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.
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 features 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.](image1)

![Figure-2. Table of the machine by using CATIA.](image2)

![Figure-3. Clamping system by using CATIA.](image3)

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:

\[ F_c = FH/L/R \tan (\alpha + \phi) \] .......................... (1)

Where \(F_c\) is clamping force, and \(FH\) is pressure applied to the handle

### 6.3 Clamping Force

A person can apply \(1/3\) of his/her weight without any damage. Assume the average weight of a person is \(60\) kg. The clamping force applied to the handle

\[ F_c = m \times g = 20 \times 9.8 \times 60 = 1180\] N

Where \(F_c\) is the clamping force applied to the handle

The frictional force applied to the sheet metal is

\[ F_f = \mu F_c \] .......................... (2)

### 6.4 Force Developed by Screw Clamp (Fs)

\[ F_s = F_c \times L/2 \] .......................... (3)

Where \(L\) is the length of the lever

\[ R \tan (\alpha + \beta) \] .......................... (4)

\(\alpha\) is the angle of the screw thread and \(\beta\) is the friction angle of the thread

\[ F_s = \frac{F_c \times L}{2} \] .......................... (5)

### 6.5 Thickness and the Width of the Clamp Frame

Direct stress acting on the clamp frame is given by

\[ \sigma_d = \frac{P}{A} \] .......................... (6)

Where \(P\) is the force developed by the clamp frame and \(A\) is the area of the clamp frame

\[ A = b \times t, \] .......................... (7)

\(b\) is the width and \(t\) is the thickness

\[ \sigma_d = \frac{1361}{2t^2} \] .......................... (8)

The bending stress acting on the clamp frame is given by

\[ \sigma_b = \frac{M}{Z} \] .......................... (9)

Where \(M\) is the bending moment and \(Z\) is the section modulus

\[ M = P \times L \] .......................... (10)

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

\[ M = 1361 \times 642 = 8.74 \times 10^5 \text{ Nmm} \] .......................... (11)

\[ \sigma_b = \frac{1361}{2t^3/3} = \frac{13.12 \times 10^5}{t^3} \] .......................... (12)

### 6.6 Torque Developed by the Circular Disc

\[ T = \frac{F_p \times D}{2 \times \pi} \] .......................... (13)

Where \(T\) is the torque generated by the motor (T), \(D\) is the diameter of the disc, \(F_p\) is the force developed by the screw clamp, and \(D\) is the diameter of the disc.
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 notched 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.

<table>
<thead>
<tr>
<th>Indian standard designation</th>
<th>Ultimate tensile strength, MPa</th>
<th>Yield strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 C 8</td>
<td>560 - 670</td>
<td>320</td>
</tr>
<tr>
<td>45 C 8</td>
<td>610 - 700</td>
<td>350</td>
</tr>
<tr>
<td>50 C 4</td>
<td>640 - 760</td>
<td>370</td>
</tr>
<tr>
<td>50 C 12</td>
<td>700 Min.</td>
<td>390</td>
</tr>
</tbody>
</table>

Let \( d \) = Shaft diameter

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

\[
T = \frac{60}{\pi N} \times \tau \times D^3
\] ................................. (7)

\[
T = 3830 \times 60 / 2 \times 3.14 \times 220 = 166.33 \text{N-m.}
\]

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, \( \tau \) is allowable shear stress for material? And 42Mpa=42N/mm² for 50C4.

\[
D^3 = \frac{16T}{\pi \tau} = \frac{16 \times 616.33 \times 1000 \times 3.14 \times 42}{21188.5} = 28 \text{mm} = 0.028 \text{m}
\]

Shafts subjected to bending moment only

\[
M = \frac{\pi}{32} \times \sigma_b \times d^3
\] ................................. (9)

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

\[
\sigma_b = \frac{\sigma_u}{\sigma_{FS}} = \frac{700 \text{Mpa}}{4} = 175 \text{Mpa}.
\]

\[
M = \frac{\pi}{32} \times \sigma_b \times d^3 = \frac{\pi \times 175 \times 28^3}{32} = 377 \text{N-m.}
\]

8. BELT DESIGN

Length of the belt,
Let the total length of the belt be \( L \)

\[ X = \text{center distance between the motor pulley and driven pulley is 1m} \]

\[ L = \pi (r_2 + r_1) + 2x + \frac{(r_2 - r_1)^2}{x} \] .......................... (13)

\[ L = \pi (0.25 + 0.05) + 2 \times 1.2 + (0.25 - 0.05)^2 / 1.2 = 3.45 \text{ m} \]

And the velocity of the pulley or belt

\[ V = \frac{\pi D N}{60} \] .......................... (14)

8.1 Width of the Belt

a. Belt width

Let the width of the belt be \( b \) in meters,

\[ \rho = \text{density} \]

\[ \sigma = \text{allowable stress for belt=2.1Mpa and assuming} \]

\[ t = \text{thickness of the belt in meters and assuming} 10\text{mm}, \]

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

\[ A = bxt \] .......................... (15)

\[ = 0.01xb = 0.01 \times b \text{ m}^2. \]

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

\[ m = \text{area x length x density} \] .......................... (16)

\[ = 0.01b \times 1 \times 1000 = 10b \text{Kg/m.} \]

Therefore, centrifugal tension,

\[ T_c = mv^2 \] .......................... 16

\[ = 10bx (5.76)^2 = 331.776b \text{ N} \]

We know the maximum tension in the belt,

\[ T = \sigma bt \] .......................... (17)

\[ = 2.1 \times 10^6 \times b \times 0.01 = 21000b \text{ N} \]

The tight side tension \( (T_t) \) of the belt is:

\[ T_t = T - T_c \] .......................... (18)

\[ 12908.9 \text{ N} = (21000b - 331.776b) \text{ N}, \text{ from this } b = 36\text{mm} \]

The width of the belt from the standard is \((36+13) = 49\text{mm}, \text{ and the thickness of the belt varies from} \)

\( d/300+2\text{mm to} d/200+3\text{mm for the single belt.} \)

\( (t=500/300+2\text{mm}) = 4\text{mm}. \)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of bearing</td>
<td>Specifications</td>
<td>( \frac{X}{X_{RE}} \leq \varepsilon )</td>
<td>( \frac{X}{X_{RE}} &gt; \varepsilon )</td>
</tr>
<tr>
<td>Deep groove ball bearing</td>
<td>( \frac{X}{X_{RE}} = 0.35 )</td>
<td>1</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>( \frac{X}{X_{RE}} = 0.04 )</td>
<td>1</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>( \frac{X}{X_{RE}} = 0.07 )</td>
<td>1</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>( \frac{X}{X_{RE}} = 0.13 )</td>
<td>1</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>( \frac{X}{X_{RE}} = 0.25 )</td>
<td>1</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>( \frac{X}{X_{RE}} = 0.50 )</td>
<td>1</td>
<td>0.57</td>
</tr>
<tr>
<td>Angular contact ball bearings</td>
<td>Single row</td>
<td>0</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Two rows in tandem</td>
<td>0</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Two rows back to back</td>
<td>0.55</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>Double row</td>
<td>0.73</td>
<td>0.62</td>
</tr>
<tr>
<td>Self-aligning bearings</td>
<td>Light series : for bores</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>10 – 20 mm</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>25 – 35 mm</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>40 – 45 mm</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>50 – 55 mm</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Medium series : for bores</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>12 mm</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>15 mm</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>20 mm</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>25 mm</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>50 mm</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Spherical roller bearings</td>
<td>For bores</td>
<td>2</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>25 – 35 mm</td>
<td>2</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>40 – 45 mm</td>
<td>2</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>50 – 60 mm</td>
<td>2</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>100 – 200 mm</td>
<td>2</td>
<td>0.67</td>
</tr>
<tr>
<td>Taper roller bearings</td>
<td>For bores :</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>30 – 40 mm</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>45 – 110 mm</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>120 – 150 mm</td>
<td>1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Radial load \( W_r = 12908.9 \text{N}. \)

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

\[ LH = 5 \times 300 \times 10 = 15 000 \text{ ... (Assuming 300 working days per year) and life of the bearing in revolutions,} \]

\[ L = 60 \times LH = 60 \times 1600 \times 15 000 = 1440 \times 10^6 \text{rev} \]

The basic equivalent dynamic radial load,
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 \( W_i \) is the increment load due to dynamic action.

9.2 Design Procedure for Spur Gears

\[ W_T = \frac{p}{v} \]

Where \( W_T \) 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 \( P_c = \frac{D}{m} \); \( D = mT \); \( m = \frac{D}{T} \).

Pitch velocity \( v = \frac{\pi DN}{60} \); 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.

\[ T_p = \frac{2Aw}{G(1 + \frac{1}{\left[\frac{D}{m} + 1\right] \sin^2 \theta - 1})} = \frac{2 \times 1}{5(1 + \frac{1}{\left[\frac{8}{22.5} + 1\right] \sin^2 22.5° - 1})} = 0.159 \]

\[ = 12.58 \text{ say 13} \]

\[ TG = G \times T_p = 5 \times 13 = 65 \]

\( (AW = 1 \text{ module}) \)

\( \text{... (TG / Tp = 5) .......... Gear ratio} \)

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

\[ x = \frac{DG}{2} + \frac{Dp}{2} \text{; but } \frac{DG}{Dp} = 5, DG = 5Dp \]

Therefore, \( x = \frac{DG}{2} + \frac{DG}{2} = 3DG \), 1200mm=3DG, \( DG = 400 \text{mm} \)

\( Dp = \frac{400}{9} = 80 \text{mm} \)

c. Necessary width of the pinion

We know that the torque acting on the pinion, \( T = \frac{P \times 60}{2 \pi N_p} = \frac{3.83 \times 1000 \times 60}{2 \times 3.14 \times 220} = 166.33 \text{Nm} \)

\( \therefore \) Tangential load, \( WT = \frac{166.33 \times 4.15825}{0.08/2} = 4158.25 \text{KN} \).

(DP is taken in meters) and normal load on the tooth, \( W_N = \frac{4158.25}{\cos 22.5°} = 4501 \text{KN} \)

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

We know that the radial load on the bearings due to the power transmitted, \( W_k = W_N \times \sin 22.5° = 1722.458 \text{N} \)

\( = 1.722458 \text{KN} \)

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.
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.

REFERENCES


