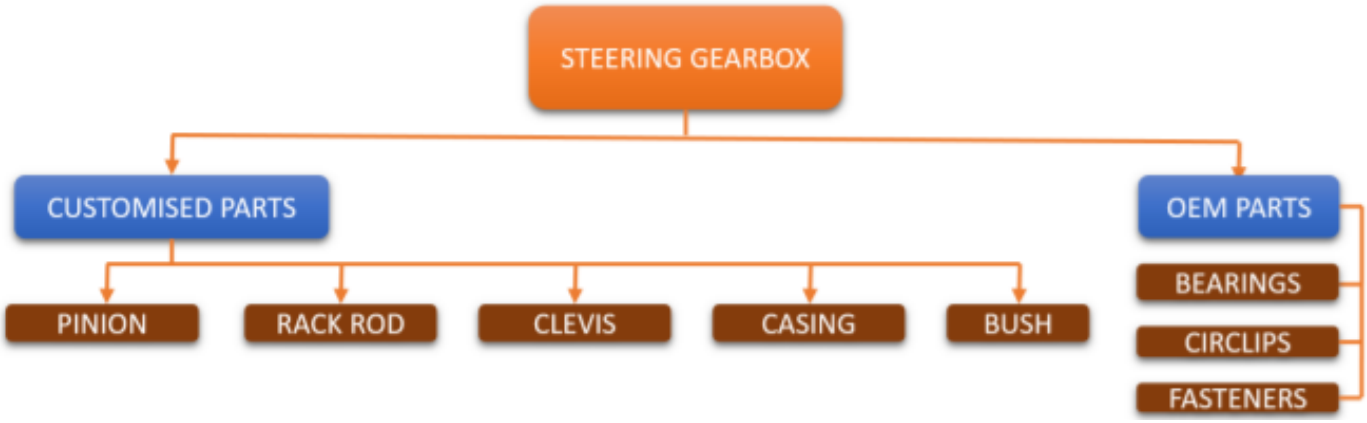
Section 1: Prototype Cost

1.1: Planned Process Description



PINION:

- Raw material used for pinion is Aluminium 6061-T6 of size Ø36 *70mm.
- For the first step of machining of the billet, turning and facing operation is done on the billet.
- Lathe machine is used for this purpose. In turning, the required outer and inner diameters were achieved.
- Groove for external circlip of 25mm was made on lathe machine. The thickness of groove is 1.3 mm.
- Then spline cutting operation is done on other end for positive locking between pinion and column.
- It is then followed by gear cutting on gear hobbing machine (PCD – 33mm, Module – 1.5mm, Ø- 20˚).

RACK ROD:

- Raw material used for rack rod is Aluminium 6061-T6 billet of size Ø 18*160 mm.
- For the first step of machining of the billet, turning and facing operation is done on the billet.
- It is then followed by milling up to depth of 6mm, rack cutting (Module – 1.5mm Ø20˚). Milling machine is used for this purpose.

- Drilling (Ø8mm) and internal tapping (M10 x 1.5) operations were performed on both face ends.

CASING:

- Raw material used for Rack casing is Aluminium 6061-T6 billet of size 240*68*38mm.
- The Casing is manufactured on VMC.

CLEVIS:

- Raw material used for clevis is Aluminium 6061-T6 billet of size Ø26*165 mm Quantity- 2
- For the first step of machining of the billet, turning and facing operation is done on the billet.
- It is then followed by step turning (Ø10mm) up to 20mm length from one face end.
- CNC milling is done till depth of 24 mm. Followed by drilling of through holes (Ø6mm).
- External threading (M10 x 1.5) is done on the step diameter 10mm with Die.

BUSH:

- Raw material used for bush is Nylatron billet of size Ø26 *35mm.
- For the first step of machining of the billet, turning, facing and boring operation is done on the billet.
- Followed by step turning Ø 22mm, length 10 mm and keeping Ø 26mm length 5mm at other end and giving tolerance of 0.015mm to bore for running fit and 0.015mm to minor diameter step for interference fit.

BEARING TYPE:

- SKF Bearing 61805-2RS1 (Deep groove ball bearing)

FASTNER:

- External circlip DIN 471025*1.2
- Internal circlip D1300-0370*1.5

ASSEMBLY:

- For assembly, bearing (NTN 6805JRZZ/2AS) was press fit in the bore of 37mm diameter.
- First internal circlip was installed and pinion was press fitted and second internal circlip was installed with the rack in position with meshing of gear teeth on rack and pinion.
- Bush was press fit in casing at its position.
- Clevis were hand tightened to rack rod.

Serial No.	Particulars	Details/ Description	Purchased /Fabricated	Unit	Cost / Unit	Quantity	Sub Total
1.	Pinion	Aluminium 6061-T6	P	Kg	350	0.193	67.5
		Lathe	F	Hr	80	1	80
		Spline Cutting	F	Hr	450	0.5	225
		Gear Cutting	F	Hr	500	0.5	250
		Anodizing	F	Kg	50	0.088	4
2.	Rack Rod	Aluminium 6061-T6	P	Kg	350	0.11	38.5
		Lathe	F	Hr	80	0.25	20
		Milling	F	Hr	300	0.25	75
		Rack Cutting	F	Hr	500	0.5	250
		Anodizing	F	Kg	50	0.067	3.35
3.	Clevis	Aluminium 6061-T6	P	Kg	350	0.236	82.6
		Lathe	F	Hr	80	1	80
		M1TR (Milling)	F	Hr	300	0.166	49.8
		M1TR (Holes)	F	Hr	200	0.08	16

4.	Casing	Aluminium 6061-T6	P	Kg	250	1.67	417.5
		VMC	F	Hr	300	2.5	750
5.	Bush	Nylatron	P	Kg	240	0.008	1.92
		Lathe	F	Hr	80	0.25	20
6.	Bearing	SKF 61805-2RS1	P	Number	182	1	182
7.	Circlip	DIN 471025*1.2	P	Number	1	1	1
		D1300-0370*1.5	P	Number	1.5	1	1.5
8.	Bolts	M6 Bolts	P	Number	7	4	28
9.	Nuts	M6 Nuts	P	Number	0.75	4	3
10.	Assembly	Labour	F	Hr	100	0.25	25

Total: INR 2,671.67/-

Section 2: Mass Production

2.1: Planned Process Description

- Annual requirement is to supply Steering Gearboxes for 4000 ATVs per year for next five years.
- So, considering 280 working days in a year including downtime due to maintenance, breakdown or holidays daily target is to produce 15 units. This also includes the rejections that may occur due to quality check.

Daily Process Flow for Casing:

- Heating of material for Batch 1 starts at 7:00 am. It will take approximately 2 hr to reach right temperature. Casting starts at 9:00 am.
- Casting of first batch takes about 1 hr and 6 components will be casted at the end.
- Before end of batch 1, heating of batch 2 will be started.
- After being cooled, it is taken for cleaning operations. This includes runner, riser cutting, trimming, removal of gating system.
- Components from each batch will be ready for fettling at the end of process and the proceeds on M1TR for drilling and boring.

- On M1TR inner diameters of both pinion and rack rod housings are achieved and boring is done for 37 mm bearing surface with standard tolerance of 37(+0.00 -0.02).
- Machining of component is then followed by powder coating.

Daily Process Flow for Pinion:

- Cutting of billet for pinion starts at 7 am. Billet cutting continues until requirement is met.
- Billet then proceed to CNC for turning and groove for circlip of 1.3mm.
- It is followed by spline cutting on M1TR by fixing indexing head.
- Finally, gear cutting is done on gear hobbing machine (PCD – 33mm Module – 1.5mm, Ø- 20˚).

Daily Process Flow for Rack Rod:

- Cutting of billet for rack rod starts at 7 am. Billet cutting continues until requirement is met.
- Billet then proceed to Conventional Lathe for turning, drilling of Ø8 is drilled on it and a tap of M10X1.5 on both face ends.
- Machined billet is then milled on M1TR up to depth of 6mm.
- The billet is brought to rack cutting machine where rack having module 1.5mm and pressure angle 20˚ is cut.

Daily Process Flow for Clevis:

- Cutting of billet for rack rod starts at 7 am. Billet cutting continues until requirement is met.
- Billet then proceed to CNC turning, facing and threading.
- Machined billet is then milled on M1TR up to depth of 24mm and drill of Ø6.

Daily Process Flow for Bush:

- Cutting of billet for rack rod starts at 7 am. Billet cutting continues until requirement is met.
- Billet then proceed to CNC turning, facing and given tolerances for required fits.

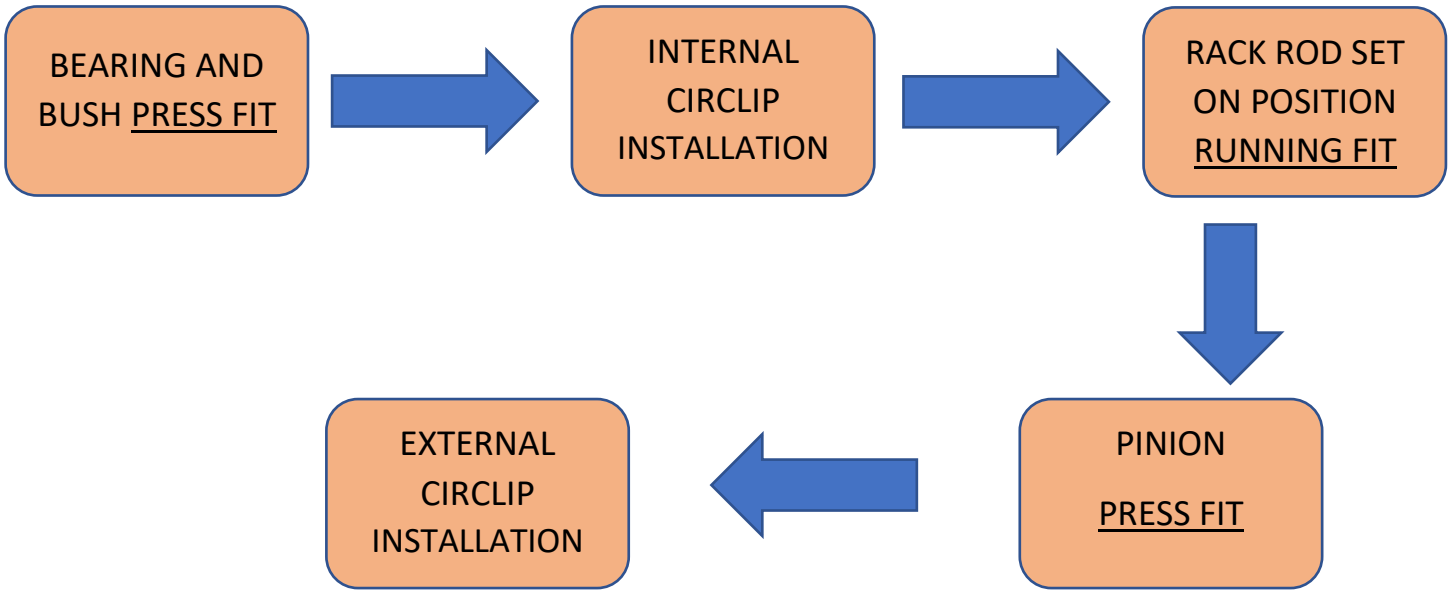
Daily Process Flow Steering Gearbox Assembly:

- After parts are manufactured, they are brought up to assembly line.
- Bearing and bush is press fitted in casing at its position, followed by internal circlip fitted in groove provided in casing.
- The rack rod is placed in casing and clevis are tightened.
- The Pinion is the press fitted in bearing, with the teeth of rack and pinion meshed, followed by external circlip fitted on groove provided on pinion.
- The time required for assembly is 15mins.

Assembly Method:

- After each component inspection, the parts are transferred to the assembly line.
- The accessories required for the assembly are as follows:
    1. Overhaul press fit machine.
    2. Set of internal and external circlip pliers.

Assembly process is as follows:



- Considering the time of assembly i.e., 15 min.
- Assembly time includes:
    1. Bearing Press Fit: 4 mins
    2. Bush Press Fit: 3 mins
    3. Total Circlip Installation: 2 mins
    4. Rack Rod to Clevis hand tight and Installation: 2 min
    5. Pinion Press Fit: 4 mins

At the end of day total 15 products are produced. So, it will take 280 days to complete the production of 4000 units a year.

2.2 Bill of Material (4000 Units)

Serial No.	Particulars	Details/ Description	Purchased /Fabricated	Unit	Cost / Unit	Quantity	Sub Total
1.	Casing	Die	F	Number	60000	1	60,000
		Casting AL (LM-24)	F	Kg	270	1580	4,26,600
		Drilling and Boring	F	Hr	110	2000	2,20,000
2.	Pinion	Mild Steel	P	Kg	50	2,120	1,06,000
		CNC	F	Hr	200	1000	2,00,000
		Spline Cutting	F	Hr	110	666	73,260
		Gear Cutting	F	Hr	200	2000	4,00,000
3.	Rack Rod	Mild Steel	P	Kg	50	880	44,000
		Lathe	F	Hr	80	666	53,280
		Milling	F	Hr	110	1000	1,10,000
		Rack Cutting	F	Hr	200	2000	4,00,000
4.	Clevis	Mild Steel	P	Kg	50	4640	2,32,000
		CNC	F	Hr	200	2000	4,00,000
		M1TR (Milling, Drilling)	F	Hr	110	1330	1,46,300
5.	Bush	Nylatron	P	Kg	240	36	8,640
		CNC	F	Hr	200	340	68,000
6.	Bearing	SKF 61805-2RS1	P	Number	182	4000	7,28,000
7.	Circlip	DIN 471025*1.2	P	Number	1	4000	4,000
		D1300-0370*1.5	P	Number	1.5	4000	6,000
8.	Bolts	M6 Bolts	P	Number	5.53	16000	88,480
9.	Nuts	M6 Nuts	P	Number	0.75	16000	12,000
10.	Assembly	Labour	F	Hr	100	1000	1,00,000

Total: INR: 38,86,560/-

Cost per Unit: 971.64/-

Cost Reduction due to mass production: 63.63%

Comparison Table:

No	Factors	Prototype	Mass Production
1.	Raw Material	*Rack Rod, Pinion and Clevis-* Aluminium 6061-T6	*Rack Rod, Pinion and Clevis-* Mild Steel
		Casing- Aluminium 6061-T6	*Casing* Aluminium (LM24)
2.	Part production technique	*Rack Rod, Pinion, Clevis and Bush-* Lathe- Facing and Turning Gear Hobbing Spline Cutting	*Rack Rod, Pinion, Clevis and Bush-* CNC/ lathe- Facing and Turning. Gear Hobbing Spline Cutting
		Casing- VMC	*Casing-* Hot Chamber Pressure die casting
3.	Implementation of manufacturing techniques to reduce time and efforts.	*Rack Rod, Pinion and Clevis-* Cycle time for lathe is more as well as there is requirement of skilled labour (for pinion and bush).	*Rack Rod, Pinion and Clevis -* Lathe is used for rack for drilling and tapping. CNC used for pinion and bush as tolerances are closely achieved with repeatability.
		Casing- VMC requires 2 hrs (Machining) + 0.5 Hrs (Setting time)	*Casing-* Pressure die casting eliminates time for lathe turning and reduces setting time.
4.	Manufacturing Process and rationale	On lathe Machine, components are manufactured with good surface finish.	Pressure Die Casting requires Lesser machining. Components are manufactured with close tolerance and high accuracy on CNC.
5.	Cost per Piece (Including Bearings & Fasteners)	INR 2726.67/-	INR 971.64/-

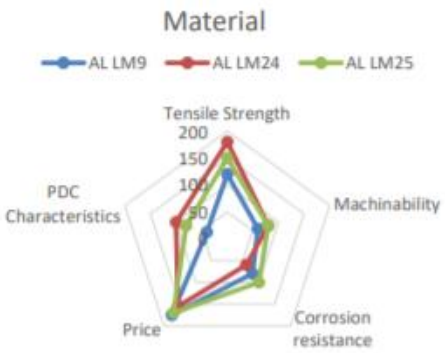
3.1 Material evaluation and process selection:

1. Rack Casing:

- Rack casing have integrated shape which will increase the cycle time for VMC machining. Cycle time is around 8 hrs as well as it increases billet cost and wastage is also more in the form of chips.
- For that purpose, we manufacture rack casing by casting process.

	Sand Casting	Die casting	Investment casting
Tooling Cost	LOW	HIGH	MEDIUM
Production cost	LOW	LOW	MEDIUM
Range of casting material	HIGH	LOW	HIGH
Surface finish	LIMITED	GOOD	GOOD
Casting tolerances	LOW	HIGH	HIGH
Production volume	LIMITED	HIGH	MEDIUM
Blow holes, Cavities	HIGH	LOW	MEDIUM

- Based on above comparison we have selected **Hot Chamber Pressure Die Casting.**



- For Rack casing LM 24 Aluminium Alloy is selected as it possesses high tensile strength and good fluidity. LM 24 is easy to cast and have good corrosion resistance. It offers good machinability.
- LM 24 is suitable for intricate and thin walled castings in all types of moulds, also used where corrosion resistance or ductility is required.

2. Rack Rod, Pinion and Clevis:

- Considering strength, life and wear resistance requirement of rack rod, pinion and clevis, Steel (Mild Steel) was selected. Steel possesses high wear resistance than Aluminium and is cheaper.
- Tensile strength of steel is typically 1.4 times higher than aluminium. As well as fatigue strength and wear strength of mild steel is more than that of Aluminium 6061.
- Rack and pinion are made of same material i.e. Mild steel. Thus, same material reduces pitting action and improves endurance strength of rack and pinion. Life of rack and pinion (Mild steel) is more than that of aluminium rack and pinion as reasons discussed above.

- Diameter of Rack Rod is 18mm for prototype and 15mm for mass production, while the face width of pinion is 18mm and 15 mm for prototype and mass production respectively.
- CNC turning machines are used to manufacture pinion and bush to reduce cycle time also tolerances are closely achieved with repeatability and more than 1 parts can be machined.
- Rack is turned, drilled and taping is done on conventional lathe then milled on M1TR and multiple racks are milled at a time by arranging in such a way that the position of slot is achieved in less time.
- Rack cutting is used to make teeth on rack rod by rack cutting attachment. This rack generation is generally preferred due to ease of setup and long rack cutter is used to cut multiple threads in single stroke which reduces cycle time.
- Gear hobbing is used for gear cutting on pinion. In mass production, number of pinions are mounted on arbor shaft due to these attachments, gear cutting time and setup time is reduced.
- As compare to other gear manufacturing process, Rack generation for rack and gear hobbing for pinion is preferred in mass production industries as it gives better dimensional accuracy and lesser cycle time.

3. Bush:

- The main function of bush is to provide support to rack rod with minimum friction to avoid wearing and smooth operation of mechanism. Nylatron is chosen due to its less coefficient of friction and has less weight.
- The required number of bushes are manufactured on CNC due to high dimensional accuracy requirement as the tolerance provided for interference fit between bush and casing and sliding fit between rack rod and bush to has be achieved.
- Multiple bushes can be manufactured in one setup by using longer billet which will reduce time consumption.

3.2 Selection of Machining and Tooling:

Machines:

1. **CNC (Computer numerical control):**

- For mass production CNC gives a higher production rate with a single operator per machine, reducing labour requirements. A quick change tool turret gives multiple tool options for different operations (Turning, threading, grooving) in quick succession thus reducing the overall cycle time. Total 2 CNCs are used.
- **CNC 1**- Pinion and Bush are to be manufactured. 5 pinions will be manufactured at a time from a single billet in about 2Hrs. So total 6Hrs will be required to achieve daily target.
- A set of 15 bush will be manufactured at a time and one set will take about 2Hrs, so total time will be 4Hrs, including setting time.
- **CNC 2-** This CNC will be used for clevis turning only, each clevis requires 0.5Hrs for turning.
- The total CNC running time will be 10Hrs for CNC-1 and 7.5Hrs for CNC-2 daily with repeatable programs.

2. **DRO (Digital Read Out):**

- DRO is selected for Milling of rack rod and Drilling and boring of Casing.
- DRO offers high accuracy and repeatability.
- By using fixtures, the time consumption for single casing will be minimal and less skilled workers can operate with least error.
- **DRO 1-** Boring, grooving of Pinion housing and rack housing and drilling of bolting holes will take 0.5Hr each casing, so total time required for casing will be around 8 Hrs with consideration of fixture setup for each setting.

- Rack milling will be done 5 rack in a set and each set will take 0.25Hrs, hence the total rack milling time will be 1Hr with consideration of fixture setup for each setting.
- **DRO 2-** Clevis milling will take total 2.5Hrs and drilling will take 1 Hrs. Pinion spline cutting will be done by setting indexing head on bed, each pinion will take 10mins, so total time will be 2.5Hrs.
- The daily running time of DRO 1 will be around 9 Hrs and DRO 2 will be around 5 Hrs.

3. Conventional Lathe:

- As these operations have less time consumption and cannot be done on mass scale on our lathe in a single setting, conventional lathe is used as less skilled workers can operate and the setup time is also less.
- Rack rod is turned followed by drilling and tapping.

4. <u>Gear Cutting Machines:</u>

- Gear Hobbing machine is used for gear cutting on pinion.
- An arbor shaft can be used for mounting 5 gears.
- By using fixture plate, 5 racks can be produced in a single setup.
- Total time for pinion is 2Hrs and for rack is 2 Hrs.

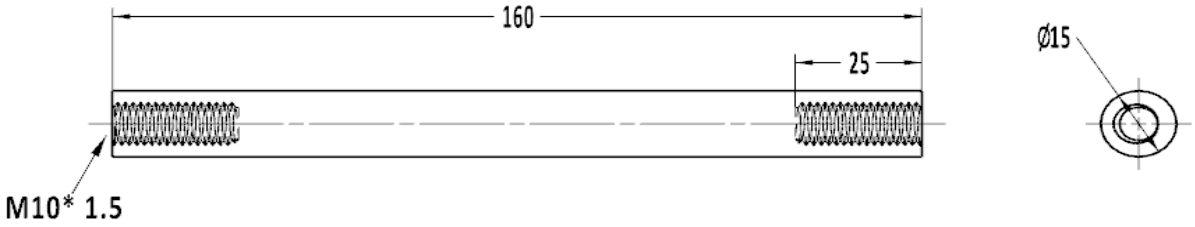
5. Pressure Die Casting:

- Pressure die casting gives a better dimensional accuracy and surface finish and does not produce defects associated with sand casting such as blow holes and porosity.
- Pressure die casting gives high production rate reduces secondary machining operations.

The following table shows the types of machines which will be used in the production plant with their specifications and cost.

Sr. No	Machine	Specification	Quantity	Per unit price In Rs	Total Cost
1.	CNC Model-DX 100	X axis travel-360 mm Z axis travel-200 mm Feed-24m/min Fanuc spindle speed-7.5 KW Spindle rpm-50-4000 rpm Spindle bore-50 mm No. of tools-5. Tool size-25 X 25 mm	2	8,00,000	16,00,000
2.	DRO Model-M3	Table size-254 X 1270 mm X axis travel-780 mm Y axis travel-395 mm Z axis travel-380 mm Motor output-3 HP Spindle speed-80-5400 rpm	2	2,81,000	5,62,000
3.	Hobbing Machine Model-JS5	Max module -5 Motor output -2 HP Max dia. of spur gear-1/2”-18”	1	4,20,000	4,20,000
4.	Rack cutting Model-ZFM 300H	Magnet plate dimension-310 X 1650 mm Table size-1850 X 250 mm Horizontal movement of Milling head-400 mm Max diameter of cutter-165mm Max width of cutter-115mm	1	4,00,000	4,00,000
5.	Pressure Die Casting	Locking force-120-660 ton Die height distance-125-450mm. Shot force-8-20 ton	1	9,00,000	9,00,000
6.	Precision Lathe Machine 4s	Length of bed- 1370mm Range of Spindle Speed- 40 to 950 rpm	1	62,500	62,500

TOTAL: 39,44,500/-



TEAM RED BARON	MATERIAL: MILD STEEL		NAME	DATE
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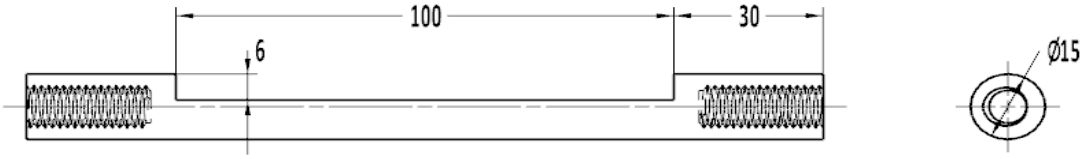
	SCALE : 1:1	CHECKED BY	NACHIKET J.	08/04/21
	RACK ROD LATHE			SHEET NO.1
				SIZE-A4



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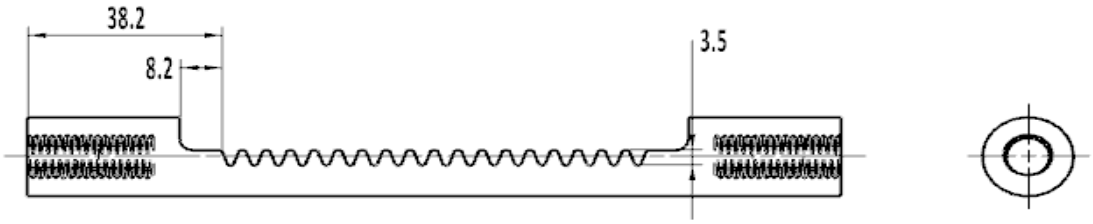

Rack Specifications:

Module: 1.5mm

Number of Cuts: 18

Depth of Cuts: 3.5mm

TEAM RED BARON	MATERIAL: MILD STEEL		NAME	DATE
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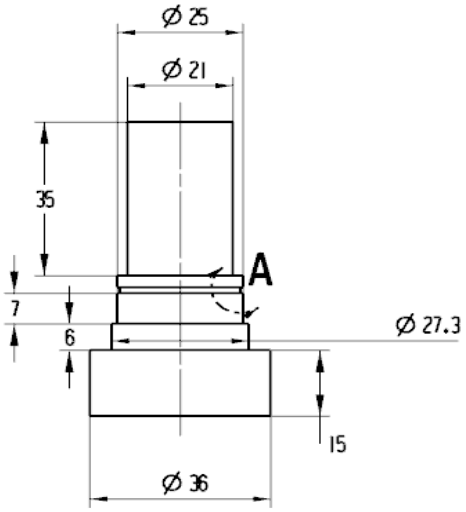
	SCALE : 1:1	CHECKED BY	NACHIKET K.	08/04/21
	TITLE: RACK ROD TEETH CUTTING			SHEET NO. 3
				SIZE-A4

CNC Turning



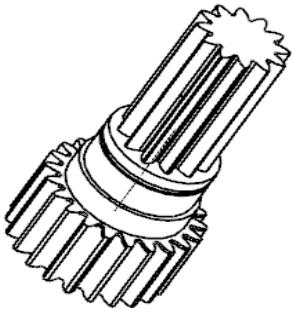
Specification of Gear:

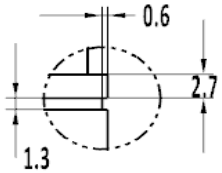
Module: 1.5mm

PCD: 33mm

Pressure Angle: 20

No. of Spline: 12





DETAIL A

SCALE 2:1

TEAM RED BARON	MATERIAL: MILD STEEL		NAME	DATE
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	SCALE : 1:1	CHECKED BY	Gayatri K.	08/04/21
	TITLE: PINION			SHEET NO. 1
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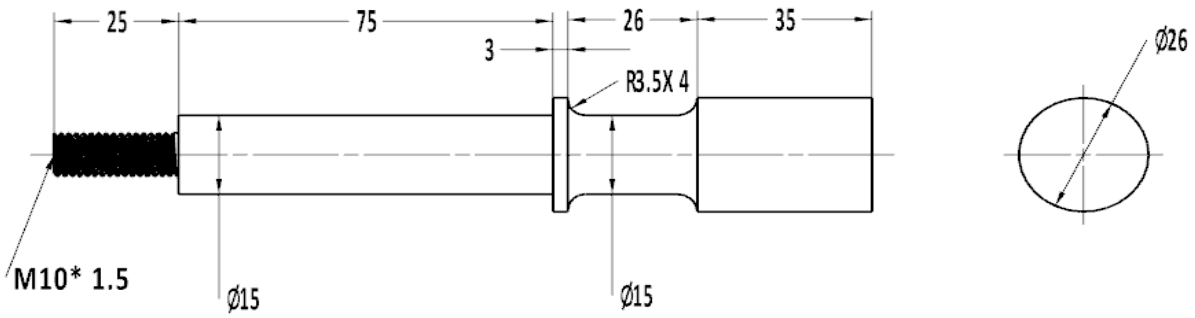

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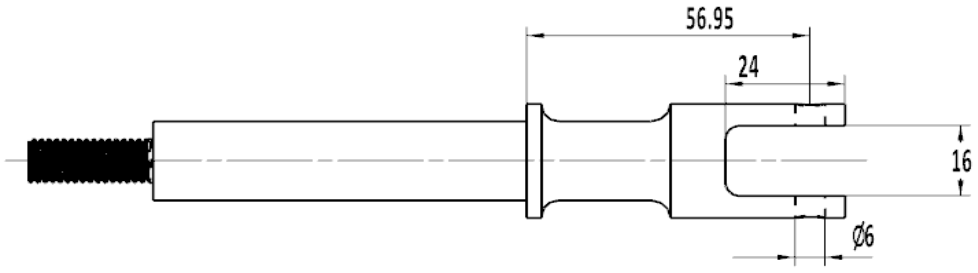

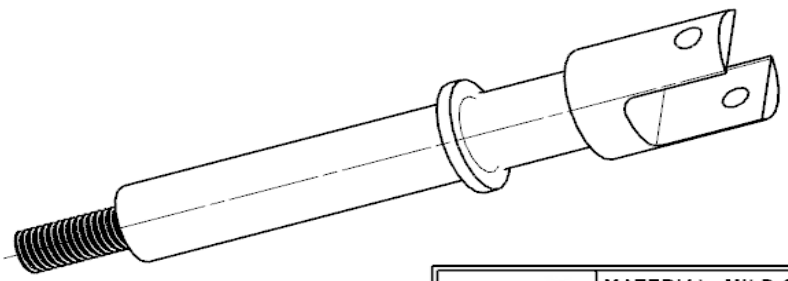

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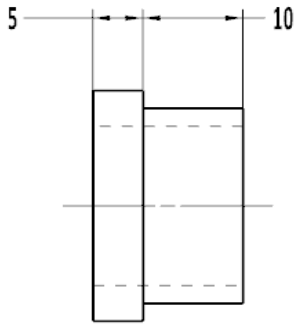

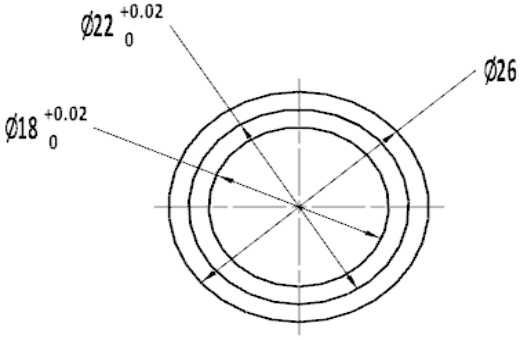

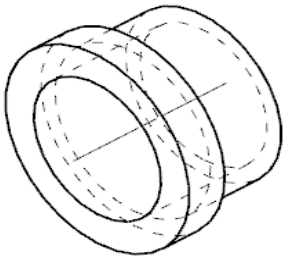

TEAM RED BARON	MATERIAL: NYLATRON		NAME	DATE
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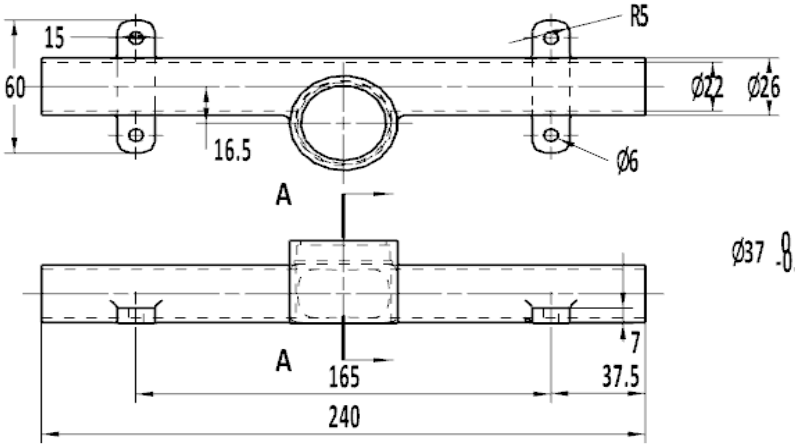
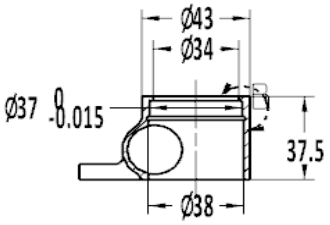
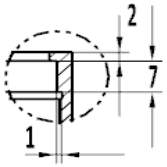


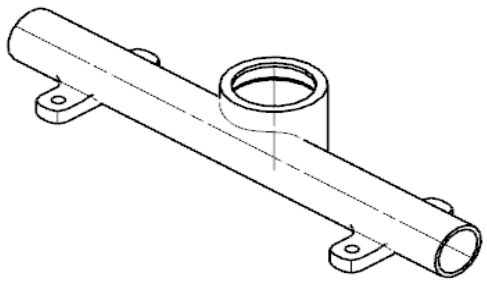


SECTION A-A

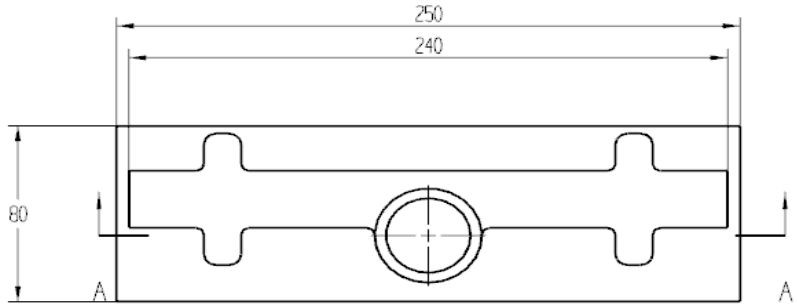


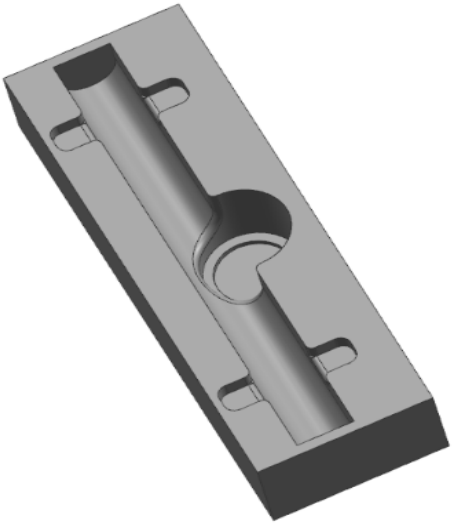
DETAIL B

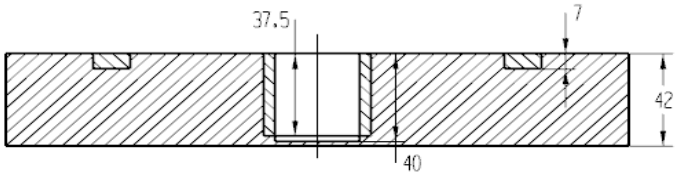
SCALE 1:1



TEAM RED BARON	MATERIAL: Al LM24		NAME	DATE
	DWG NO. 1	DESIGN BY	NACHIKET J.	10/04/21
	SCALE : 1:2	CHECKED BY	GAYATRI K.	12/04/21
	TITLE: CASING			SHEET NO. 1
				SIZE-A4

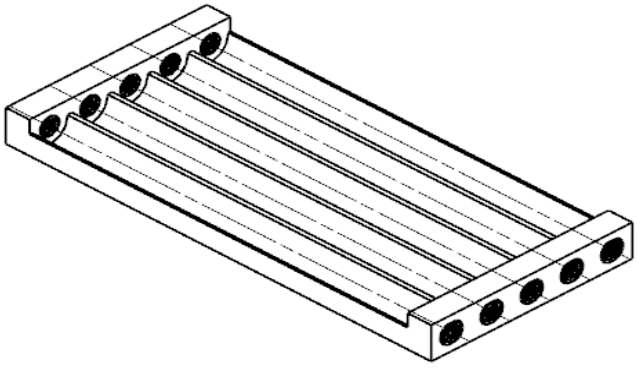


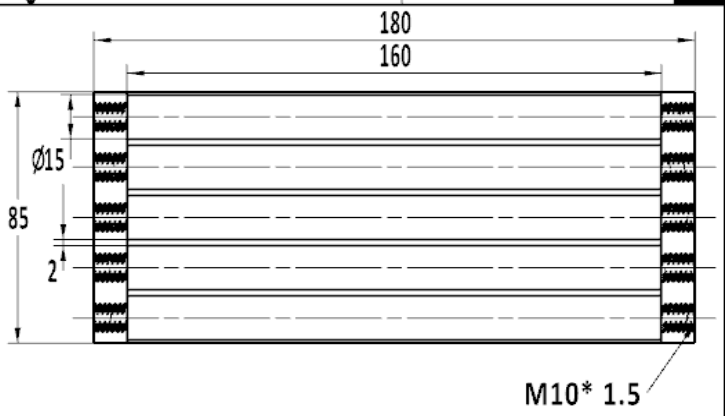


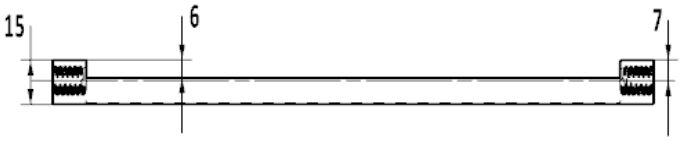


SECTION A - A

TEAM RED BARON	MATERIAL: MILD STEEL		NAME	DATE
	DWG NO. 1	DESIGN BY	DIGVIJAY T.	12/04/21
	SCALE : 1:2	CHECKED BY	NACHIKET J.	13/04/21
	TITLE: CASING FIXTURE FOR BORING			SHEET NO. 1
				SIZE-A4







TEAM RED BARON	MATERIAL: MILD STEEL		NAME	DATE
	DWG NO. 1	DESIGN BY	DIGVIJAY T.	10/04/21
	SCALE : 1:2	CHECKED BY	GAYATRI K.	12/04/21
	TITLE: RACK ROD FIXTURE			SHEET NO. 1
				SIZE-A4