Edinburgh Napier University

Engineering Applications

MEC09107

Report - Gearbox Design Exercise.

Olivier Chaligne.

40292302.

25.03.19

Note :- Failure to include this in the coursework report will result in a flat penalty of 10% for the overall mark of the coursework.

Weeks	Progress record for coursework	
	Signature of Judith	Notes
Week 19 Starting 14/01/19		
Week 20 Starting 21/01/19		
Week 21 Starting 28/01/19		
Week 22 Starting 04/02/19		
Week 23 Starting 11/02/19		
Week 24 Starting 18/02/19		
Week 25 Starting 25/02/19		
Week 26 Starting 04/03/19		
Week 27 Starting 11/03/19		
Week 28 Starting 18/03/19		
Week 29 Starting 25/03/19		
Week 30 Starting 01/04/19		
Week 31 Starting 08/04/19		

TO BE SCANNED AND ATTACHED TO THE COURSEWORK

Table of Content

Introduction.

This report will describe the steps taken to design a power transmission system from an electrical motor to a belt drive using a gearbox. The first section will present the present the aspects of power and output specifications. Secondly, an explanation of the process followed to calculate and select the appropriate gears will be provided. Then, following the specifications obtained from the previous sections, an account of the calculations to determine the shaft diameter will be given. Finally, relevant technical drawings of the design and parts will be offered.

I. System Power and Speed.

A. System and Motor Selection.

It was decided the system would need to output 300 RPMs for a power of 2kW.
Following those requirements the motor pictured in figure 1 was selected.
This electrical motor outputs 2.2kW with a max rotation speed of 940 RPMs. This motor offers specifications allowing to meet the requirements of the system.

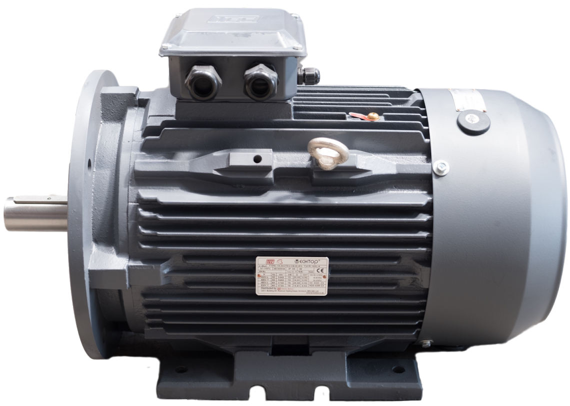


Figure 1. TEC 2.2kw, 6 pole cast iron motor B35.

B. GearBox Speed Ratio Calculation.

Using the desired power output of 2 kW and Table 1, it is possible to determine the system would require a pulley of 150mm diameter and a wheel of 200mm spaced by 350mm.

Table 1. Drive Belt System Specifications According to Power.

Selected power	Pulley (d)	Wheel (D)	Centre distance (C)
20 KW	315 mm	400 mm	700 mm
10 KW	250 mm	330 mm	450 mm
2 KW	150 mm	200 mm	350 mm
500 W	80 mm	110 mm	200 mm

Those specifications can be used to calculate the belt speed ratio:

$$Belt\ Speed\ Ratio\ = \frac{Wheel}{Pulley} = \frac{200}{150} = 1.333$$

It is now possible to calculate the rotational speed of the Pulley:

$$Rotational\ Speed\ Pulley\ = 300 \times 1.333 = 399.9\ RPMs$$

Using the pulley rotational speed (399.9 RPMs) and the rated rotational speed of the motor (940 RPMs) the gearbox speed ratio can be obtained:

$$Gearbox\ Speed\ Ratio\ = \frac{motor}{Pulley} = \frac{940}{399.9} = 2.35$$

C. Belt Length and Tensions Calculations.

- Angular Length of the Pulley and Wheel Calculations:

D_{wheel} = 200mm, d_{pulley} = 150mm, centre distance = 350mm.

$$\theta_d = \pi - 2\times \sin^{-1}\left(\frac{D-d}{2\times C}\right) = \pi - 2\times \sin^{-1}\left(\frac{200-150}{2\times 350}\right)$$

$$\theta_d = 2.999 \text{ rads}$$

$$\theta_D = \pi + 2\times \sin^{-1}\left(\frac{D-d}{2\times C}\right) = \pi + 2\times \sin^{-1}\left(\frac{200-150}{2\times 350}\right)$$

$$\theta_D = 6.14 \text{ rads}$$

- Belt Length Calculations:

$$L = \sqrt{4\times C^2 - (D-d)^2} + \frac{1}{2}\left(D\theta_D + d\theta_d\right)$$

$$L = \sqrt{4\times 350^2 - (200-150)^2} + \frac{1}{2}(200\times 6.14 + 150\times 2.999)$$

$$L = 1.54\ m$$

- Belt Tensions (F1 and F2) Calculations:

V - Pitch Line Velocity

$$V = \omega \times r = \omega_D \times r_D = \frac{300\times 2\times \pi}{60} \times \frac{200}{2}$$

$$V = 3.14\ {}^{m}\!/_{s}$$

Equations to resolve for F1 and F2:

$$\frac{F1}{F2} = e^{\mu \times \theta_d}$$

$$\frac{F1}{F2} = e^{0.8 \times 2.999}$$

$$Power = (F1 - F2) \times V$$

$$2kW = (F1 - F2) \times V$$

Double Equations:

$$\begin{cases} 2000 = (F1 - F2) \times 3.14 \\ F1 = F2 \times \left(e^{0.8 \times 2.999}\right) \end{cases}$$

$$\begin{cases} F1 = -700.5\ N \\ F2 = -63.5\ N \end{cases}$$

II. Gears Selection Calculations.

The calculations were realised using the “Simple Gear Selection Method” by provided in the book Mechanical Design Engineering Handbook (Childs, 2018).

The procedure was repeated several times to find gears which would fit the required specifications. The calculations described here only show the case were the gear were matching.

Selected number of teeth for small gear: 15.

Module: 2.0

Large Gear teeth number:

$$small\ gear\ teeth \times\ gear\ ratio\ =\ 15 \times\ 2.35\ =\ 35.25$$

Pitch Diameters:

$$Pitch\ Diameter = module\ \times\ number\ of\ \ teeth$$

$$Pitch\ Diameter_{Small\ Gear} = 2 \times 15$$

$$Pitch\ Diameter_{Large\ Gear} = 2 \times 35$$

Pitch Line Velocities:

$$V = \left(\frac{d}{2}\right) \times RPMs_{desired} \times \left(\frac{2\pi}{60}\right)$$

$$V_{Small} = \left(\frac{30}{2}\right) \times 300 \times \left(\frac{2\pi}{60}\right) = 0.4712\ {}^{m}\!/_{s}$$

$$V_{Large} = \left(\frac{71}{2}\right) \times 300 \times \left(\frac{2\pi}{60}\right) = 1.1074\ {}^{m}\!/_{s}$$

Dynamic Factors:

$$Kv = {}^{6.1}\!/_{(6.1 + V)}$$

$$Kv_{Small} = {}^{6.1}\!/_{(6.1 + 0.4712)} = 0.92828$$

$$Kv_{Large} = {}^{6.1}\!/_{(6.1 + 1.1074)} = 0.84635$$

Transmitted Load:

$$Wt = {}^{Power}\!/_{V}$$

$$Wt_{Small} = {}^{2000}\!/_{0.4712} = 4244.13\ N$$

$$Wt_{Large} = {}^{2000}\!/_{1.1074} = 1806.01\ N$$

Form Factor (from table 8.6 p.412)**:**

Y_{Small} = 0.26622

Y_{Large} = 0.36731

Permissible Bending Stress (From Table 8.12 p.424)**:**

Material: 655M13.

Treatment: Case hardened.

Permissible bending stress σP (MPa): 345.

Gears Face Width Calculations using Lewis Formula:

$$F = \frac{Wt}{Kv \times module \times Y \times \sigma_p}$$

$$F_{Large} = \frac{4244.13}{0.92828 \times 2 \times 0.2662 \times 345 \times 10^6} = 24.89\ mm$$

$$F_{Small} = \frac{1806.01}{0.84635 \times 2 \times 0.36731 \times 345 \times 10^6} = 8.42\ mm$$

Both gears are below the 25mm face width limit for gears of module 2.0. To simply the design process the small gear will be given the same face width as the large one.

III. Gearbox Shaft Calculations.

The calculations for the main shaft calculations were realised using an adapted method describe by RN. Childs in example 7.10 (2018, p.347).

Belt tensions previously calculated:

F1 = 700.5 N

F2 = 63.5 N

Total tension:

$$Total\ Tension = F1 + F2$$

$$Total\ Tension = 700.5 + 63.5 = 764.1\ N$$

Small Gear and Pulley Volume and Mass Calculations:

Gear PCD:

Large Gear: 0.07m.

Small Gear: 0.03m.

Volume Calculations:

$$Volume = \pi \times \left(\frac{\mathrm{d}}{2}\right)^2 \times \mathrm{Face\ width}$$

$$\mathrm{Volume}_{\mathrm{Small}} = \pi \times \left(\frac{0.03}{2}\right)^2 \times 0.02489 = 0.00001759\ \mathrm{m}^3$$

$$\mathrm{Volume}_{\mathrm{Pulley}} = \pi \times \left(\frac{0.15}{2}\right)^2 \times 0.02489 = 0.00043983\ \mathrm{m}^3$$

Mass Calculations:

$$\rho_{steel} = 7980\ {}^{kg}\!/_{m^3}$$

$$Mass = Volume \times \rho$$

$$Mass_{large} = 0.00001759 \times 7980 = 0.1403\ kg$$

$$Mass_{Pulley} = 0.00043983 \times 7980 = 3.51\ kg$$

Torque Calculation:

$$Torque = \frac{Power}{\omega} = \frac{2000}{\left(300 \times \frac{2\pi}{60}\right)} = 63.66\ Nm$$

Tangential Load:

$$Ft = \frac{Torque}{r_{gear}} = \frac{63.66}{\left(0.03/_2\right)} = 4244.74\ N$$

Radial Load:

$$\phi = 20$$

$$Fr = Ft \times \tan(\phi) = 4244.13 \times \tan(20)$$

$$Fr = 9494.80\ N$$

Bending Moments Calculations:

L1 = 0.01m ; L2 =0.01m ; L3 = 0.05m.

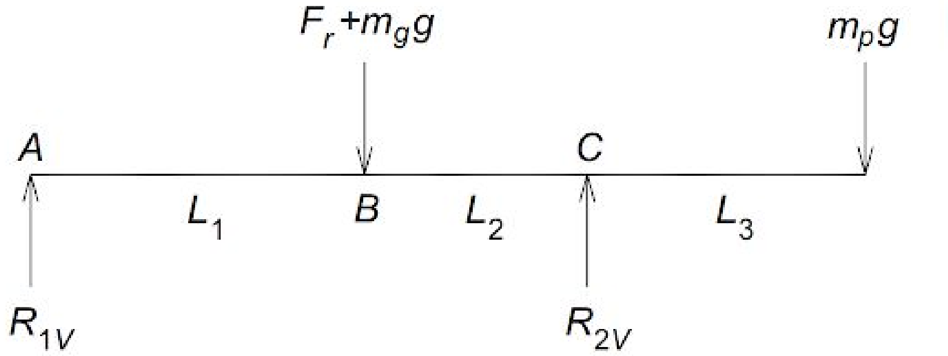


Figure.2 Vertical Loading diagram.

Reaction at R_{2V}:

$$R_{2V} = \frac{\left(Fr + m_g g\right) \times L1 + m_p g \times (L1 + L2 + L3)}{L1 + L2}$$

$$R_{2V} = \frac{(9494.81 + 0.14039 \times 9.81) \times 0.01 + 3.5099 \times 9.81 \times (0.01 + 0.01 + 0.05)}{0.01 + 0.01}$$

$$R_{2V} = 4868.60\, N$$

Reaction at R_{1V}:

$$R_{1V} = Fr + m_g g + m_P g - R_{2V}$$

$$R_{1V} = 9494.81 + 0.14039 \times 9.81 + 3.5099 \times 9.81 - 4868.60$$

$$R_{1V} = 4662.01\, N$$

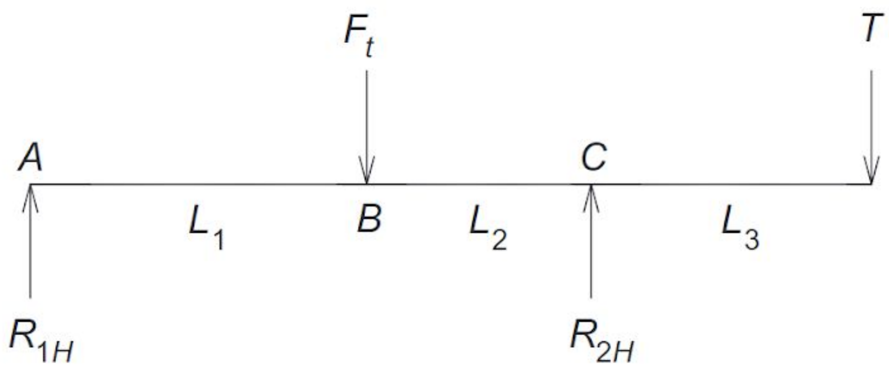


Figure. 3 Horizontal Loading diagram.

Reaction at R_{2H}:

$$R_{2H} = \frac{Ft \times L1 + T(L1 + L2 + L3)}{L1 + L2}$$

$$R_{2H} = \frac{4244.13 \times 0.01 + 764.1 \times (0.01 + 0.01 + 0.05)}{0.01 + 0.01}$$

$$R_{2H} = 4796.41\,N$$

Reaction at R_{1H}:

$$R_{1H} = Ft + T - R_{2H}$$

$$R_{1H} = 4244.13 + 764.1 - 4796.41$$

$$R_{1H} = 211.82\,N$$

Vertical Bending Moment at M_{BV}:

$$M_{BV} = R_{1V} \times L1 = 4662.01 \times 0.01$$

$$M_{BV} = 46.62\,Nm$$

Vertical Bending Moment at M_{CV}:

$$M_{CV} = R_{1V}(L1 + L2) - \left(\left(Fr + m_g \times g\right) \times L2\right)$$

$$M_{CV} = 4662.01 \times (0.01 + 0.01) - ((9494.81 + 0.14039 \times 9.81) \times 0.01)$$

$$M_{CV} = -1.722\ Nm$$

Horizontal Bending Moment at M_{BH}:

$$M_{BH} = R_{1H} \times L1$$

$$M_{BH} = 211.82 \times 0.01$$

$$M_{BH} = 2.12\ Nm$$

Horizontal Bending Moment at M_{CH}:

$$M_{CH} = R_{1H}(L1 + L2) - (Ft \times L2)$$

$$M_{CH} = 211.82 \times (0.01 + 0.01) - (4244.13 \times 0.01)$$

$$M_{CH} = -38.205\ Nm$$

Resultant Bending Moments:

$$\left|M_x\right| = \sqrt{\left(M_{xV}\right)^2 + \left(M_{xH}\right)^2}$$

$$\left|M_B\right| = \sqrt{(46.62)^2 + (2.12)^2} = 46.67\ Nm$$

$$\left|M_C\right| = \sqrt{(-1.722)^2 + (-38.205)^2} = 38.24\ Nm$$

Endurance Limit Calculations:

To realise the calculations it assumed the diameter of the main shaft should be around 18mm.

Material (817M40):

Ultimate Tensile Stress $\boldsymbol{\sigma}_{UTS}$ = 1000 MPa and $\boldsymbol{\sigma}_y$ = 770 MPa.

Endurance limit of test specimen:

$$\sigma'_e = 0.504\sigma_{uts}$$

$$\sigma'_e = 0.504 \times 1000 = 504\ MPa$$

Material finish (Hot Rolled):

a = 57.7 MPa.

b = - 0.718.

Surface Finish Factor (k_a):

$$K_a = a\sigma_{uts}{}^b = 57.7 \times 1000^{-0.718}$$

$$K_a = 0.405$$

Size Factor (k_b):

$$K_b = \left(\frac{d}{7.62}\right)^{-0.1133} = \left(\frac{18}{7.62}\right)^{-0.1133}$$

$$K_b = 0.9072$$

Reliability Factor (k_C): 0.897

Duty Cycle Factor (k_e): 1

Filet radius at the shoulder: 3mm.

Ratio of Diameters:

$$D/d = (3 + 18 + 3)/18 = 1.333$$

$$r/d = 3/18 = 0.1667$$

From the graph “Stress concentration factors for a shaft with a fillet subjected to bending” (Childs, 2014, p.286), we can determine the geometric stress concentration factor k_t = 1.65.
Notch sensitivity index for a 1000 MPa strength material and notch radius of 3mm is q = 0.9.

Surface Finish Factor (k_f):

$$K_f = 1 + q\left(k_t - 1\right) = 1 + 0.9 \times (1.65 - 1)$$

$$K_f = 1.585$$

$$k_f = 1/K_f = 1/1.585 = 0.631$$

Miscellaneous Factor (k_g): 1.

Endurance limit (using the formula from the 2018 edition) :

$$\sigma_e = k_a k_b k_c k_d k_e k_g \sigma_e'$$

$$\sigma_e = 0.405 \times 0.907 \times 0.897 \times 1 \times 1 \times 1 \times 504$$

$$\sigma_e = 166\ MPa$$

Shaft Diameter Calculation (Using ASME Equation and a factor of safety n_s = 2):

$$d = \left[\left(\frac{32 n_s}{\pi}\right)\sqrt{\left(\frac{M}{\sigma_e}\right)^2 + \frac{3}{4}\left(\frac{T}{\sigma_y}\right)^2}\right]^{1/3}$$

$$d = \left[\left(\frac{32 \times 2}{\pi}\right)\sqrt{\left(\frac{46.67}{166 \times 10^6}\right)^2 + \frac{3}{4}\left(\frac{63.66}{770 \times 10^6}\right)^2}\right]^{1/3}$$

$$d = 0.01808\ m\ ;\ 18.80\ mm.$$

The minimum recommended shaft being 18.80 mm which is not a standard size, a shaft diameter of 20.00 mm was selected for the design. This will increase the safety factor but also allow to choose bearings of a standard size whilst still fitting within the large gear bore. The second shaft will be assumed to be of a diameter of 12 mm, a value close to the bore of the smaller gear.

IV. Design Drawings.

The Engineering drawings are available at the end of the report.

They will include:

- The Casing Top and Bottom.
- An exploded view of the Assembly with a Parts List.
- Gears and Shafts.

Conclusion.

Following the requirements of the project it was possible to find a suitable electrical motor to provide 2kW and 300 RPMs output. This report presented the various calculations realised to select the gear fitting the requirements of the design and the subsequent calculations realised to define the best shaft diameters.

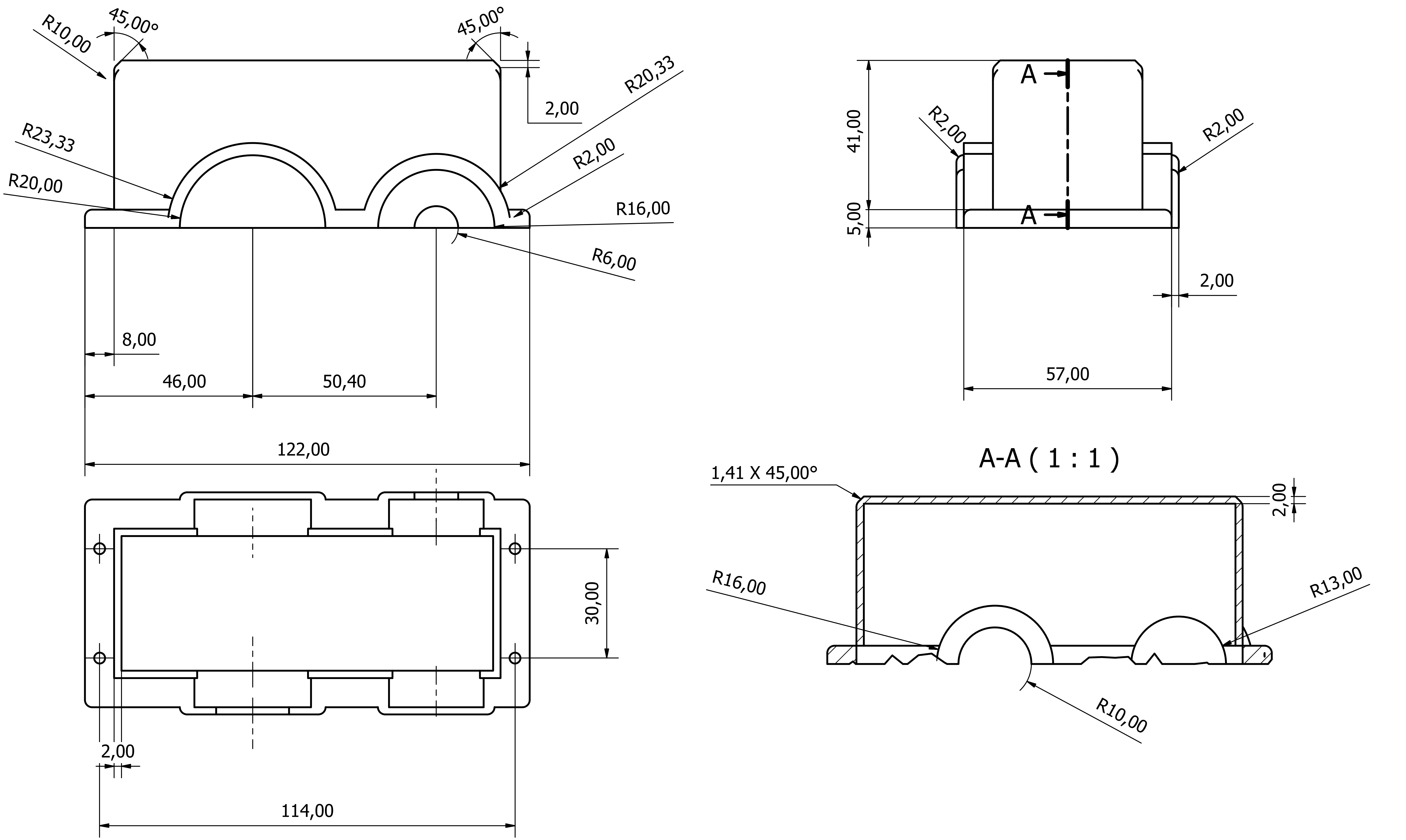
Throughout this project a lot of assumptions were made to be able and realise the design. To simply the CAD design the face width of the gears was set 25mm. The shafts were also pushed to the bore size of the gears. All of these sizes were selected with caution to keep the system safe.

There were a lot of difficulties with realising the 3D CAD due to lack of CAD design module in the previous year. Although a design was provided it would have to be reviewed in order to provide a manufacturable gearbox.

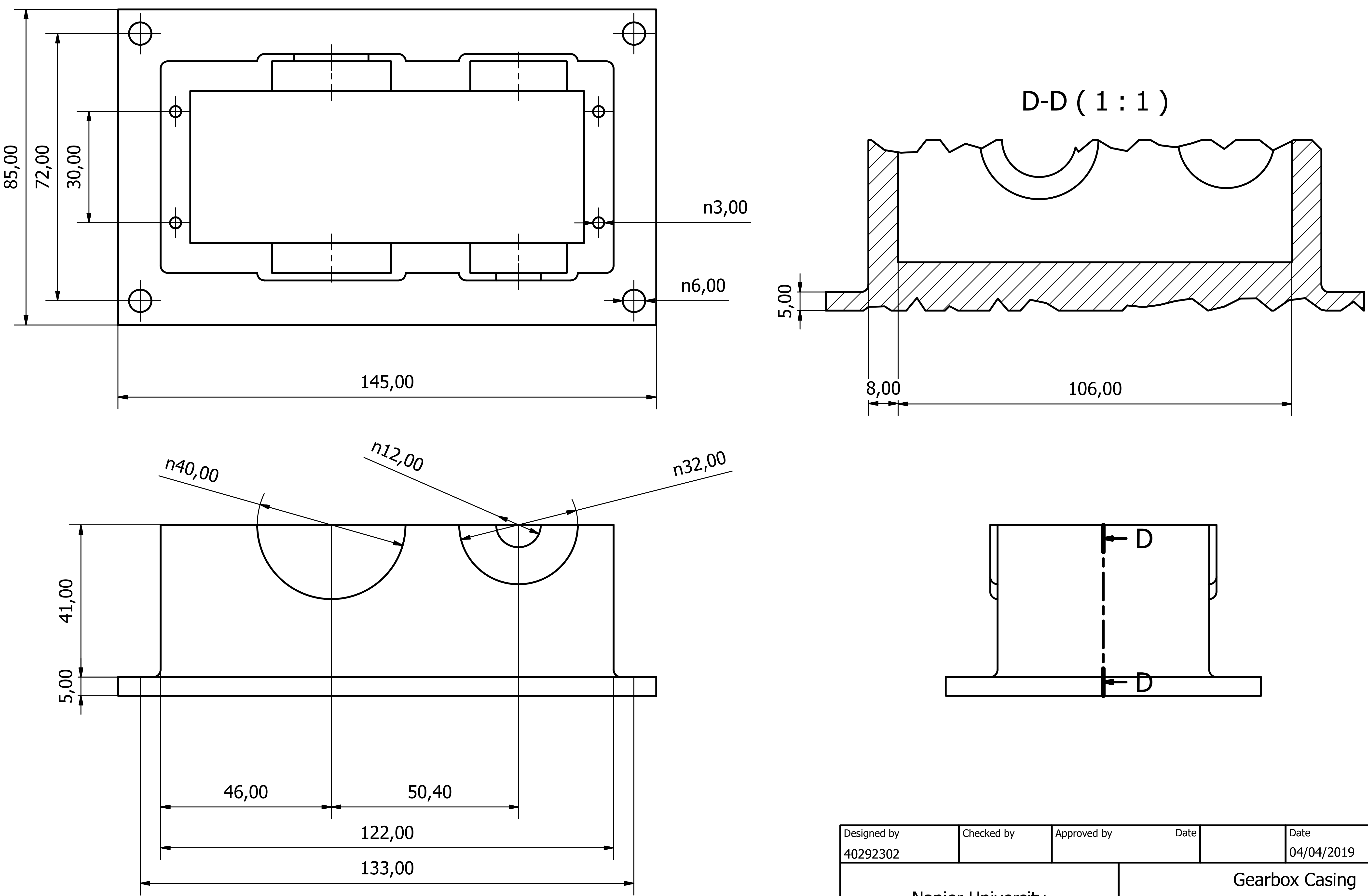
References.

Childs, P. (2014). *Mechanical design engineering handbook*. 1st ed. London, UK: Elsevier Ltd.

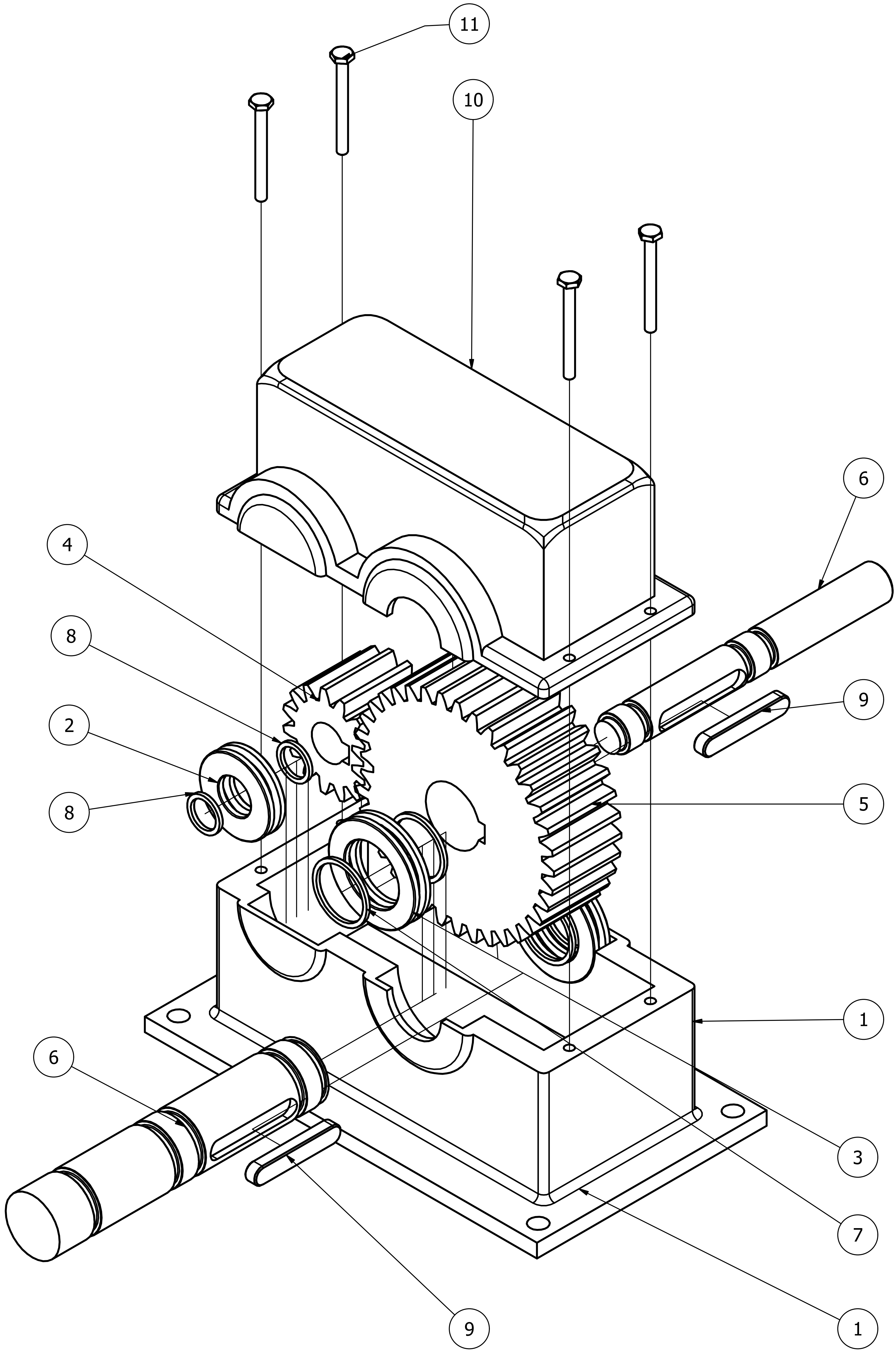
Childs, P. (2018). *Mechanical design engineering handbook*. 2nd ed. London, UK: Elsevier Ltd.



Designed by	Checked by	Approved by	Date	Date	Scale
40292302				04/04/2019	1:1
Napier University	Gearbox Casing				
	Casing			Edition	Sheet 1 / 2



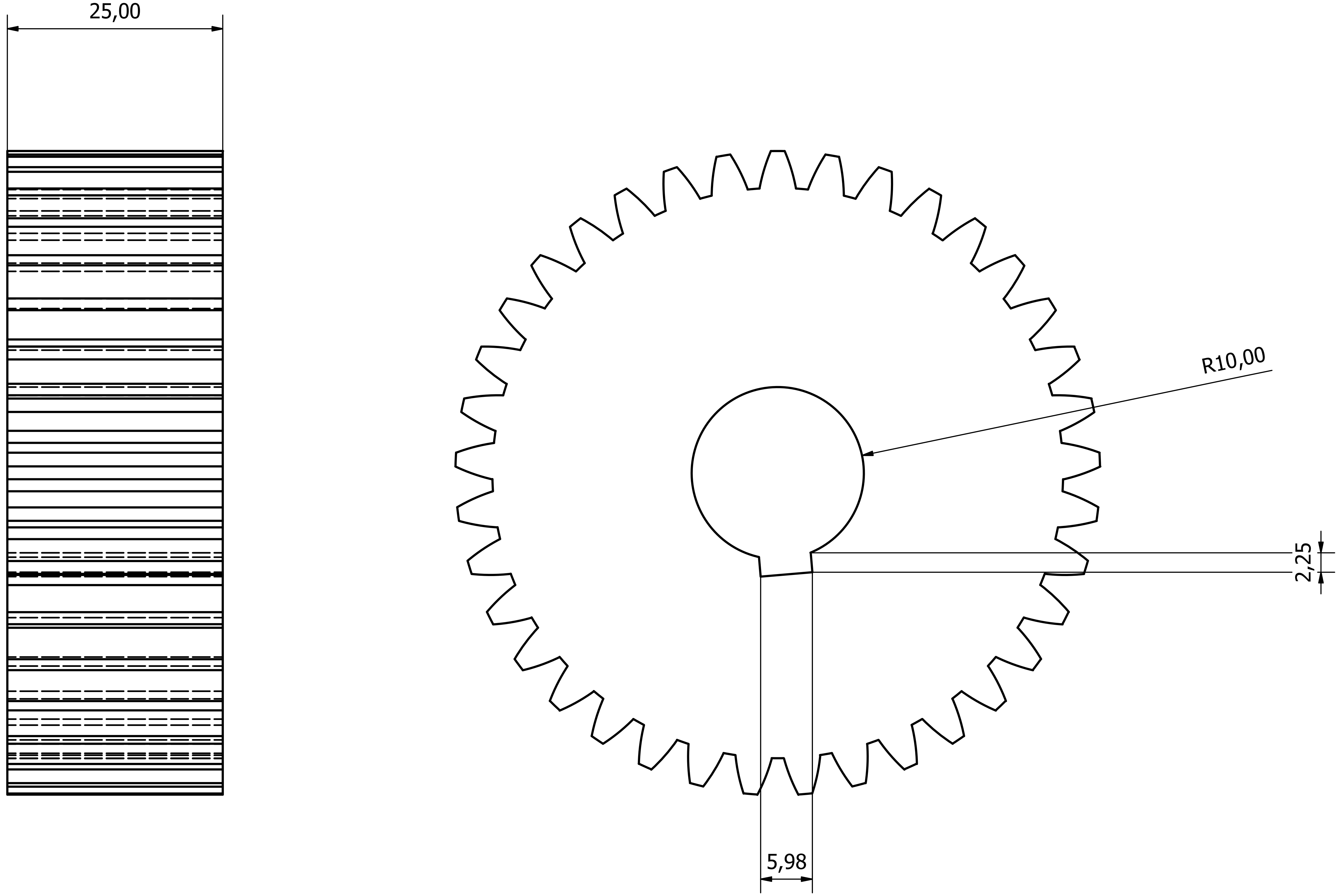
Designed by	Checked by	Approved by	Date	Date	Scale
40292302				04/04/2019	1:1
Napier University	Gearbox Casing				
	Casing			Edition	Sheet 2 / 2



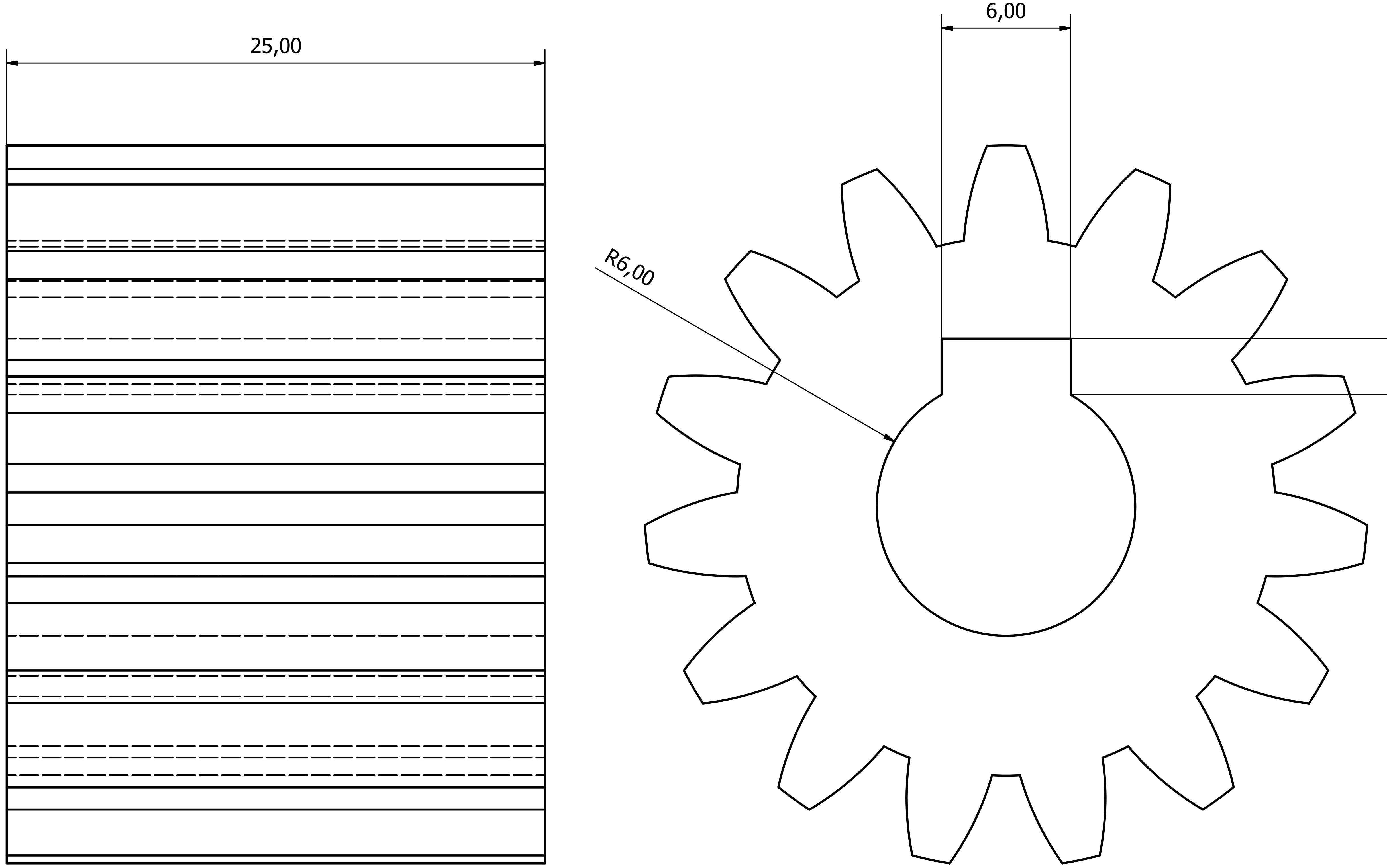
Designed by	Checked by	Approved by	Date		Date	Scale
40292302					04/04/2019	1:1
		Gearbox Exploded View				
		GearBox Exploded			Edition	Sheet 1 / 2

PARTS LIST				
ITEM	QTY	PART NUMBER	DESCRIPTION	MATERIAL
1	1	Casing Bottom	Bottom part of the case. Holds the bearings and provides fixture holes.	Steel
2	2	ISO 104 - 1 71 - 12 x 26 x 6	Rolling bearing-Thrust bearing(Single Direction).	Steel, Mild
3	2	ISO 104 - 0 70 - 20 x 32 x 6	Rolling bearing-Thrust bearing(Single Direction).	Steel, Mild
4	1	Small Spur Gear1	Bore Diameter: 12mm. 15 teeth	Steel
5	1	Large Spur Gear	Bore Diameter: 20mm. 35 teeth	Steel
6	2	Shaft	Small Shaft Diameter: 12mm Large Shaft Diameter: 20mm	Steel
7	4	ISO 3601-1 - A 0170 G	Fluid power systems - O-ring.	Rubber
8	4	ISO 3601-1 - A 0087 G	Fluid power systems - O-ring.	Rubber
9	2	ISO 2491 - A 6 x 4 x 32	Thin parallel keys. Constrains Gears to shafts.	Steel, Mild
10	1	Casing Top	Top of the Casing to protect the gear system.	Steel
11	4	ISO 4014 - M3 x 30	Hexagon head bolt - product grades A and B.	Stainless Steel, 440C

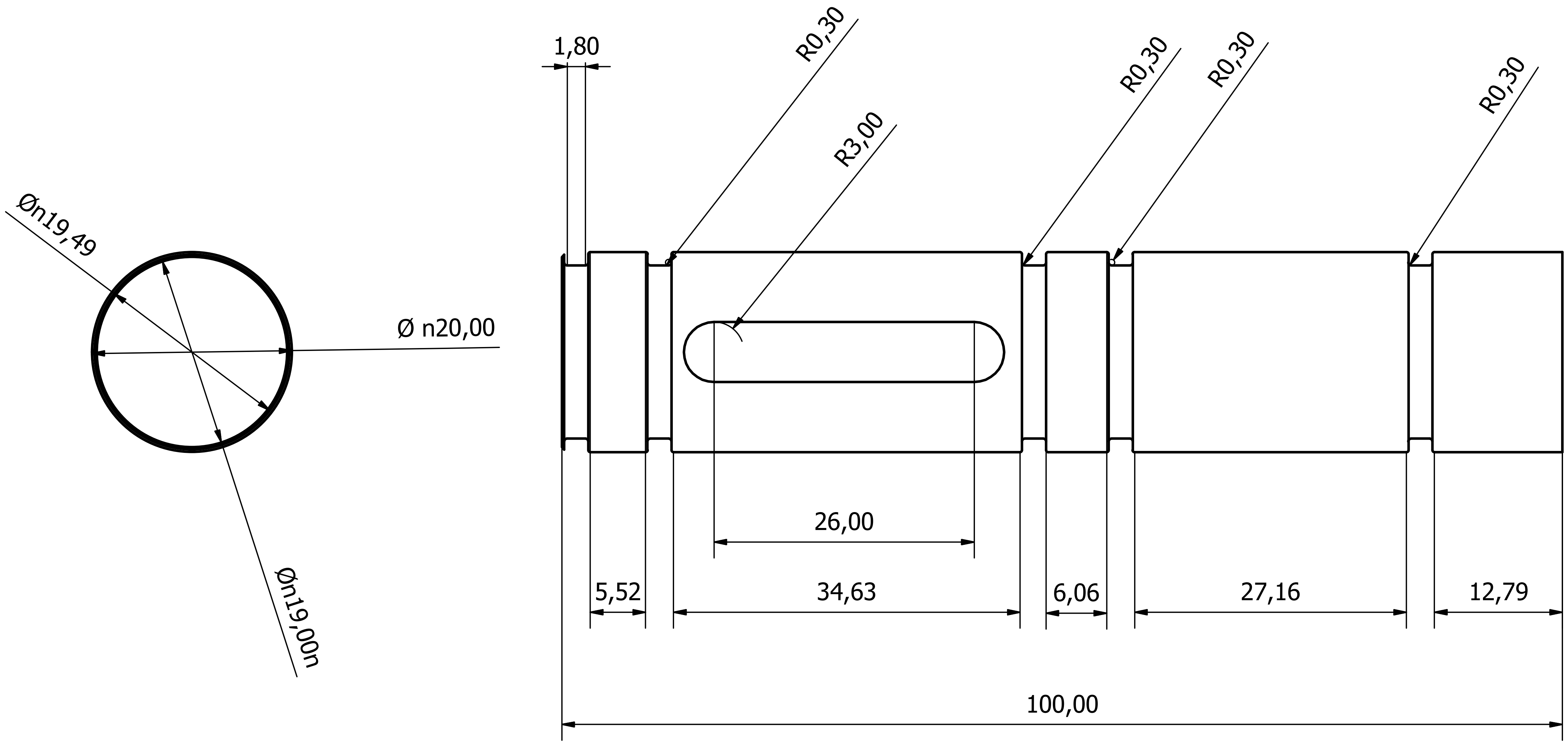
Designed by	Checked by	Approved by	Date		Date	Scale
40292302					04/04/2019	1:1
			Gearbox Exploded View			
			GearBox Exploded		Edition	Sheet 2 / 2



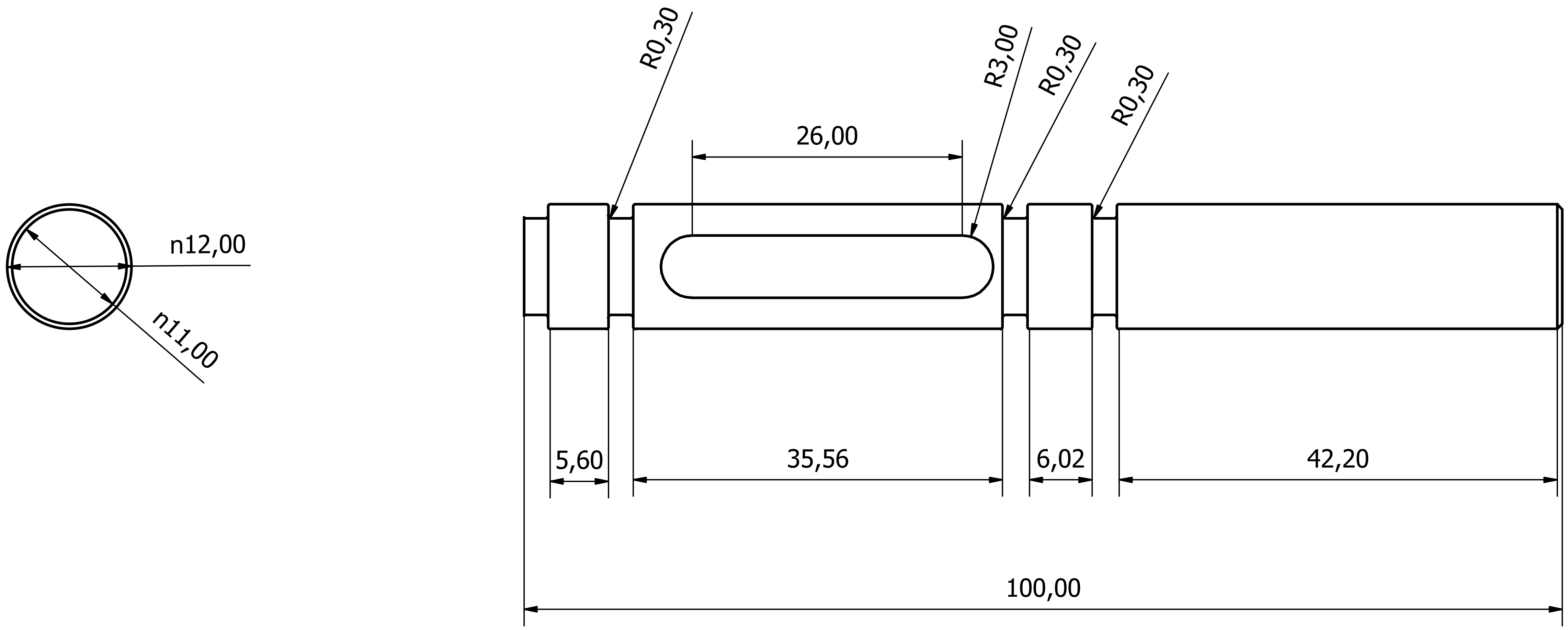
Designed by	Checked by	Approved by	Date		Date	Scale:
40292302					04/04/2019	2:1
		Large Gear				
		large gear			Edition	Sheet 1 / 1



Designed by	Checked by	Approved by	Date		Date	Scale:
40292302					04/04/2019	5:1
		Small Gear				
					Edition	Sheet 1 / 1



Designed by	Checked by	Approved by	Date		Date	Scale
40292302					04/04/2019	2:1
		Large Shaft				
		Large shaft			Edition	Sheet 1 / 1



Designed by localadmin	Checked by	Approved by	Date	Date 04/04/2019	Scale: 2:1
	Smaller Shaft			Edition	Sheet 1 / 1