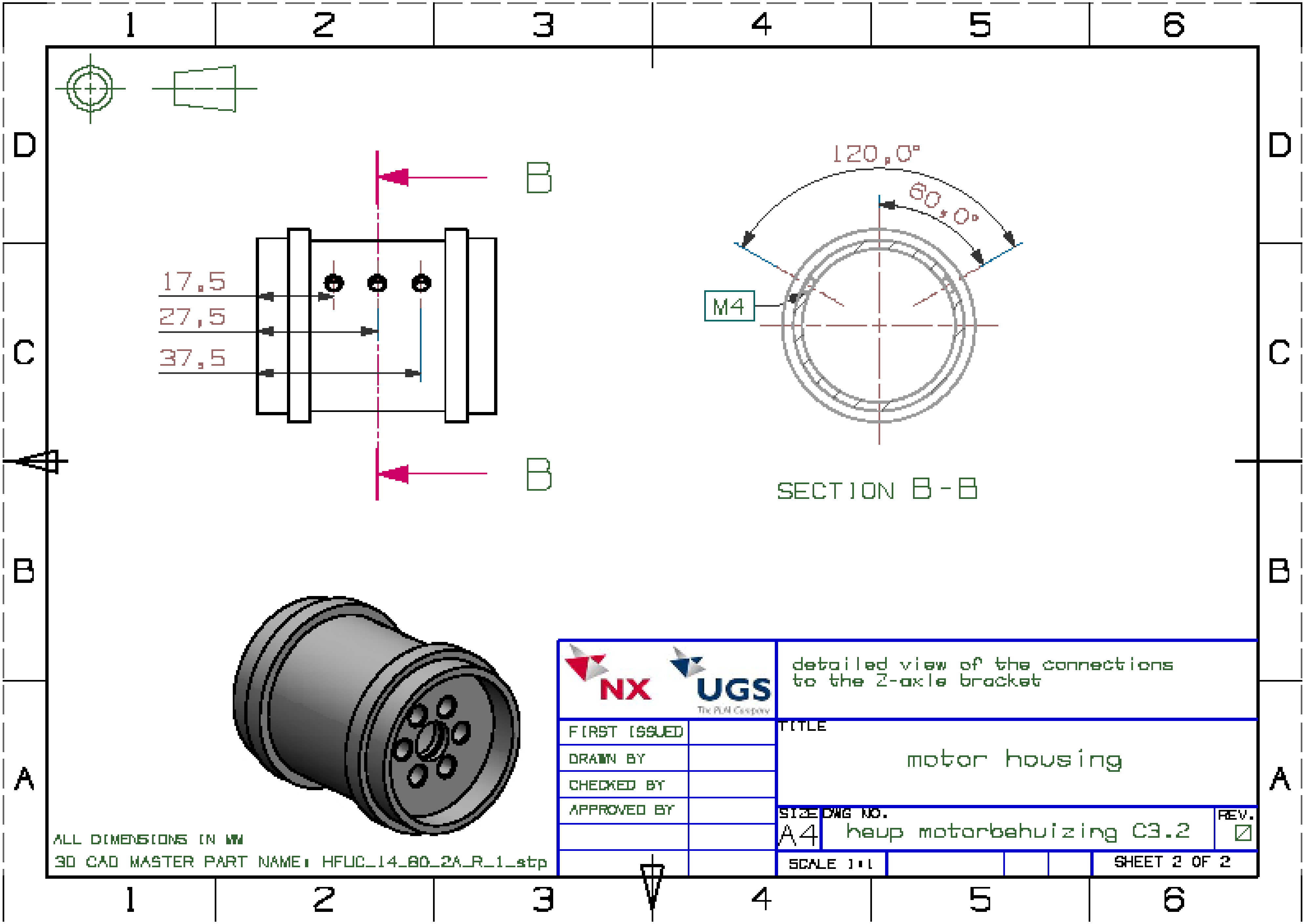
ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

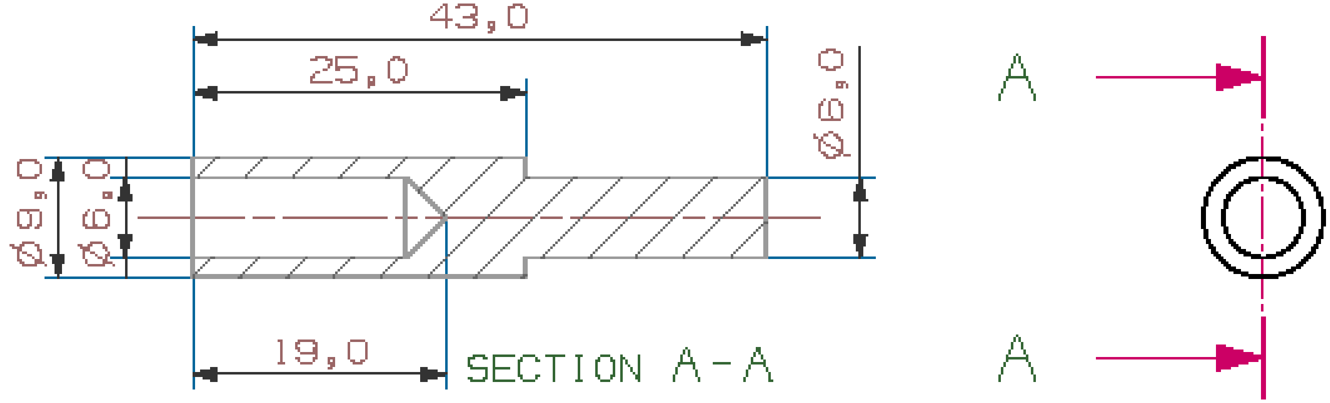
NX UGS	the inner bolt pattern is to connect the harmonic drive the outer bolt pattern is to secure the cover the hip joint
FIRST ISSUED	TITLE Harmonic drive cover
DRAWN BY	
CHECKED BY	
APPROVED BY	SIZE A4 — DWG NO. heup behuizingskap C3 — REV.
	SCALE 1:1 — SHEET 1 OF 1

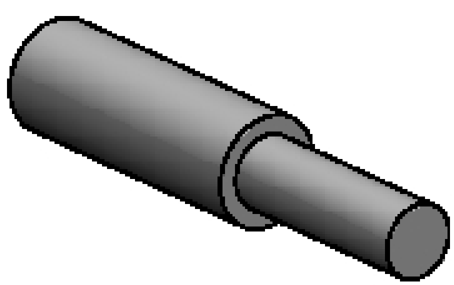


A
6 x 60,0°
Ø4,5
A
Ø44,0
Ø40,0
Ø39,5
Ø36,0
Ø35,0
Ø11,6
Ø9,6
SECTION A-A
NX
UGS
overall geometry to accomodate the harmonic
drive the grove on the right in the section
view forms the placement for a seal
FIRST ISSUED
DRAWN BY
CHECKED BY
APPROVED BY
TITLE
motor housing
SIZE
A4
DWG NO.
heup motorbehuizing C3.2
REV.
SCALE 1:1
SHEET 1 OF 2
ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME: HFUC_14_80_2A_R_1_stp



17,5
27,5
37,5
B
B
120,0°
60,0°
M4
SECTION B-B
ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME: HFUC_14_80_2A_R_1_stp
NX
UGS
The PLM Company
detailed view of the connections to the Z-axle bracket
FIRST ISSUED
DRAWN BY
CHECKED BY
APPROVED BY
TITLE
motor housing
SIZE
A4
DWG NO.
heup motorbehuizing C3.2
REV.
SCALE 1:1
SHEET 2 OF 2





connecting shaft between the motor and the harmonic drive

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

TITLE

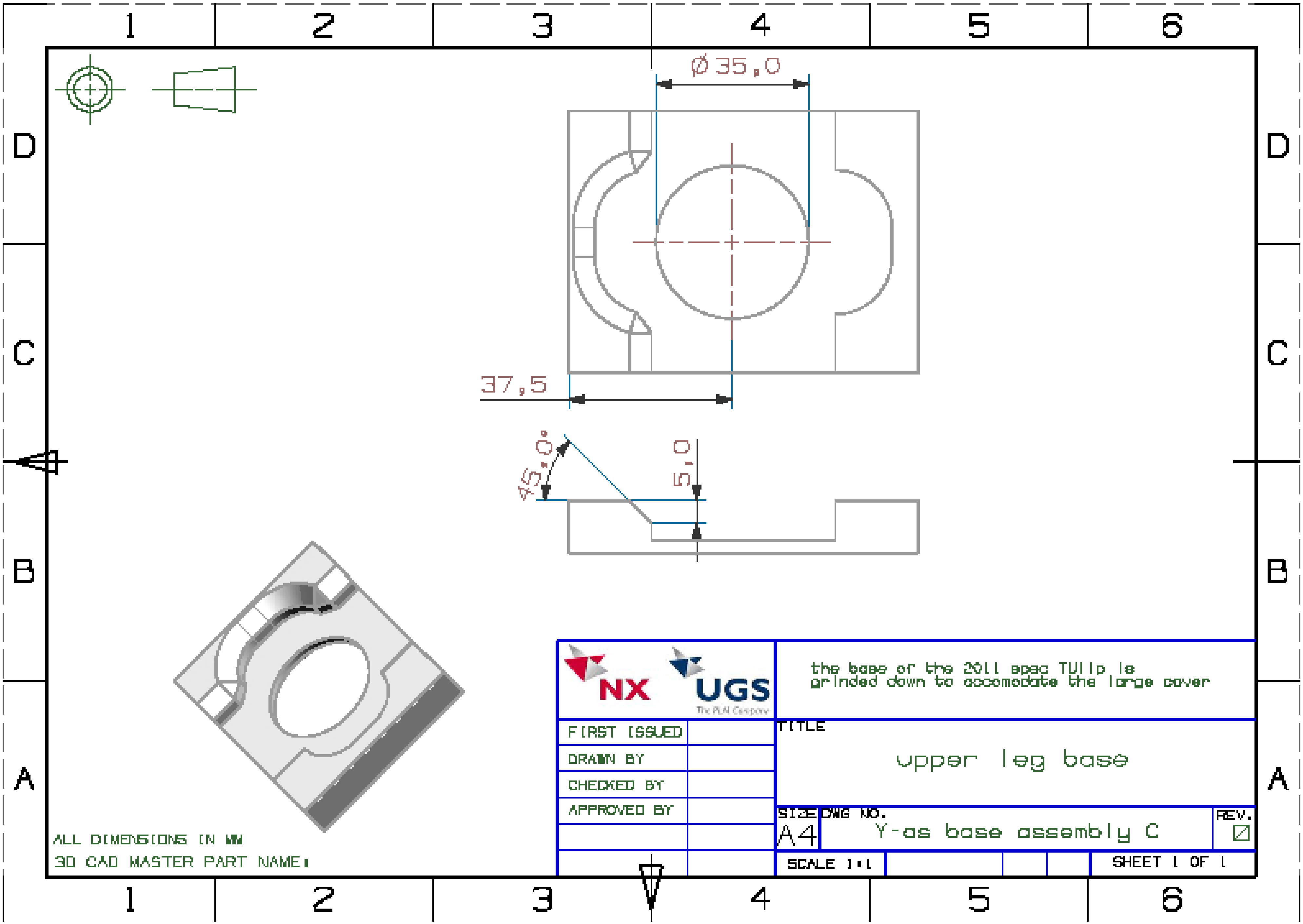
connecting shaft

SIZE	DWG NO.	REV.
A4	conecting shaft C3	

SCALE 2:1 | SHEET 1 OF 1

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:



Ø35,0
37,5
45,0°
5,0
the base of the 2011 spec TUlip is
grinded down to accomodate the large cover
NX
UGS
FIRST ISSUED
DRAWN BY
CHECKED BY
APPROVED BY
TITLE
upper leg base
SIZE
A4
DWG NO.
Y-as base assembly C
REV.
SCALE 1:1
SHEET 1 OF 1
ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME:

Appendix G: Maxon gearbox

The dimensions of the hip joint are drawn in Unigraphics NX 7.5. The drawings are digitally printed to be a .pfd file. The 2011 spec TUlip hip joint begins with A1 as name of the different files. Only the parts that are altered are drawn. For parts that are not worked out in this appendix see appendix A

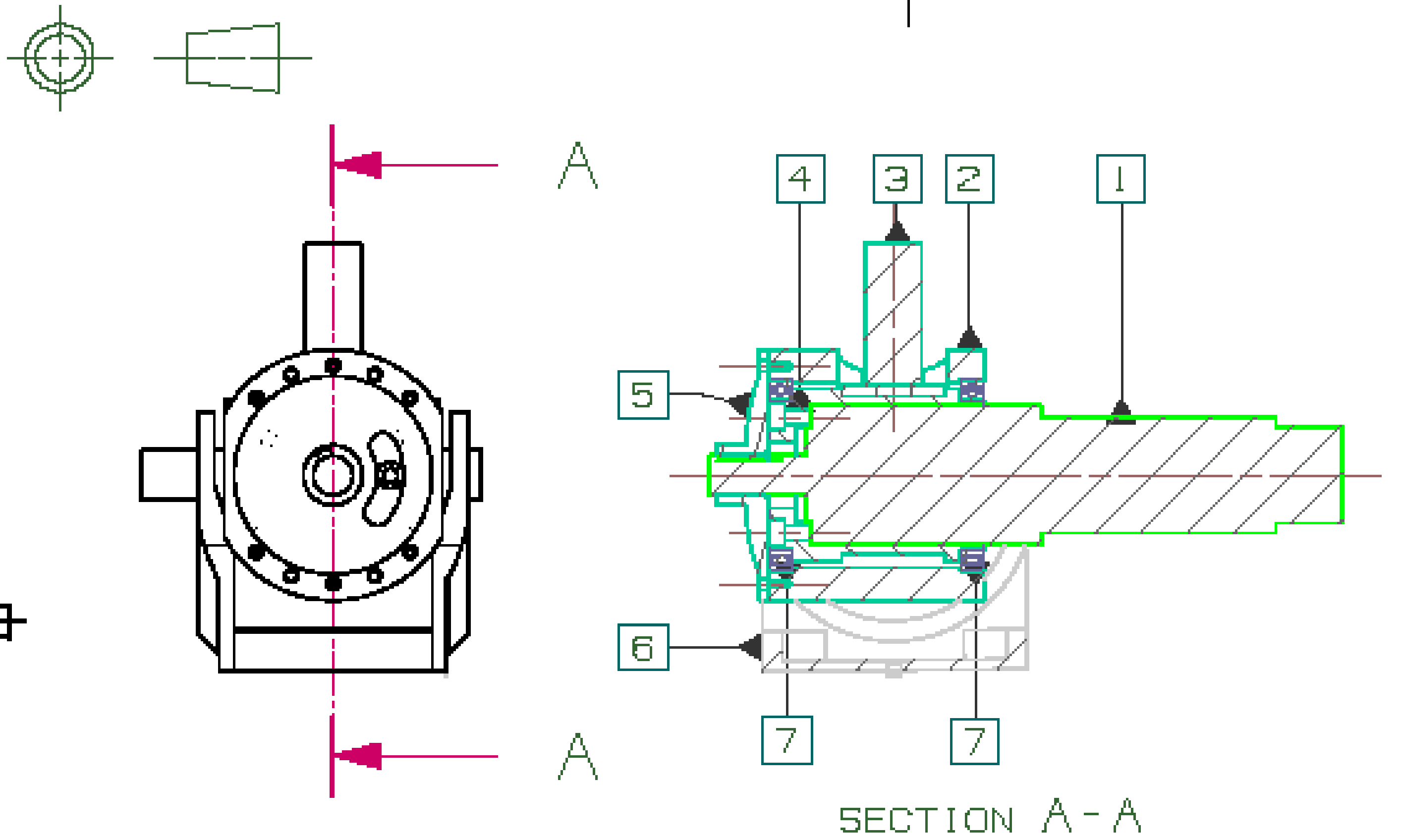
1) Overall view

2) X-Y axle housing

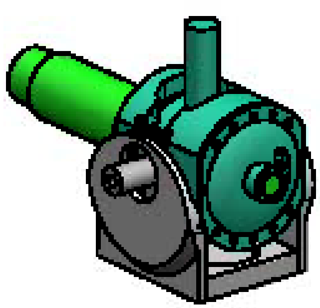
3) X-axle housing

4) Cover

5) Z-axle bracket



1	motor-gearbox assembly
2	X-Y axle housing
3	Z-axle bracket
4	X-axle houzing
5	cover
6	upper leg connecting base
7	bearing



ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

NX UGS

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

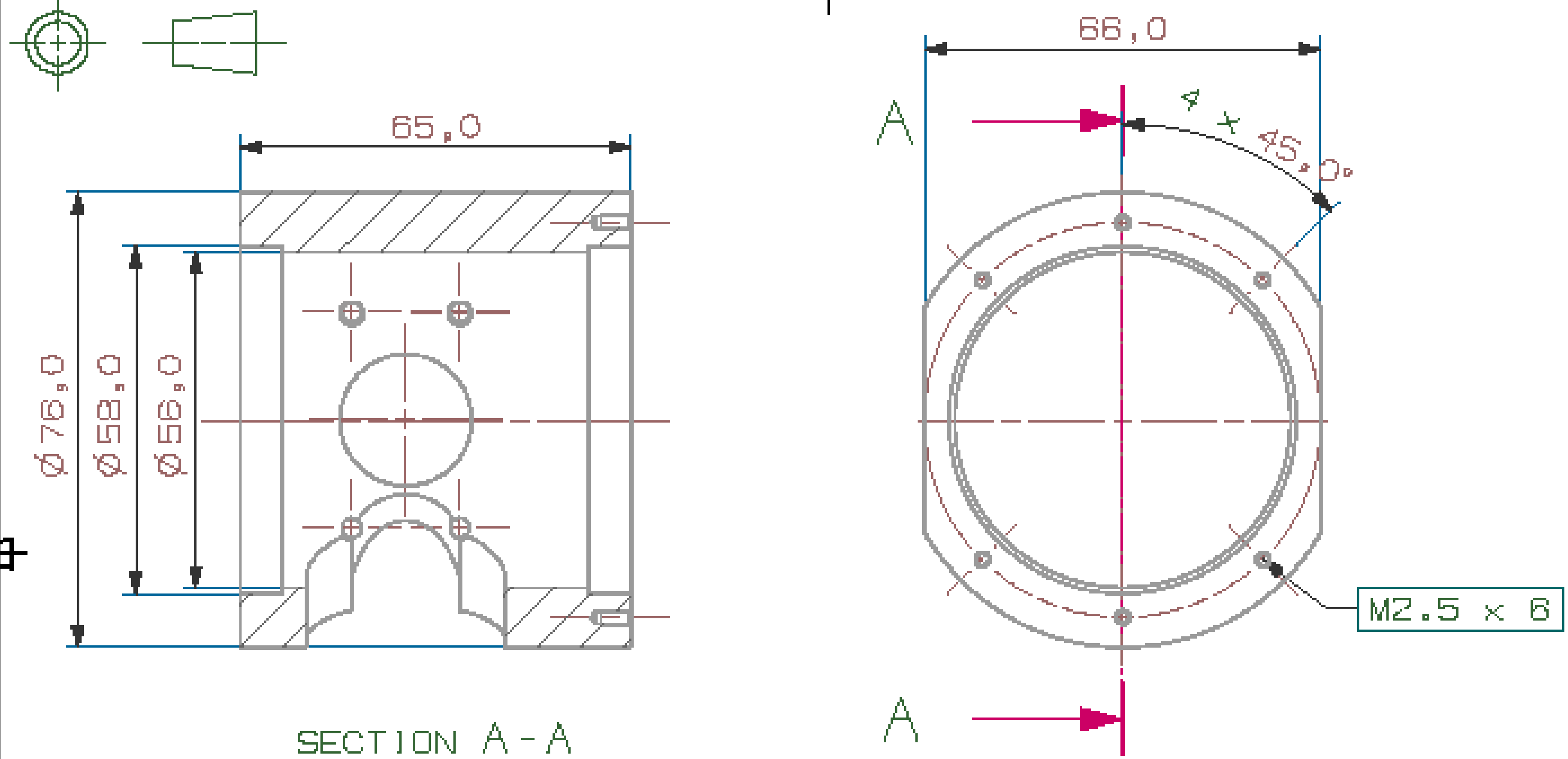
TITLE

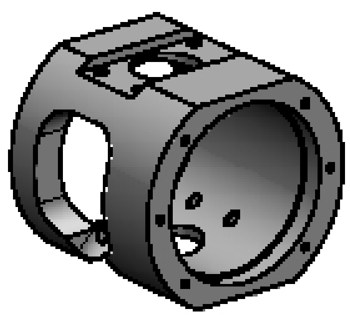
concept: GP42 gearbox

SIZE	DWG NO.	REV.
A4	C2 assembly heup R	

SCALE 1:2

SHEET 1 OF 1





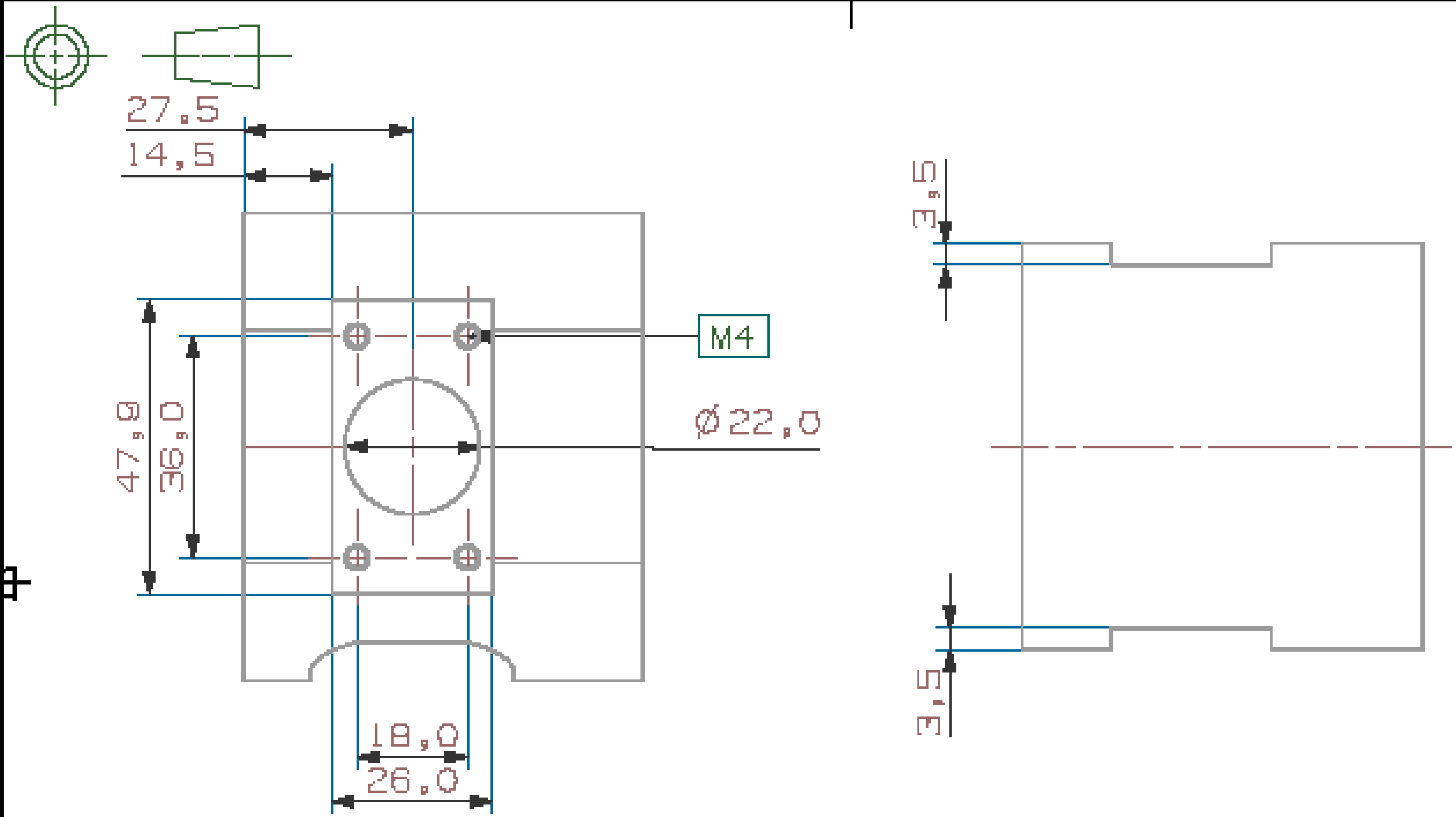
ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME:

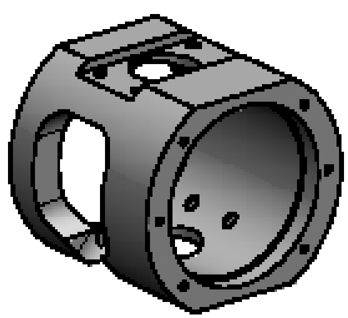
NX UGS	overall geometry
FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

TITLE
X-Y axle housing

SIZE	DWG NO.	REV.
A4	C2 Y+X as frame	

SCALE 1:1 | SHEET 1 OF 3





ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

dimensions of the Y-axle brackets placement
the placement is semetrical about the centre
plane

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

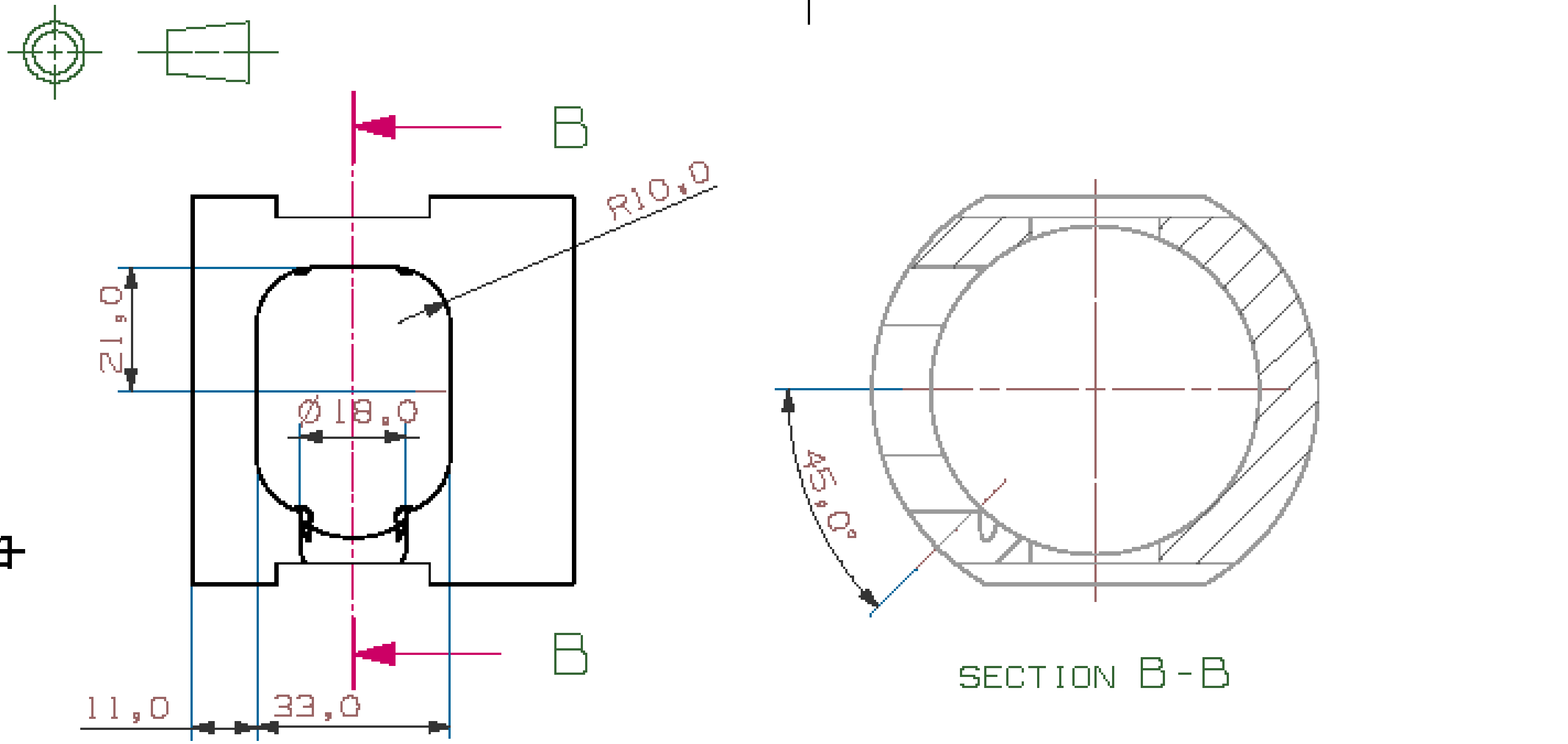
TITLE

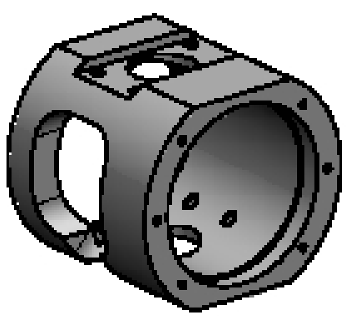
X-Y axle housing

SIZE	DWG NO.	REV.
A4	C2 Y+X as frame	

SCALE 1:1

SHEET 2 OF 3

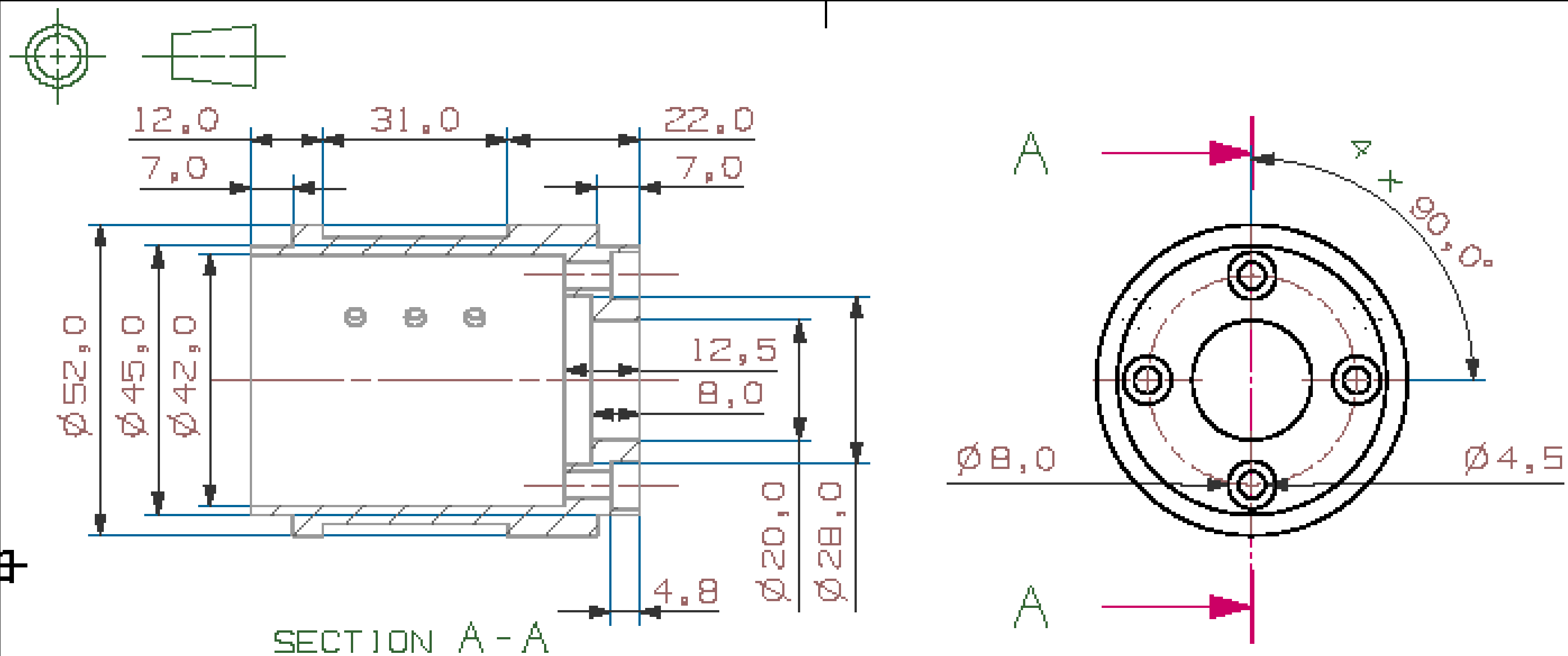




ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

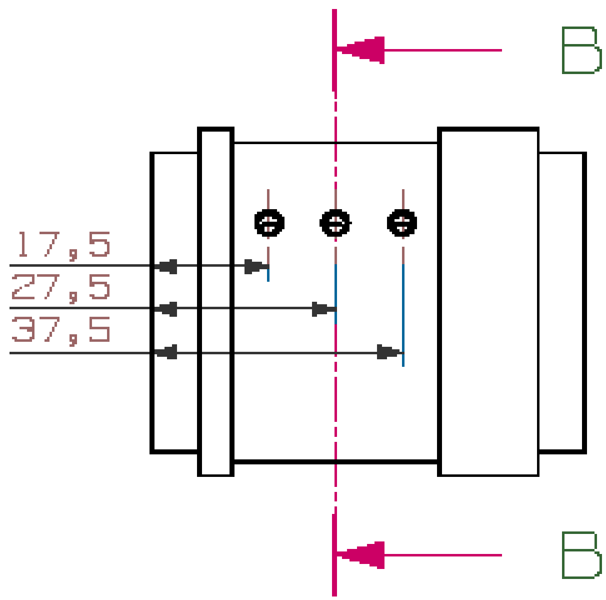
NX UGS	Installation space Z-axle bracket
FIRST ISSUED	TITLE X-Y axle housing
DRAWN BY	
CHECKED BY	
APPROVED BY	SIZE A4 · DWG NO. C2 Y+X as frame · REV.
	SCALE 1:1 · SHEET 3 OF 3

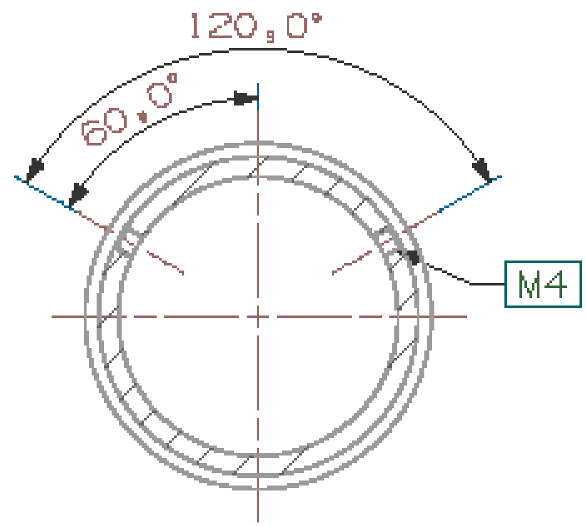


NX UGS	overall geometry
FIRST ISSUED	TITLE
DRAWN BY	motor-gearbox(GP42) housing
CHECKED BY	
APPROVED BY	SIZE A4 — DWG NO. heup motorbehuizing C2 — REV.
	SCALE 1:1 — SHEET 1 OF 2

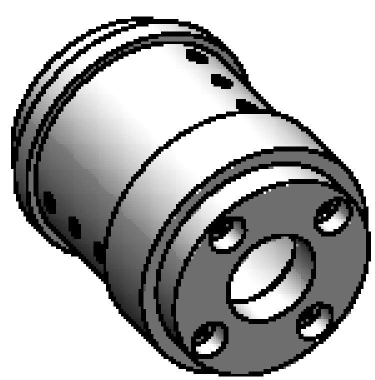
ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:





SECTION B-B



ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

Z-axle bracket mounting points

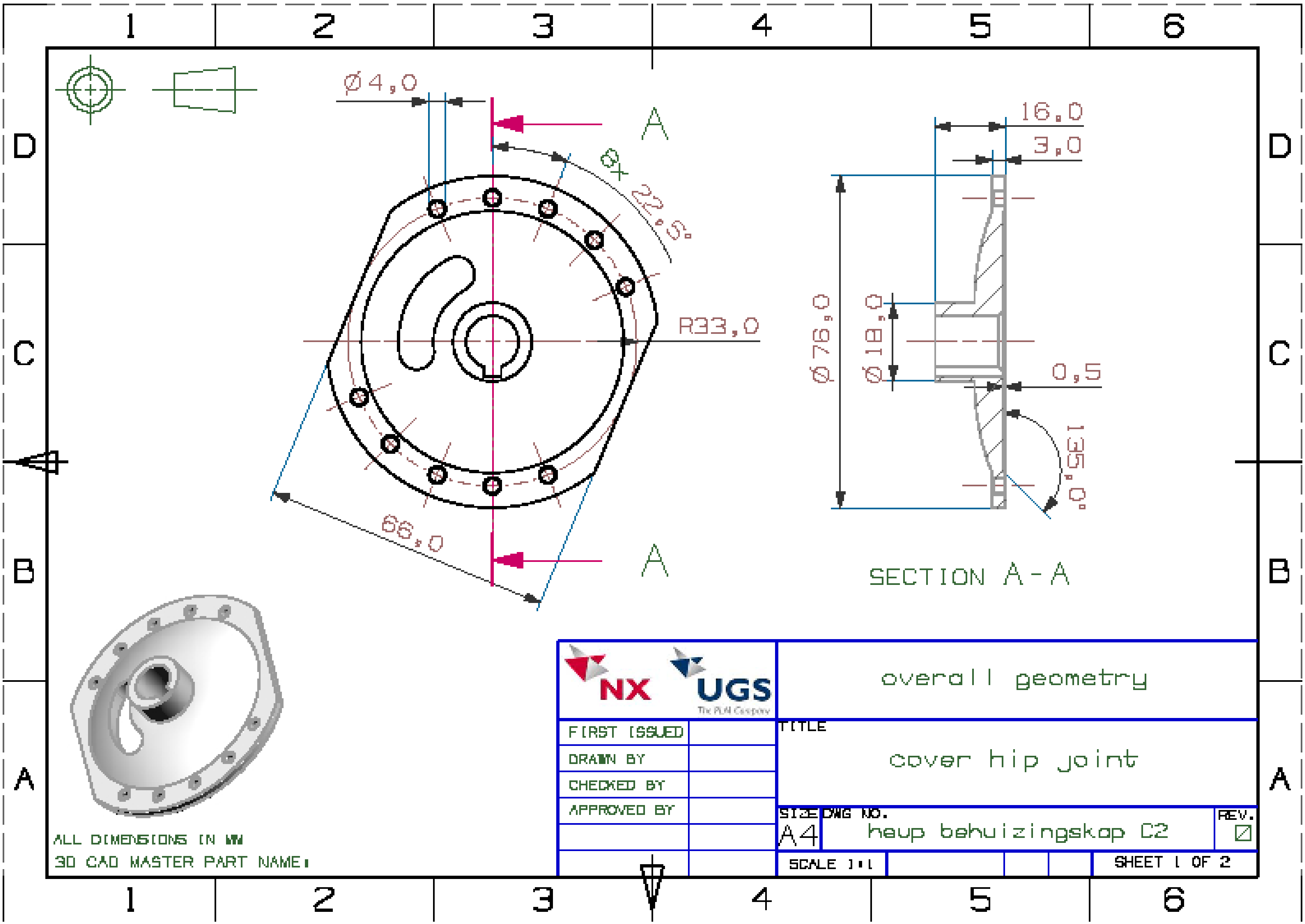
TITLE

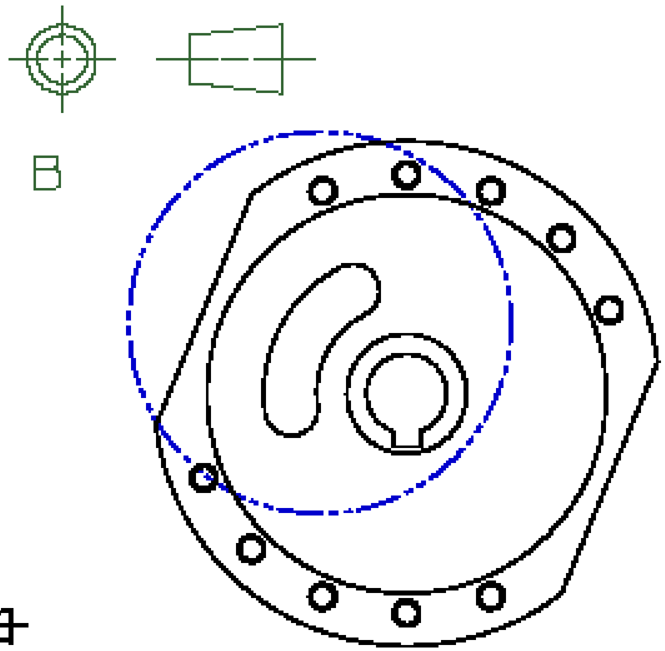
motor-gearbx(GP42) housing

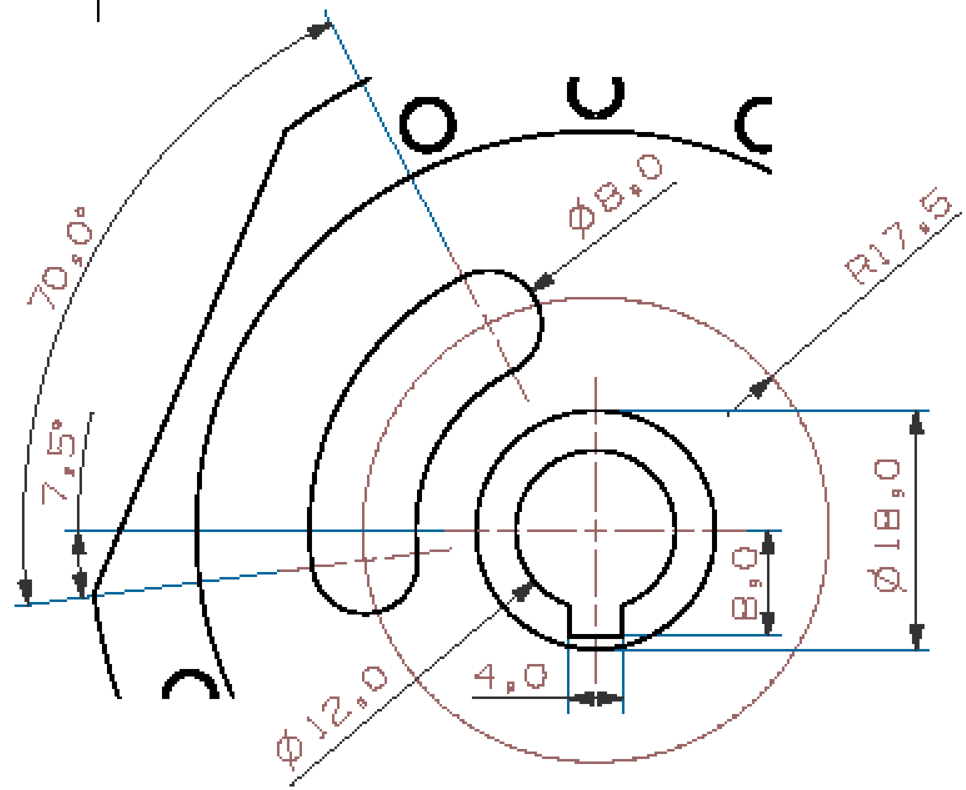
SIZE	DWG NO.	REV.
A4	heup motorbehuizing C2	

SCALE 1:1

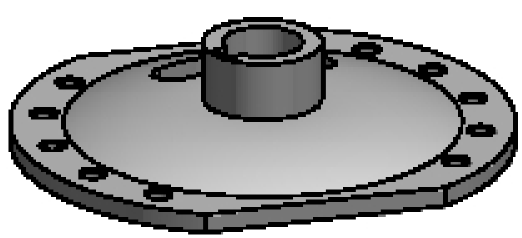
SHEET 2 OF 2


Ø4,0
A
8x 22,5°
R33,0
66,0
A
16,0
3,0
Ø76,0
Ø18,0
0,5
135,0°
SECTION A-A
ALL DIMENSIONS IN MM
3D CAD MASTER PART NAME:
NX
UGS
overall geometry
FIRST ISSUED
DRAWN BY
CHECKED BY
APPROVED BY
TITLE
cover hip joint
SIZE
A4
DWG NO.
heup behuizingskap C2
REV.
SCALE 1:1
SHEET 1 OF 2





DETAIL B
SCALE 2:1



NX UGS	detalls vlew of the encoder and shaft slot
FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

TITLE

cover hip joint

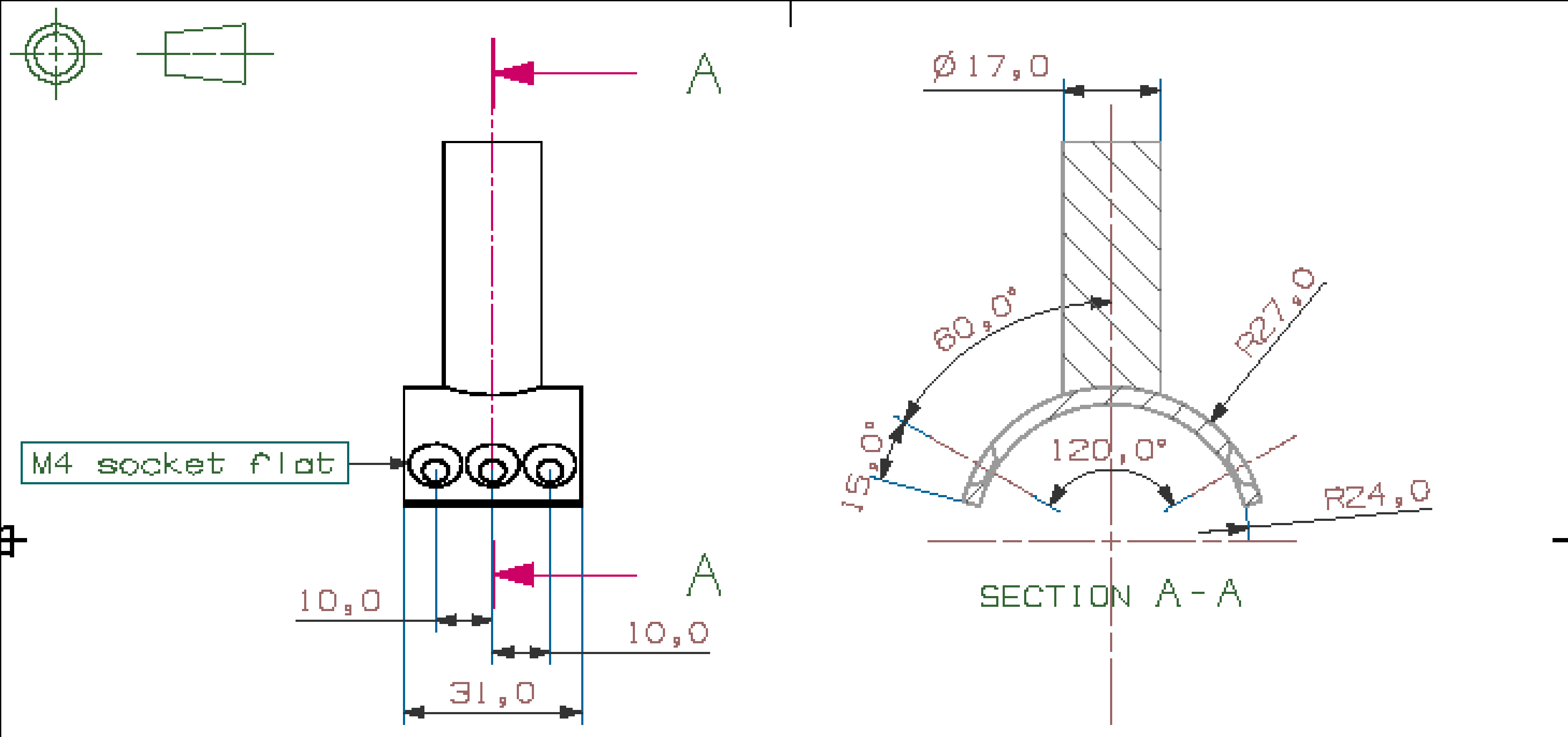
SIZE	DWG NO.	REV.
A4	heup behuizingskap C2	

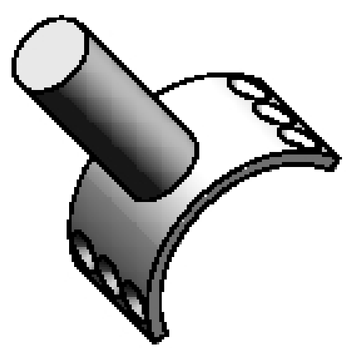
SCALE 1:1

SHEET 2 OF 2

ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:





ALL DIMENSIONS IN MM

3D CAD MASTER PART NAME:

NX UGS	the geometry of the base to the motor housing
FIRST ISSUED	
DRAWN BY	
CHECKED BY	
APPROVED BY	

TITLE: Z axle bracket

SIZE	DWG NO.	REV.
A4	z-as axle C2	

SCALE 1:1 | SHEET 1 OF 1