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DESIGN AND FABRICATION OF CIRCULAR SHEET METAL SHEARING MACHINE

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ABSTRACT

The growing use of sheet metal in various industries such as automotive, packaging, medical appliances, cylinder production, Apparatus construction, Tank construction, Aircraft bodies, Missile production, Satellite dishes, road building and road signs, and household appliances, is attributed to its ease of manufacturing, handling, and use. To meet customer demands, sheet metal product manufacturing industries are working towards producing circular feature products of good quality at a large scale and low cost. To this end, this research emphasis the design, analysis, and fabrication of an electric circular sheet metal shearing machine, this would replace the punching and blanking operations and reduce scrap value from the stock material. The research includes concept design, detail design and analysis, assembly, 3D modelling, and fabrication of the Machine.

Keywords: 3D modelling, force analysis, shaft design, belt design, and gear design.

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1. INTRODUCTION

Sheet metal is vital in many industrial fields, from slow-growing too rapidly developing industries such as automotive, aerospace, food process, house construction, and naval. It is used for a variety of purposes, including cutting, shearing, and bending into various shapes [1], [2], [3-6]. Traditionally, sheet metal cutting has been done manually, but in recent years there has been a shift to semi-automatic machines like gas-cutting machines, punching machines, and circle-cutting machines, making the process faster and more efficient. When it comes to small and medium-scale industries, it is not always feasible to use separate machines for sheet metal cutting for various applications. Therefore, inventors have designed and fabricated special machines specifically for this purpose [7]. The most popular type of semi-automatic machine for cutting circular blanks from sheet metal is the blanking punch and dies machine, which is weak to diameter variation. The circular disc or roller disc type shearing machine is better for heavy-duty work but is expensive to construct. Fully automatic sheet metal cutting machines are also available for mass production [8]. Developing a 'circular sheet metal cutting machine' for light and medium duty work, adjustable for different diameters is essential [9]. This machine would allow medium and small-scale industries to increase their production capacity, and improve the quality and quantity of their products.

2. STATEMENT OF THE PROBLEM

Circular saw machining is currently employed by many industries for cutting sheet metal for various purposes. However, this method of cutting sheet metal causes deformation and creates excess scrap, making it costly to produce [10], [11-14]. Circular sheet metal shearing machines, however, are able to reduce the production cost of items such as LPG cylinders, missile cones, automobile brake drums, cooking vessels, and tractor-plowing discs. Therefore, the use of a circular sheet metal shearing machine to produce circular blanks is more economical.

3. GENERAL OBJECTIVE

The general objective of the research is to design and fabricate a circular sheet metal shearing machine for small-scale and light work.

3.1 Specific Objectives of this Research are Illustrated Below

- To do the basic analytical calculations to obtain the machine geometry.
- To evaluate and design the parts to produce a conceptual design in the appropriate calculation for carrying the required available load to do its duty.
- To develop a visualization of a circular sheet metal machine geometrically by applying different software to create a 3-dimensional assembly of the machine.
- To create manufacturing drawings and operation procedures by process plan for all the parts of the machine and manufacture them.

4. METHODOLOGY

To achieve the objectives of this research follow the methodology enumerated below.

- Studying the literature review of sheet metal cutting in detail
- Collecting sufficient information from industries
- Analyze and synthesize the process to arrive at the appropriate manufacturing solution
- Study and understand sheet metal cutting behavior
- Interpret the analytical calculations into manufacturing.

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5. SIGNIFICANCE AND SCOPE OF THE RESEARCH

This research aims to investigate an economical solution to the problem of small-scale production industries that use a circular sheet metal stock. It covers the entire process, from material selection and conceptual design to the final design and simulation of the geometrical formulation [15], [16-18]. Additionally, the study includes the development of software to produce the final product design.

The scope of this research is mentioned as follows:

- To do detailed analytical calculations for the various parameters to manufacture circular sheet metal shearing machines,
- To consider the possibility of manufacturing the circular sheet metal shearing machine for the calculated optimum parameters.

A critical review of a particular area of research is an essential step in the research process. To ensure a thorough literature review, it is recommended to include the entire process of selecting, reading, and writing about relevant research studies, including a discussion of the modelling techniques used to reach maximum efficiency and save time [19-21], [30], [31]. Furthermore, this section should also include an argument of the different designs to determine which provides the best performance [9].

6. MODELING AND ANALYSIS OF THE MACHINE

6.1 3D Modeling

The design and analysis of a product are essential in determining its main function. Breaking down this main function into sub-functions and deciding how to satisfy these sub-functions are just as vital to the design as the main function itself [22], [23], [24-29],[58]. To illustrate the importance of this process, one can compare two products that have the same main function but differ in basic structure [57]. Figure-1 shows the **f**eatures of the machine**,** Figure-2 shows the table of the machine, and Figure-3 clamping system using CATIA.

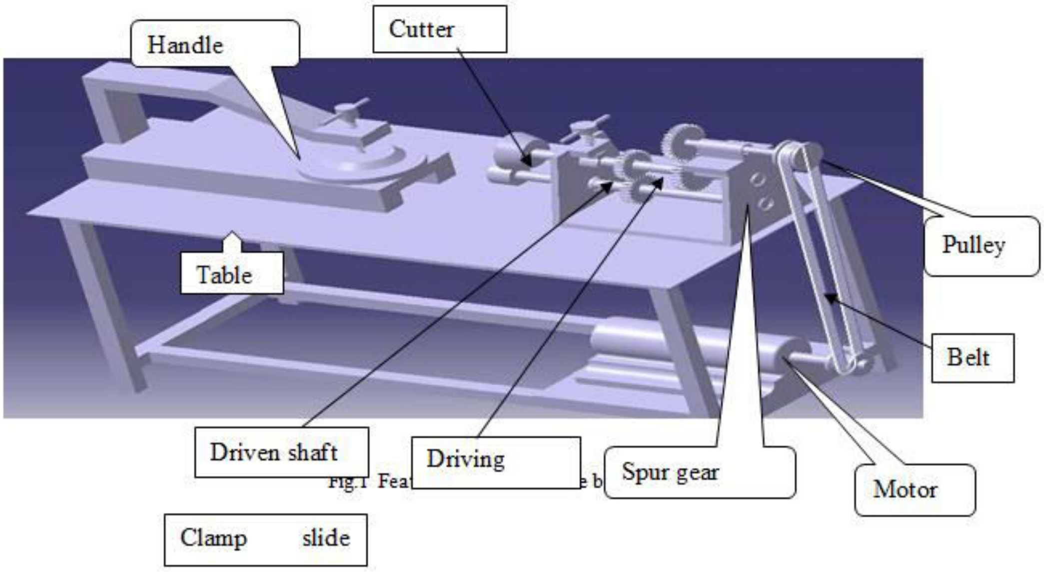

Figure-1. Features of the machine by using CATIA.

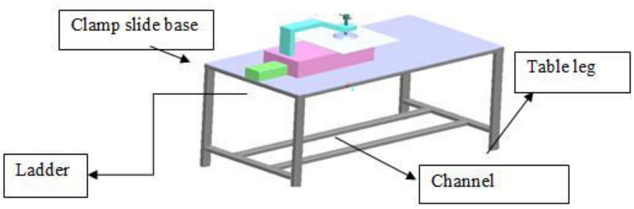

Figure-2. Table of the machine by using CATIA.

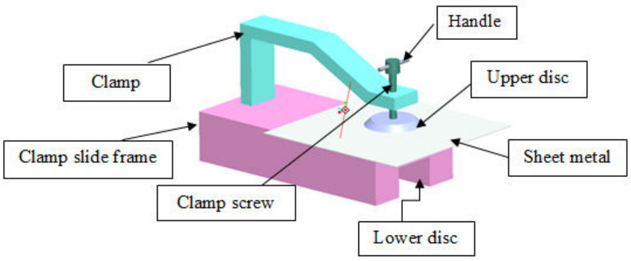

Figure-3. Clamping system by using CATIA.

6.2 Clamping System Design

The clamping system of the circular sheet metal shearing machine is designed for clamping the sheet metal and protects the material from undergoing deflection when cutting force is applied during operation. Area of contact $(A) = \pi r^2$ where r is the contact area of sheet metal. The force developed by the screw clamp is:

Fc = FH*L /R tan $(\alpha+\phi)$ ……………..…………… (1)

Where Fc is clamping force, and FH is pressure applied to the handle

6.3 Clamping Force

A person can apply $\frac{1}{3}$ of his/her weight without any damage. Assume the average weight of a person is 60kg,$\frac{1}{3}$ of the weight is 20kgf.

Fc_l = mxg = 20kgx9.81m/s² =196.2N, where Fc_l is the clamping force applied to the handle

The frictional force applied to the sheet metal is

F_f = μxFc_l, μ is the coefficient of friction, taking 0.74 = 0.74x196.2=145.2N

6.4 Force Developed by Screw Clamp (Fs)

Fs = FclX L/2, where L is the length of the lever
Rtan (α +Ø), R radius at the screw thread
α is the angle of the screw thread and Ø is the friction angle of the thread

$$Fs = \frac{FclxL/2}{R\tan(\alpha+Ø)} = 196.2 \times 0.15\ \frac{196.2x0.15}{0.0125\tan(30+30)} = 1361N$$

6.5 Thickness and the Width of the Clamp Frame

Direct stress acting on the clamp frame is given by

σ_d =P/A, where P is the force applied to the clamp and A is the area of the clamp frame

A=bxt, assume b=2t, A=2t², where b is the width and t is the thickness

σ_d =1361/2t² Mpa
= 680.5/ t² Mpa

The bending stress acting on the clamp is given by

σ_b =M/Z, where M is the bending moment and Z is the section modulus

M =PxL,

Where P is the force developed by the screw clamp Fs and L is the length between the centre of the handle screw and the width frame

M=1361Nx642mm=8.74x10^{5}Nmm

$$z = \frac{(txb^3)/12}{b/2} = \frac{2t^3}{3}$$

$$\sigma b = \frac{M}{Z} = \frac{8.74x10^5 Nmm}{2t^3/3} = 13.12x10^5$$

The total stress acting on the clamp frame is $\sigma_d + \sigma_b = \sigma_{all}$

$$\frac{680.5}{t^2} Mpa + \frac{13.12x103}{t3} Mpa = 580Mpa$$

$$\frac{1.17}{t^2} + \frac{2.262x10^3}{t^3} - 1 = 0$$

t= 14mm, b= 2 t =28mm

$(T_1 - T_2)$ V=P ……………………………………… (2)

Where T_1 &T_2 tension in the tight and slack side of the belt in Newton's respectively and v-is velocity of the belt in m/s. balancing the vertical force and the tension,

T_1+T_2 =12908.9N …………………..…………….. (3)

Ignoring the tension in the slack side (T_2), T_1=12908.9N

The velocity of belt is given by v =πd1N/60 ……….. (4)

Assume D_2= 0.5m and the motor rpm is 1050 – 1500RPM.

Take the rpm of the motor 1100 RPM

Take 1 to 5 ratio N=220 RPM and we have the relation N1/N2=D2/D1

D_1= 0.5mx220/1100 = 0.1m

From the equation (3)

V=πD1N/60=3.14X0.1x1100/60=5.76/s.

And from, T1/T2=$e^{\mu\theta}$ ………………………………… (5)

Where μ-coefficient of friction for belt material For leather belt $\mu = 0.25$, θ-is the angle of contact of the pulley with a belt.

θ= (180+2α) $in\ rad/sec$ ……………………….……… (6)

$\alpha = sin^{-1}\ (r2 - r1)/x$Where x is the center distance
$\alpha = sin^{-1}\ (r2 - r1)/x$=$sin^{-1}$(0.25-0.05)/1.2=9.6 degree

θ = (180+2x11.54) x$\frac{\pi}{180}$ =3.48 rad/se.

From Eq (4) 2.3logT1/T2= $\mu\ \theta$=0.869.

Solving this equation T2=6259.8N

Now, P= (T_1-T_2) V= (12908.9-6176.5)5.76m/s=3.83kW standard motor power p=3.83 kw =5 hp

Torque generated by motor (T),

T=60xP/2πN=60X3878/2X3.14X1100=33.27 N-m.

6.7 Torque Developed by the Circular Disc

T= 60Xp/2πN= (60x3830)/(2x3.14x1100) =33.27Nm

The corresponding force across the radius of the sheet metal (Fp)

$$Fp = \frac{T}{R} = \frac{33.27Nm}{0.5m} = 66.53N$$

7. SHAFT DESIGN

Shafts are essential machine elements that are widely used. They typically have a circular cross-section and are used to transfer power by rotating pulleys or gears. These shafts can be either solid or hollow and are supported on bearings so they can rotate. The shaft is typically subjected to bending moments, torsion, and axial forces [31], [32-36]. Designing a shaft involves calculating the stresses at critical points that arise due to the above-mentioned forces. Two other forms of a shaft are an axle and spindle [37], [38-39], [58]. In this section, the detailed design of the shaft will be discussed, including its unique features that may require special treatment, and its material is specified in Table-1.

- Stress and strength, Deflection and rigidity, Bending deflection and Torsional deflection

7.1 Shaft Types

From a subject perspective, two types of shafts are essential:

a) Transmission shafts: These are used to transfer power from one machine to another. Examples include counter shafts, line shafts, overhead shafts, and factory shafts. These shafts are often fitted with various machine parts such as pulleys, gears, etc., so they must be able to withstand bending and twisting.

b) Machine shafts: These are a key component of many machines. For instance, the crankshaft is one example of a machine shaft that plays an essential role in the functioning of the machine.

7.2 Shafts should be Composed of a Material that has the Following Properties

a. It should have high strength.
b. It should have good machinability.
c. It should have low notch sensitivity factor.
d. It should have good heat treatment properties.
e. The material should possess strong resistance to wear.

Table-1. Mechanical properties of steels used for the shaft.

Indian standard designation	*Ultimate tensile strength, MPa*	*Yield strength, MPa*
40 C 8	560 - 670	320
45 C 8	610 - 700	350
50 C 4	640 - 760	370
50 C 12	700 Min.	390

Let d= Shaft diameter

It is understood that the maximum torque transmitted through the shaft is given by [18]:

T= p× $\frac{60}{2\pi N}$.. (7)

T=3830X60/2X3.14X220=166.33N-m.

The torque transmitted by a solid shaft (T) can be determined using the equation:

T= $\frac{\pi}{16} \times \tau \times D^3$... (8)

Where, τ is allowable shear stress for material? And 42Mpa=42N/mm2 for 50C4.

D^3=16T/$\pi\tau$ = 16X166.33x1000/3.14X42 = 21188.5mm

D= $\sqrt[3]{21188.5}$ =28mm =0.028m

Shafts subjected to bending moment only

$M = \pi/32 \times \sigma b \times d^3$ .... (9)

The ultimate tensile stress of the material is 700Mpa and FOS is 4

$\sigma b = \sigma t = \frac{\sigma U}{FS} = \frac{700\text{Mpa}}{4}$ =175Mpa.

$M = \pi/32 \times \sigma b \times d^3 = \frac{\pi*175*28^3}{32}$ =377 N-m.

Shafts that experience both a combined twisting moment and a bending moment have to be designed with extra precautions to ensure that they can withstand the forces they are exposed to 1. Maximum shear stress theory and 2. Maximum normal stress theory

According to the Maximum Shear Stress Theory, the shear stress induced in a shaft due to a twisting moment, τ, and the bending stress induced due to a bending moment, σb, can be used to calculate the maximum shear stress in the shaft is expressed as follows:

$.\pi/16 \times \tau max \times d^3 = \sqrt{M^2 + T^2}$ .... (10)

The equivalent twisting moment is represented by the symbol Te

Te=$\sqrt{M^2+T^2}$ =$\sqrt{377^2+166.33^2}$ =412 N-m

According to the maximum normal stress theory, the maximum normal stress in the shaft (which is equal to the yield point of the material) is the sum of the individual normal stresses.

$\sigma b(max) = \frac{1}{2}\sigma b + \frac{1}{2}\sqrt{\sigma b^2 + 4\tau^2}$ .... (11)

$\frac{\pi}{32}\sigma b(max) \times d^3 =$
$\frac{1}{2}$[M+$\sqrt{M^2+T^2}$] .... (12)

The bending moment equivalent to this expression is represented by me

Me = $\frac{1}{2}$[M+$\sqrt{M^2+T^2}$], Me= $\frac{1}{2}$[377+$\sqrt{377^2+166.33^2}$] =394.95N-m

8. BELT DESIGN

Length of the belt,

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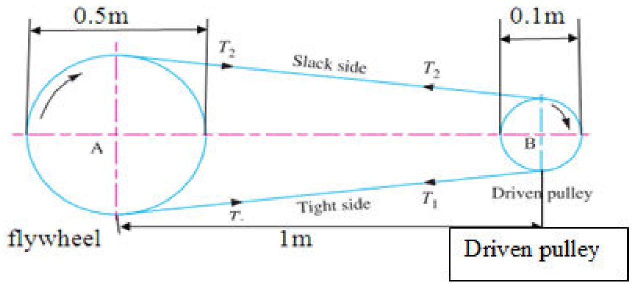

Let the total length of the belt be L

X=is e center distance between the motor pulley and driven pulley is 1m

$$L = \pi(r2 + r1) + 2x + \frac{(r2-r1)2}{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

L= π(0.25+0.05) +2X1.2+$(0.25 - 0.05)^2/1.2$=3.45 m

And the velocity of the pulley or belt

$$V = \frac{\pi DN}{60} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

8.1 Width of the Belt

a. Belt width

Let the width of the belt be b in meters, $\rho - density$ Of belt material=1000Kg/m3, σ-be allowable stress for belt=2.1Mpa and

t-is thickness of the belt in meters and assuming 10mm,

We have the cross-sectional area (A) of the belt.

A= bxt ………………………………………………. (15)

= 0.01xb=0.01 x b m².

The mass of the belt per unit length is given by:

m=area x length x density …..………………………. (16)

=0.01b x 1 x 1000=10bKg/m.

Therefore, centrifugal tension,

Tc = mv^2……………16 =10bx (5.76)2=331.776b N

We know the maximum tension in the belt,

T= σbt ……………………………….. (17)

=2.1x10^6x b x0.01=21000b N

The tight side tension (T_1) of the belt is:

T_1=T-Tc ……………………….………. (18)

12908.9 N = (21000b -331.776b) N, from this b=36mm

The width of the belt from the standard is (36+13) =49mm, and the thickness of the belt varies from d/300+2mm to d/200+3mm for the single belt. (t=500/300+2mm) =4mm.

Table-2. Shows the values of X and Y in dynamically loaded bearings in 'A Textbook of Machine Design' by R.S. Khurmi and J.K. Gupta.

Type of bearing	Specifications	$\frac{W_A}{W_R} \leq e$		$\frac{W_A}{W_R} > e$		e
		X	Y	X	Y	
Deep groove ball bearing	$\frac{W_A}{C_0}$ = 0.025				2.0	0.22
	= 0.04				1.8	0.24
	= 0.07				1.6	0.27
	= 0.13	1	0	0.56	1.4	0.31
	= 0.25				1.2	0.37
	= 0.50				1.0	0.44
Angular contact ball bearings	Single row		0	0.35	0.57	1.14
	Two rows in tandem		0	0.35	0.57	1.14
	Two rows back to back	1	0.55	0.57	0.93	1.14
	Double row		0.73	0.62	1.17	0.86
Self-aligning bearings	Light series : for bores					
	10 – 20 mm		1.3		2.0	0.50
	25 – 35	1	1.7	6.5	2.6	0.37
	40 – 45		2.0		3.1	0.31
	50 – 65		2.3		3.5	0.28
	70 – 100		2.4		3.8	0.26
	105 – 110		2.3		3.5	0.28
	Medium series : for bores					
	12 mm		1.0	0.65	1.6	0.63
	15 – 20		1.2		1.9	0.52
	25 – 50		1.5		2.3	0.43
	55 – 90		1.6		2.5	0.39
Spherical roller bearings	For bores :					
	25 – 35 mm		2.1		3.1	0.32
	40 – 45	1	2.5	0.67	3.7	0.27
	50 – 100		2.9		4.4	0.23
	100 – 200		2.6		3.9	0.26
Taper roller bearings	For bores :					
	30 – 40 mm				1.60	0.37
	45 – 110	1	0	0.4	1.45	0.44
	120 – 150				1.35	0.41

Radial load Wr =12908.9N.

Assuming the average life of the bearing is 5 years at 10 per day, therefore life of the bearing in,

LH= 5 × 300 × 10 = 15 000 ... (Assuming 300 working days per year) and life of the bearing in revolutions,

L= 60 N× LH= 60 × 1600 × 15 000 = 1440 × 106rev

The basic equivalent dynamic radial load,

W=X.V. WR+ Y. WA .... (19)

Where X-radial load factor and Y- axial or thrust load factor for the dynamically loaded bearings.
Considering only radial load, W=XVWR=1X1X12908.9N=12908.9 N
V=1 for inner race rotation & X=1

Assuming the service factor KS=2.5 for a heavy shock load. Therefore, the design dynamic equivalent load should be taken as, W = 2.5x12908.9 N = 32272.25 N

9. DESIGN OF SPUR GEAR

The type of material used to make gears is determined by the strength needed and the conditions they will be subjected to, such as noise and wear.

9.1 Design Considerations for a Gear Drive

When designing a gear drive, the power to be transmitted, the speed of the driving and driven gears, and the centre distance are usually given [39-41], [57]. To get a more accurate understanding of the conditions, equations based on various tests can be used. These equations include $W_d = W_T + W_I$, where W_d stands for the total dynamic load, W_T represents the steady load transmitted by torque, and WI is the increment load due to dynamic action.

9.2 Design Procedure for Spur Gears

$W_T = \frac{PxCs}{\upsilon}$

Where WT permissible tangential tooth load in N, P is power transmitted in watts,
v is pitch line velocity in m/s=$\frac{\pi DN}{60}$, D is pitch circle diameter in m

We know that circular pitch Pc=$\frac{\pi D}{T}$;D=m.T ;m=$\frac{D}{T}$
Pitch velocity $\upsilon=\frac{\pi DN}{60}=\frac{\pi mTN}{60}=\frac{PcTN}{60}$; where m is a module in m, T is the number of teeth; N is the RPM

9.3 Spur Gear Design Calculation

The aim is to design spur gear depending on the following data specifications.

a. Gear ratio 5:1

Distance between centre=1200mm, Pinion transmits 3.83 kW at 220 rpm.

Standard involute teeth with a pressure angle of 22.5° have a permissible normal pressure between teeth of 14.34 N per mm of width.

$$Tp = \frac{2Aw}{G[1+\frac{1}{G}\sqrt{\left(\frac{1}{G}+2\right)\sin^2\emptyset}-1]} = \frac{2X1}{5[1+\frac{1}{5}\sqrt{\left(\frac{1}{5}+2\right)\sin^2 22.5}-1]} = \frac{2}{0.159}$$

=12.58 say 13

TG = G × Tp = 5 × 13 = 65 ...
(AW = 1 module)
... (TG / Tp = 5) ……………. Gear ratio

We know that the distance b/n the centre of the 2 pulleys is

x= $\frac{DG}{2}+\frac{Dp}{2}$; but $\frac{DG}{Dp}$=5, DG = 5Dp

Therefore, X=$\frac{DG}{2}+\frac{5DG}{2}$ =3DG, 1200mm=3DG, DG=400mm
Dp = $\frac{400}{5}$=80mm

We also know that DP = m .TP, m = DP / TP = 80 / 3 = 6.15 mm

Since the nearest standard value of the module is 6 mm, therefore we shall take
m = 6 mm

b. Number of teeth on each wheel

We know that the number of teeth on the pinion, $T_P = \frac{DP}{m} = \frac{80}{6}$ = 14, and the number of teeth on the gear,
TG = G × TP = 5 × 14= 70

c. Necessary width of the pinion

We know that the torque acting on the pinion,
$T = \frac{Px60}{2\pi Np} = \frac{3.83x1000x60}{2x3.14x220} = 166.33Nm$
∴ Tangential load, WT =$\frac{166.33}{0.08/2}$=4158.25=4.15825KN …. (DP is taken in meters) and normal load on the tooth, $W_N = \frac{WT}{\cos\emptyset} = \frac{4158.25}{\cos 22.5} = 4501Nm$

Since the normal pressure between teeth is 14.34N per mm of width, therefore necessary width of the pinion, $b = \frac{4501}{14.34} = 313.88mm$

We know that the radial load on the bearings due to the power transmitted,

$W_R = W_N$xsinφ = 4501 × sin 22.5° = 1722.458 N = 1.722458KN

The manufacturing process is the sum of separate processes involved in the conversion of raw material into the final product [47], [48-52], [57]. The manufacturing process includes not only the manufacturing of a product but also preparatory processes such as production planning, process planning tooling preparation, etc. The manufacturing process involved in this study is shearing, bending, turning, and facing milling and drilling operations [54], [53-56], [57]. Among these processes shearing and bending have significant roles in the manufacturing of the part. After a detailed design, the machine is manufactured. The prototype of the machine is shown in the figure below. Fig.4, Fig.5, and Fig.6 show the Preparation of the proposed machine from local material first stage, second stage, and final prototype respectively.

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Figure-4. Preparation of machine from local material first stage prototype.

Figure-5. Preparation of machine from local material second stage prototype.

Figure-6. Fabricated machine as prototype.

10. CONCLUSIONS

Through the implementation of the table slider mechanism, the size of the machine has been successfully reduced. Extensive design calculations have been conducted to ascertain the load distribution and stability of the machine. Force calculations indicate the possibility of manufacturing the machine. To make the production easier, a detailed design has been created, along with various part drawings and sub-assembly drawings. Lastly, a comprehensive manufacturing process and process plan for each part of the machine has been put together, which any manufacturer can understand and use to produce the desired machine parts and their main sub-assemblies. The following recommendations are given for manufacturing and operating of circular sheet metal shearing machine.

- While manufacturing the components strictly follow the dimension given to achieve size and weight reduction.
- . Strictly follow the bill of materials given. Material property is directly related to strength.
- During installation, to ensure the exact coincidence of the main attachment slider in the slide compartment, adjust the height of the table and operate the lateral displacement control mechanism of the slider.
- It is prohibited to transport the machine if the holders are not inserted into their place and if the machine is assembled.

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