Spur Gears

PROJECT REPORT

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Contents

Acknowledgement

We would like to extend our sincere gratitude to our esteemed faculty for the subject and our advisor Dr. Anand Sekhar R, for granting us the opportunity to make this summary report on the mechanical device we have decided to come forward with. On ensuring the fulfilment of the objectives meant to be laid out by the outcome of the course as we learn through this semester, we have also assimilated a vague yet crucial understanding of a project we will have to carry out in the coming semesters.

We would also like to appreciate the efforts of all our faculties in the Machine Tools Workshop, whose guidance has provided us a great advantage in the regular learning process we had to come across throughout the project, in the form of having a substantial background of the machines and related equipment we had to use for obtaining the end product, and knowing the purposes, uses and having an insight on what was learnt from it.

All the efforts put forward by our group members to gather the requisites to make the required product would surely be the next thing to acknowledge, and the objectives wouldn't have been completed without the sincere cooperation of our group members.

DESCRIPTION OF THE PROJECT

The mechanical component we have decided to identify, create and report on is as the title of the report suggests: Spur Gears. Before we go through the whole description about what we learned about gears and how we made it, it's a good thing to ask ourselves the reason behind selecting this mechanical marvel to discuss about.

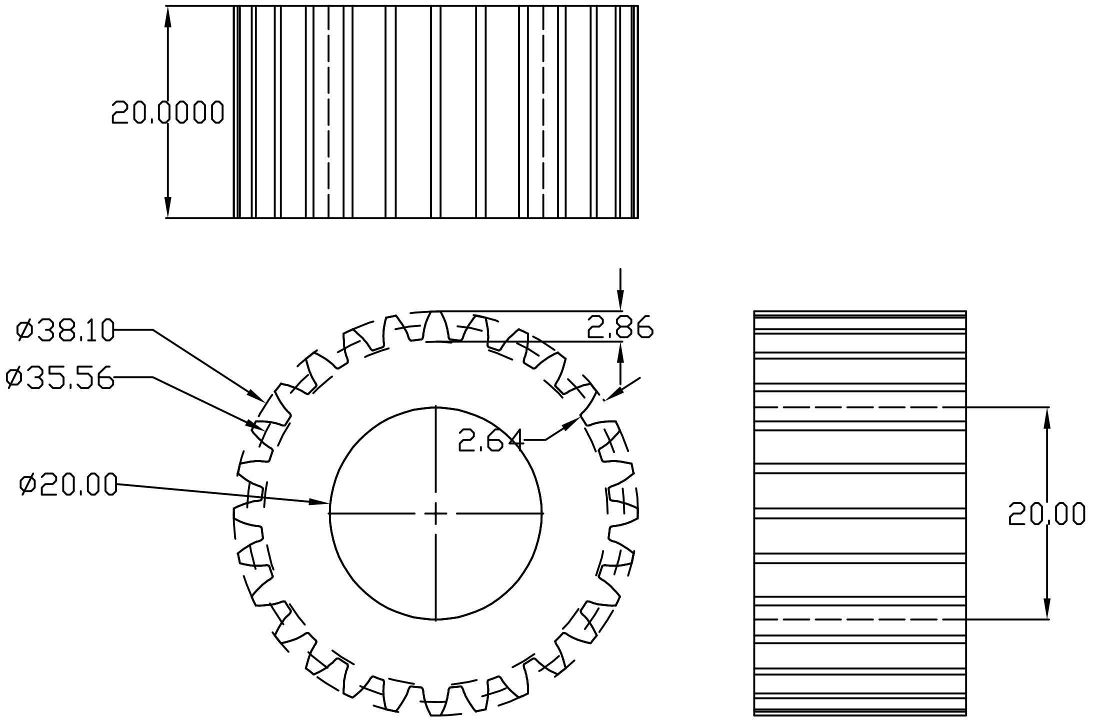
Almost every speck of machines, big or small; that we perceive with our own eyes everyday has a contribution of gears. From watches to automobiles, from ships to wind turbines, from wind-up toy cars to elevators and hand drills, and notably on lathes on which a process of making them had to start with, gears have found their use in almost every mechanical system on which the world relies on. They are nothing but **spinning levers** that **transmits** rotational motion and its byproducts: **Torque and Power**. Gears are among the most common mechanical parts. They come in great variety of shapes and materials.

We shall now have an insight on the drawing of our spur gear drafted using AutoCAD, on which is specified the required dimensions, used standards, and such. A detailed description of the processes involved to produce the gear with substantial requisites adhering to the required dimensions, and a detailed breakdown of cost computation has also been provided in the report. Precautions and things to consider beforehand has also been discussed alongside to ensure a proper completion of production.

Drawing and Specifications

The drawing along with the required dimensions and specifications are as shown in the next page. The selected gear is made using a diametrical pitch involute gear cutter, which can cut gears with a diametrical pitch of 20, as per the ISO Standards. The number of teeth obtained from the required calculations were found out to be 28, and thus the gear cutter was selected accordingly. The used material was a Cast Iron. The quality of a spur gear depends on the type of material from which the gear blank is made. High quality spur gears can only be made from high quality materials, which is a pie shaped billet. Nearly every form of material used in the manufacture of other products can be used to make spur gears, including steel, brass, plastics, aluminum alloys, grades of stainless steel, and titanium.

Cast Iron can be molded into any shape and is resistant to rust. The composition of cast iron involves the use of different ingredients each of which gives cast iron a different degree of strength and durability. Cast iron is commonly used to produce machine parts because of its low cost, rust resistance, and ability to be easily molded and shaped. It can be unbelievably strong or very weak, depending on the types of added mixtures.



GEAR SPECIFICATIONS	
Module	1.27
No: Of Teeth	28
Pitch Diameter	35.56
Teeth Height	2.64
Root Diameter	32.39
Hole Diameter	20.00
Head Diameter	38.10
Pressure Angle	20
Standard Used	ISO/TC
Material Used	Cast Iron/AISI 4140
All linear dimensions in mm	

SPUR GEAR	
Drawn By:	Group 5
BATCH	M5B
Dept. Of Mechanical Engineering	
TKMCE	

Machines Used

In order to produce our work, we had to use two machines from the workshop: A lathe and a Universal Milling Machine. Specifications are shown below.

LATHE

Manufacturer	M/s Mysore Kirloskar Ltd.
Model	Enterprise 1330
Spindle Bore	1016 mm
Type	Conventional
Centers (mm)	175 mm
Main Motor (HP)	3
Bed length	6 feet

UNIVERSAL MILLING MACHINE

Make and Model	Bharat Fritz Werner
Specifications	Table 1000 x 225 mm
Year	1982
Price	86,024
Base Swivel Angle	45 degrees (either side)
Attachments	Dividing head Vertical Rotary Slotting

Prerequisites

There were certain formulas and equations to get the parameters required to use the machine to obtain the gear with the right dimensions adhering to the International Standards. They are used in Indexing and to determine the number of teeth for a given outer diameter and diametrical pitch (DP).

As the DP cutting was the only option available to us in the apparatus provided to us in the facility, we have decided to use a standard diametrical pitch of 20, and obtain the required number of teeth for a given outer diameter.

For a selected diametrical pitch $\boldsymbol{P_d}$ on a blank of a given outer diameter $\boldsymbol{d_o}$, number of teeth required ($\boldsymbol{z}$) can be determined as follows:

$$\boldsymbol{d_o = \frac{(z+2)}{P_d}}$$

$$\Rightarrow \quad \boldsymbol{z = (d_0 \times P_d) - 2}$$

For an outer diameter of 1.5 inches (38.1 mm), with a diametrical pitch selected as 20,

$$\boldsymbol{z} = (1.5 \times 20) - 2 = \mathbf{28}$$

Hence, the required number of teeth is 28.

The next procedure is to select the index plate required for cutting. This is called as **Indexing**. It is the operation of diving the periphery of a piece of work into any number of equal parts. In cutting our required spur gear, equal spacing of teeth on the gear blank is performed by indexing. This is accomplished by using a special attachment in the machine known as **dividing head, or indexing head**. The dividing heads are of three types:

- Plain or simple dividing head
- Universal dividing head
- Optical dividing head

The available indexing methods are:

- Simple Indexing
- Direct Indexing
- Compound Indexing
- Differential Indexing

For our operation, we have chosen Universal Dividing Head with Simple Indexing method.

Before that, we have to know the available standard indexing plates corresponding to each of which is provided the number of holes.

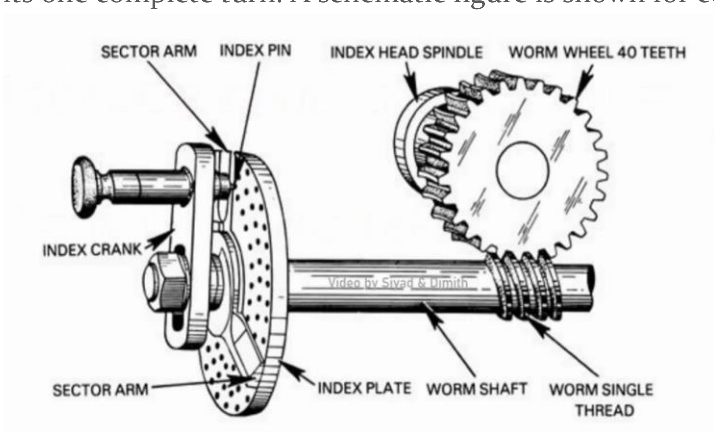
Plate Number	Number of Holes in the Index Plate
1	15, 16, 17, 18, 19
2	31, 33, 37, 39, 41
3	43, 47, 49

The next step is to determine the index crank movement. The term "index crank movement" typically refers to a mechanical process where a crank or handle is used to achieve a controlled, incremental movement or positioning of a component in a machine.

In simple indexing, the index crank movement $= \frac{40}{Z}$

Where z is the number of teeth we have previously obtained.

The reason behind this can be understood by knowing the arrangement of the dividing head that consists of the worm shaft with one end connected to an index plate, and the other end with a worm thread on which a worm gear of 40 teeth is meshed with, which is connected with the index head spindle. Which implies, 40 teeth on the worm gear means one complete turn of index crank causes the spindle and the workpiece to rotate 1/40th of its one complete turn. A schematic figure is shown for comprehension.



In this case, different index plates with varying number of holes are used to increase or decrease the range of indexing. The index is fixed in position by a pin called lock pin. The spindle is then rotated by rotating the handle which is keyed to the worm shaft. Here, the index crank movement gives the number of turns or parts of a turn.

To cut 28 teeth on our gear blank,

$$\boldsymbol{T} = \frac{40}{Z} = \frac{40}{28} = \frac{10}{7} \times \frac{7}{7} = \frac{70}{49}$$

(49 + 21 = 70)

i.e., to cut one tooth, the worm gear shaft has to be rotated by the handle through one complete revolution in the index plate which has 49 holes (Plate 3), with an extra 21 holes to be passed by the lock pin. Thus, Index Plate #3 is our candidate that satisfies the requirements for cutting our gear.

Another thing to take into consideration while performing the indexing operation is to determine the depth of cut, which can be found as follows:

$$\boldsymbol{Depth\ of\ Cut} = \frac{\mathbf{2.156}}{\boldsymbol{P_d}}$$

In our case,

$$\boldsymbol{Depth\ of\ Cut} = \frac{\mathbf{2.156}}{\boldsymbol{P_d}} = \frac{\mathbf{2.156}}{\mathbf{20}} = \mathbf{0.1078}\ \boldsymbol{inches} = \mathbf{2.73}\ \boldsymbol{mm}$$

After obtaining the required parameters, we move on with the tool setting. This is to change the cutting tool with our required DP Gear Cutter. There are certain cutter numbers ranging from 1 to 8; within which we will have to select our required cutter, which depends on the range number of teeth it can cut from. The range table is as shown below:

Cutter Number	**Cuts Gear from**
1	135 teeth to rack
2	55-134
3	35-54
4	26-34
5	21-25
6	17-20
7	14-16
8	12-13

The cutter that satisfies our gear specification is No: 4. Order Number thus is:

$\boldsymbol{GC - DP20 - 4 - 20}$; where GC refers to the type of cutter (Gear Cutter), DP20 refers to the notation for diametrical pitch followed by the value; and 4 is the cutter number selected from the above table, and finally 20 refers to the pressure angle.

Design Operations and Processes Involved

TURNING ON LATHE

The first process required was to turn the blank in the provided lathe apparatus to the required diameter. The hole has been drilled in the blank to be inserted into the mandrel, which holds our workpiece. The mandrel grips the workpiece with the help of a nut on one end. The required hole diameter was 20 mm. The mandrel is then fixed properly between the chuck and tailstock dead end. The tool used to turn the blank is a High-Speed Steel chiseled end cutting tool supported in the tool post. Ensure that the cutting tool is sharpened and if so, use a grinding machine. The blank is now reduced down to the required diameter, and is now ready for the milling process.

Figure 1: Turning process of the workpiece

GEAR CUTTING

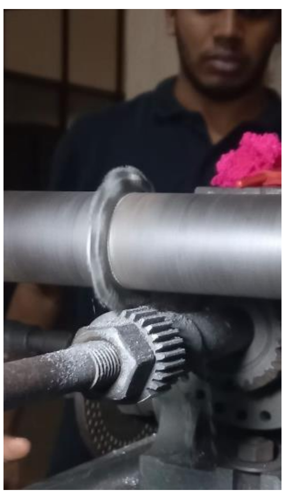


Figure 2: Cutting process of the gear

After inserting the required DP cutter into the arbor support and aligning the tool and tailstock properly by adjusting the saddle, the tapered end of the mandrel consisting of the turned workpiece was then inserted into the headstock of the dividing head, and the other end of the mandrel was then aligned with the tailstock, with the screws that holds the tailstock to the bench being ensured fastened. The required indexing plate (Plate #3) is then fixed in the dividing head. The machine was then switched on, and the cutter was set in such a manner that it just touches the periphery of the workpiece. The cutter then has to be moved away from the workpiece using the transverse handwheel. Once setting the dial of the vertical hand crank wheel to zero, the table shall be then lifted using this vertical crank handwheel to our required depth of cut (2.73 mm). Now the index crank is turned to one complete revolution in the clockwise direction, (meaning the lock pin has gone through 49 holes); and then the index crank is turned towards the 21st hole after the 49th hole, and the lock pin is pushed into the hole. Mark the hole for reference. Ensure tightening of the locknut at the backside of the dividing head. The machine is then switched on, and work is then advanced towards the cutter in the fixed arbor using the transverse handwheel. The first groove is then completed. Now, turn the index crank again to one full rotation (towards the marked hole), and then turn to the 21st hole from this position, and mark again. Remove the previous mark to avoid ambiguity. We have obtained the first tooth. Repeat the indexing process till the whole spindle completes one revolution. We have finally obtained the required spur gear.

Precautions to be taken during gear cutting process

- Ensure the dividing head is properly aligned with the milling machine spindle. Any misalignment can lead to errors in the gear teeth spacing.
- Double-check the indexing plate settings before starting. Ensure that the correct number of holes and proper indexing crank rotation are set to achieve the desired division.
- Firmly secure the workpiece in the dividing head or chuck. The workpiece should not move during the cutting process, as even slight movement can lead in inaccuracies.
- Select the appropriate gear cutter based on the DP of the gear being cut. Using the wrong cutter can lead to improper tooth profiles.
- Gradually increase the depth of cut to avoid excessive tool load, which can cause tool breakage or damage to the workpiece.
- Maintain a consistent feed rate to ensure uniform cutting, and avoid tool marks on the gear teeth.
- Inspect the dividing head, indexing plates, and cutting tools for wear or damage. Replace any worn or damaged components to maintain accuracy.
- Do not exceed the recommended cutting speed for the material being machined. Excessive speed can lead to poor surface finish and tool wear.
- Double check all calculations related to the number of teeth, indexing movements, and gear dimensions to avoid errors during the cutting process.
- Minimize backlash in the dividing head machine setup, as it can affect the accuracy of gear cutting.
- After cutting, inspect the gear for any defects, such as uneven teeth spacing or poor surface finish, to ensure the gear meets the required specifications.

Figure 3: Our final product.

Cost Computation

Factors that depend on the cost of the gear includes the gear blank and the tooth machining costs. In addition to this, post machining processes such as coating technology may also add weight to the price tag. As our motive was to have an amateur level of understanding of the manufacturing process of a certain mechanical component we were asked to select and produce and draft a report on, we have limited our extent; and decided to draw the line right after the tooth cutting process, yet knowing that from an actual industrial perspective, such processes and beyond has to be involved, and a serious level of marketing strategies such as proper equipment investing, outsourcing production and modernizing the equipment can only bring down the cost, and optimize the production rate accordingly.

Assuming that we are making gears on a business scale, the cost components to consider will be the material cost, machining costs, labor costs, tooling costs, overhead costs and profit margin.

As the material we have used here is a cast iron blank, we have found that on average, the industrial grade cast-iron would-be about ₹175/kg. Taking the dimensions into consideration, Initial volume of the material for a blank diameter of 50 mm and of a thickness 20 mm,

$$V_{init} = \pi \times \left(\frac{50}{2}\right)^2 \times 20 = 39269.9\ mm^3 = 39.2699\ cm^3$$

And the final volume after turning using lathe operation, to a diameter of 38.1 mm will be,

$$V_{final} = \pi \times \left(\frac{38.1}{2}\right)^2 \times 20 = 22801.83\ mm^3 = 22.801\ cm^3$$

The difference between the initial volume and the final volume after the turning process will be the volume of material removed. Thus,

$$V_{removed} = V_{init} - V_{final} = 39269.9 - 22801.83 = 16468.07\ mm^3 = 16.408\ cm^3$$

The average density of a cast iron is 7.63 grams per cubic centimeters. Therefore,

$$Initial\ Mass\ (m_{init}) = 7.63\frac{g}{cc} \times 39.2699\ cc = 299.629\ g = 0.2996\ kg$$

$$Final\ Mass\ (m_{final}) = 7.63\frac{g}{cc} \times 22.801 = 173.971\ g = 0.1739\ kg$$

$$Amount\ of\ Material\ Removed\ (m_{removed}) = 0.2996 - 0.1739 = 0.1257\ kg$$

And thus, the purchase cost of the blank will be at about 0.2996 $kg \times \frac{₹175}{kg} = ₹\mathbf{52.43}$

Let us now calculate the material removal rate (MRR), which is the amount of material that is removed from a workpiece per unit of time during machining operations. As we are using both lathe and milling operation, the total removal rate will thus be the sum of MRR during the lathe operation and MRR during milling operation. MRR is a requisite as it is required to determine the machining cost.

For a given feed rate (f), depth of cut (d) and spindle speed (N), the MRR during turning operation would be:

$$\boldsymbol{MRR_{lathe} = d \times f \times N}$$

which in our case would be:

$$\boldsymbol{d \times f \times N = 11.9mm \times 0.2\frac{mm}{rev} \times 560\frac{rev}{min} = 1332.8\ \frac{mm^3}{min}}$$

Now, the MRR during milling operation can be found out as

$$\boldsymbol{MRR_{milling} = W \times d \times f \times N}$$

Where *W* is the width of cut (20mm), *d* is the depth of cut (2.73 mm), *f* is the feed rate per tooth (mm/tooth) and *N* is the spindle speed *(rpm)*

To do so, we need to determine the feed rate per tooth, and the spindle speed.

The used DP cutter has 10 teeth, with a diameter of 2 inches (50.8 mm). The standard feed rate for Cast Iron is 0.1524 mm/tooth; and the spindle speed can be determined as followed:

$$\boldsymbol{N = \frac{1000\ \times V_c}{\pi \times D}}$$

Where $\boldsymbol{V_c}$ is the cutting speed of the DP cutter. The standard cutting speed for Cast Iron is 145 ft/min (44.196 m/min), and $\boldsymbol{D}$ is the diameter of the cutter (2 inch/ 50.8 mm)

Thus, the required spindle speed will be,

$$\boldsymbol{N = \frac{1000 \times 44.196}{\pi \times 50.8} \cong 276\ rpm}$$

Thus, the $\boldsymbol{MRR_{milling}}$ will be,

$$\boldsymbol{MRR_{milling} = 20 \times 2.73 \times 0.1524 \times 276 = 2296.6\frac{mm^3}{min}}$$

Finally, the total material removal rate will be:

$$MRR_{lathe} + MRR_{milling} = 1332.8 + 2296.6 = 3629.4\frac{mm^3}{min}$$

Next, we will have to determine the total machining cost, which is the sum of machining cost on lathe and on the milling machine.

To find the machining cost on lathe, we must find out the average machining time for the turning operation, which can be determined as:

$$T_{lathe} = \frac{V_{removed}}{MRR_{lathe}} = \frac{16468.07\ mm^3}{2296.6\ \frac{mm^3}{min}} = 7.17\ min$$

This is computed without taking overtravel of the tool into consideration.

Assuming a fixed machining cost per hour for conventional turning as ₹77/-, the required machining cost will then be,

$$C_{lathe} = \frac{₹77}{\text{hour}} \times \frac{7.17min}{60} \cong ₹9.205$$

Now, the total gear cutting cost shall be determined; for which we need to find out the average machining time for the required milling operation, The overtravel and approach distance will be considered the same and is equal to twice the diameter of the DP cutter.

Therefore,

$$T_{milling} = 28 \times \frac{W + 2(A)}{f \times z \times n} = 28 \times \frac{20 + 2(0.5(50.8))}{0.1524 \times 10 \times 276} = 4.71\ min$$

where W is the width of the gear, A is the approach distance, f is the feed rate in mm/tooth, z is the number of teeth in the DP cutter (10), and n is the spindle speed in rev/min. The factor 28 is used because it is the number of passes required to cut 28 teeth.

The machining cost per hour for conventional milling (combining both rough and finishing) is assumed to be ₹250/-. Thus, the required machining cost for milling process will be:

$$C_{mill} = \frac{₹250}{\text{hour}} \times \frac{4.71\ \text{min}}{60} = ₹19.625$$

Finally, the total machining cost will be:

$$C_{lathe} + C_{mill} = ₹9.205 + ₹19.625 = ₹28.83$$

Labor cost is the next component to be determined, which is the cost referred to the expenses associated with employing workers to produce goods or services. It's a crucial component of a company's overall cost structure. Hence, we shall consider the labor cost in to the final price of the product. Labor costs are of two types: namely fixed and variable labor cost. In order to maintain the company profit, variable labor cost is the only option that avails us. Assuming an hourly cost of ₹4000, the labor cost required to make one gear can be determined by taking into consideration the total machining time; Therefore,

$$\boldsymbol{Total\ labor\ cost = ₹4000 \times \frac{(7.17 + 4.71)\ min}{60} = ₹792}$$

Tooling cost refers to the expenses associated with the tools used in the production process, including the cost of purchasing, maintaining and replacing these tools over time. Now in our case, as we are manufacturing spur gears based on the previous mentioned dimensions and parameters, tooling costs are critical as they affect the precision, quality and efficiency of the operations.

Assume that an HSS cutting tool for lathe costs around ₹3000. This tool can be used to manufacture 200 gears before needing replacement. Therefore, tooling cost per gear for turning operations will then be:

$$\boldsymbol{\frac{₹3000}{200} = ₹15}$$

In milling operation, the gear teeth are cut using a specialized gear milling cutter. This operation is critical in ensuring that the gear teeth are formed precisely according to the required specifications. Consider the cost of an involute gear DP cutter of the order number $\boldsymbol{GC - DP20 - 4 - 20}$ is estimated to be of about ₹5600. This can also be used to cut 200 gears before needing replacement. Therefore, the tooling cost per gear for turning operations will then be:

$$\boldsymbol{\frac{₹5600}{200} = ₹28}$$

In addition to the tools themselves, there are other factors that add up to the final tooling cost, such as expenses for tool sharpening, holing and fixing. Such costs are generally lower and can be spread over many gears.

Thus, adding up the costs for both the lathe and milling operations, we get the total tooling cost per gear. Which is,

$$\boldsymbol{₹15 + ₹28 = ₹43}$$

Another cost component that makes up the total cost of one gear will be overhead costs, which is the ongoing expenses associated with running the business that are independent of production or sales. They can vary, meaning that their stability wouldn't be affected if the sales or production volumes change. Overhead costs components are made of rent/mortgage for facilities, utilities such as electricity bills, Insurance or worker's compensation, emoluments for administrative staffs, advertising and marketing, and such.

These can be essential when considering to evaluate profit margins, business performances and efficiency.

Assume that an overhead rate of 47% on the labor and machine costs. Thus,

$$\boldsymbol{Overhead\ cost} = \mathbf{0.47(792 + 28.03)} \cong \mathbf{₹386}$$

Finally, the Total Cost will be

$$\boldsymbol{Purchase\ Cost + Machining\ Cost + Labour\ Cost + Tooling\ Cost + Overhead\ Cost} \\ = \mathbf{₹52.43 + ₹28.03 + ₹792 + ₹43 + ₹386 = ₹1301.46}$$

Now to calculate the Profit Margin, assume a 10% profit on the Total Cost. That is;

$$\mathbf{0.1 \times ₹1301.46 = ₹130.146 \cong ₹130}$$

Thus, the Profit Margin will be ₹130.

The Final Price required to make one gear based on the current market value of the raw materials and tools, provided specifications and the available technology we used will be

$$\boldsymbol{Final\ Price = Total\ Price + Profit\ Margin} = \mathbf{₹1301.46 + ₹130 = ₹1431.46}$$

Hence, an approximate cost computation leading to the final price of one spur gear of the provided specifications has been completed.

Conclusion

The project involved a comprehensive analysis of the production processes and cost estimations comprising of machining costs to labor costs, tooling, material removal rates and overheads. With a vague assumption of certain parameters, it was determined that the total cost of producing the gear is influenced significantly by the precision required in the machining processes and the quality of the tooling used. Labor costs accounted for a major portion due to the skilled work required for the setup, operation, and inspection, while tooling costs were justified by the need for high quality and durable tools in order to achieve accurate gear cutting.

A substantial insight of the aim of the project has been understood, despite challenges that stood on our way of completing the project properly. Knowing that the metrological application on our product really plays a crucial role in the quality and satisfaction of the product, we have also observed the factor by which the product we fabricated has differed in the accuracy comparing with our drawing, which fortunately is less.

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