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Design and Fabrication of PET Bottles and Can Processing System

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***Abstract*—Recycling is one of the sectors that is growing quickly these days. There is an enormous amount of rubbish pouring into PET bottles, and aluminium cans are two significant items being recycled more frequently. Crushers are utilised in this recycling process. To recycle these cans and PET bottles, enterprises rely on human labour, which is time-consuming and ultimately lowers production rates. We are developing an aggregate crusher system that uses a scotch yoke mechanism with multi-sided or dual-sided crushing capability in order to smash the cans and PET containers faster. PET bottles and aluminium cans of soda are crushed using a crusher machine for recycling reasons and for convenient storage in recycling bins once they have been shredded. The result entails successfully designing the various parts and components of the crusher unit while taking user ergonomics and forces into account.**

Keywords: *PET Bottles, Crushers, Al-alloy, Recycling, grey cast iron.*

I. INTRODUCTION

Aluminium is a sustainable material that can be easily recycled, but it can take 80-100 years to decompose. The growing use of aluminium in the form of cans and bottles, if not recycled, can create significant environmental pollution [1]. Instead of electrolyzing aluminum, which must first be extracted from bauxite ore and then refined using the Bayer process, the procedure merely remelts the metal, which is significantly less costly and energy-intensive. Aluminium recycling accounts for only 5% of energy use, compared to fresh production, which simultaneously produces only 5% of greenhouse gas emissions. Aluminium-can recycling offers large benefits to the individual, community, government, economy, ecology and industry [2]. The US current rising percentage of aluminium can consumption is approximately 100 billion annually, as of 2025, and has a well-established curbside recycling infrastructure. Because of this, recycled scrap accounts for around 31% of all aluminium produced in the US [3]. Europe represents the second-largest regional market with a 28.1% revenue share as of 2025, driven by the European Union circular economy action plan. In the Asian Pacific fast-growing regional market, especially China and India, with rapidly urbanising middle-class populations, is shifting toward cans beverage consumption and its share is projected to rise up to 22.8% as on 2025 [1]. Recycling soft metals, in this region, such as aluminium cans, is quite difficult due to the lack of quality recycling infrastructure and a large population [4]. Delivering goods to customers has been the mainstay of industrial activity in the modern era. Smashing cans is done by hand, which takes a lot of time and wears the operator down. Additionally, there are many different kinds of equipment, such as mechanical, hydraulic, and pneumatic ones, but they are expensive, big, and need operator supervision [5]. So, the manual crushing of aluminium cans and other packaging material of aluminium becomes tedious, time-consuming, has a low production rate and is rigorous. To improve this, a machine called a can crusher is used to crush it into a small volume, making it easy for storage and recycling. Different designs and modifications were done to improve the efficiency and effectiveness of the crusher as time passed. A solar panel-based can crusher is made to improve the energy efficiency and to reduce the environmental impact [6].

The mechanism used for crushing is either by applying an impact force, pressure or a combination of both. To reduce the effort required for crushing, the proper design of parts and components is necessary. Many researchers have tried to improve the design of some parts, and many have tried to reduce the weight, energy consumption and by using different materials [7-9]. Failure in the crusher's jaw is common and addressed in many studies to prevent the fatigue failure of the jaw and supporting bolts [10-14]. Parametric failure-based dynamic motion analysis 3D software, and process mapping analysis were used for individual parts and components [10, 15].

We are creating a can crusher machine with a multiple-sided crushing capability that uses a scotch mechanism to address this issue. The primary benefits include the capacity to crush multiple materials at a minimal cost and the ease with which even an inexperienced individual can handle it.

This report's only goal is to comprehend the basic concepts of operation and design. Simple mechanism features, including a fulcrum system, a single slider crank

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mechanism, automation properties, etc., are used in this eco-friendly design. In order to significantly reduce the volume of the cans or bottles, considerable crushing power is required. The conceptualization is completed in a way that increases design, mechanism, and force understanding. The goal of this endeavor is to design and build an automatic can crusher machine while taking into account a number of crucial factors. In order to smash the cans as flat and geometrically as possible before they are shredded in the shredder, this project proposes to create a bottle or can crushing and shredding machine. It was crucial to complete this project in order to make sure that all that needed to be done was done, in addition to the manufacturing research. This project entails designing the various components of the crusher unit while taking user ergonomics and forces into account. The primary goal of this project is to come up with a novel idea for a can or bottle crusher that would be portable and make crushing the can or bottle simpler. Following completion, the design serves as a guide for the actual product.

II. MECHANISM USED

To reduce the effort required to crush the soft material cans and other packaging materials, a well-established mechanism called the slider crank mechanism is used. A reciprocating motion device, the Single Slider transforms a slider's linear motion into rotating motion or the other way around [16]. A connecting rod with a slot that engages a pin on the spinning element is directly connected to the piston or other reciprocating component. With a constant rotational speed, the piston's motion takes the form of a pure sine wave over time. Using this system, rotary motion can be transformed into reciprocating motion. To achieve the inversion, the cylinder must be fixed. Figure 1 shows that link 1 is fixed. A slider is represented by link 4, which reciprocates when link 2, which represents the crank, turns in this system [17]. To guide the Slider, the fixed link 1 is used.

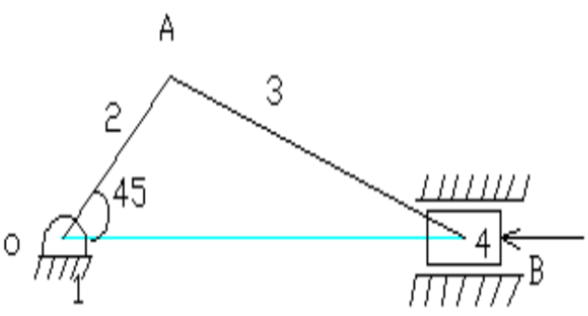


Fig. 1: Schematic of Single Slider Crank Mechanism [17].

III. WORKING

The schematic of the designed can crusher setup is shown in Figure 2. As the motor rotates, it has a smaller sprocket connected to its shaft; the smaller sprocket, through the chain, is connected to a secondary sprocket, which rotates it. There is another sprocket that is connected to the main sprocket through a chain, which also rotates it. As the main sprocket rotates, it also rotates the main shaft, which in turn rotates the disk, and the whole mechanism starts working. When the disk rotates, the connecting rod also moves with it, which moves the piston left and right and crushes the cans during moving from its extreme points. The smashed bottles will enter the Shredder through the designated rectangular slots. The large volume of cans is converted into a small volume of crushed and shredded material that can be easily carried and recycled into finished products. The mass production can be ensured because it smashes the cans satisfactorily with a high production rate. The successfully constructed can crusher utilizing a single slider crank mechanism is given in Figure 2.

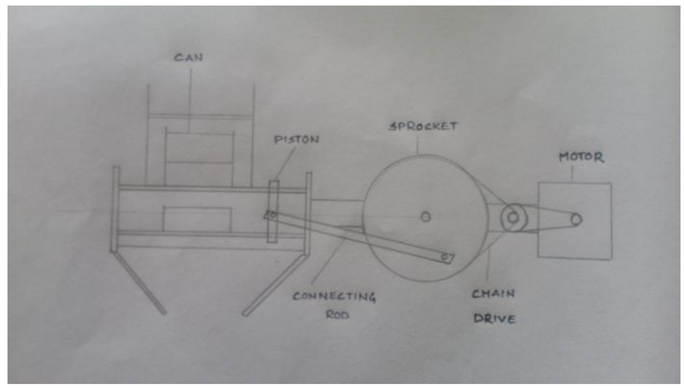


Fig. 2. Schematic view of the designed can crusher setup.

IV. DESIGN CONSIDERATION

The following parameters were considered during design and development:

- The greatest force needed to shatter the plastic bottles or cans.
- Parts and components taken in to considerations.
- The typical size of bottles and cans.
- Aluminum is the material for cans.

A. Design calculations

1. Determination of crushing force and Power

- The amount of force needed to shatter the plastic bottle.
- Power needed to shatter a soda or Pepsi can;
- Force needed to tear the can

So, we are considering the maximum of it.

Force is given by

$$\text{Force} = Pc * A$$

Where, Pc is crushing pressure = 15-41 ksi (15000-41000 psi) = 22.5 ksi (22500psi) or lbf/sq. inch = 155.13 MPa.
A is area of crushing of can = 2 * 3.14 * R * t
R is the radius of the Can = Dia/2 = 66.675/2 = 33.33.
D = 2.5 - 2.8 inch (assuming 66.675 mm).

t = The thickness of the wall of C_{an} = 0.1 mm

A = 2 * 3.14 * 33.33 * 0.1 = 20.9465 sq.mm.

F = P_c*A = 155.13*20.9465 = 3.25 KN.

- Power is given by

Power = F * V

Where V is the velocity of the piston.
F is the required crushing force.
V = piston movement/time.

Where, **Can height** = 5 inch = 0.127m.
Piston movement = 18cm = 0.18m.
Time = 1.275 sec
V=0.18/1.275 = 0.141m/s.

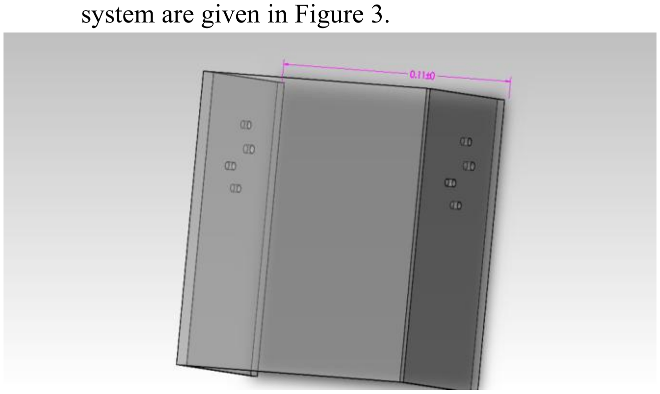
Power = force * velocity = 3.25 * 0.141 = 0.5 KW =0.683 hp.

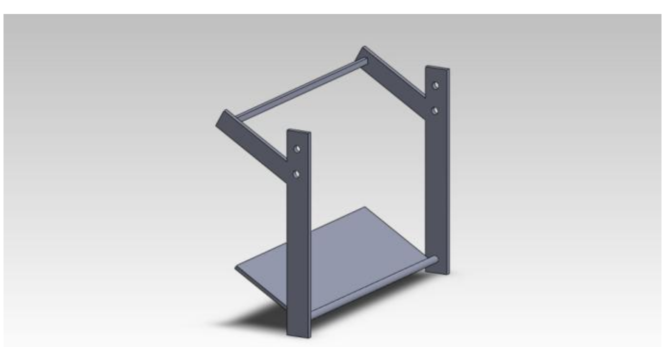
2. **RPM of Sprocket**
Velocity = 3.14 * D * N/60
Velocity = 0.141 m/s.

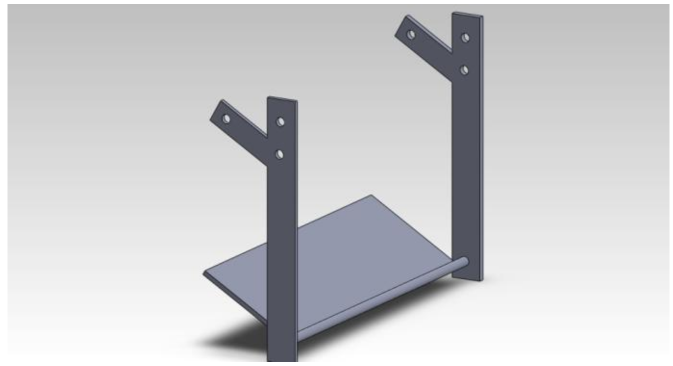
Where D is the Diameter of the Crank = 15 cm.
N is the rpm of the Sprocket.
0.141 = 3.14 * 0.15 * N/60

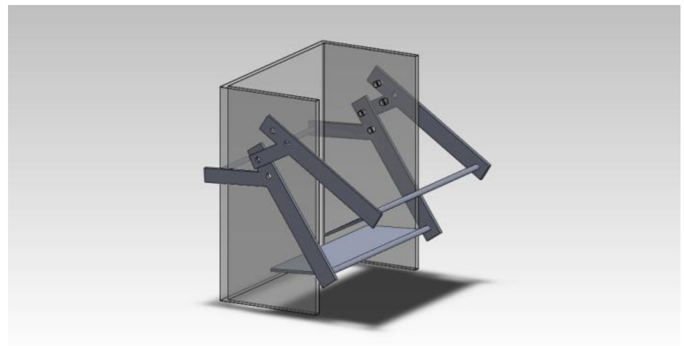
N = 18 rpm.

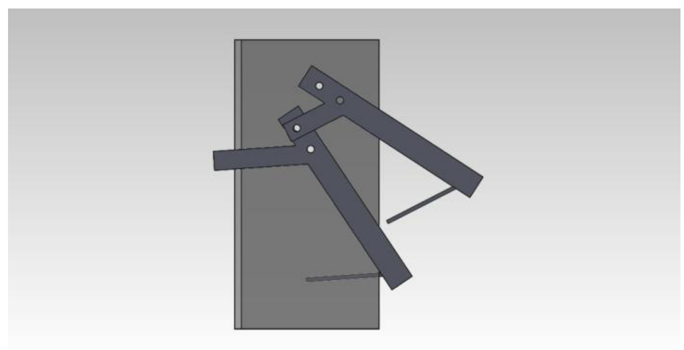
2. **Auto-feed Mechanism**
The different parts and components of the auto feed system are given in Figure 3.



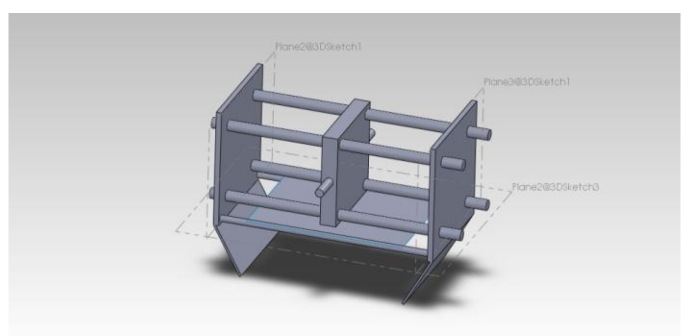


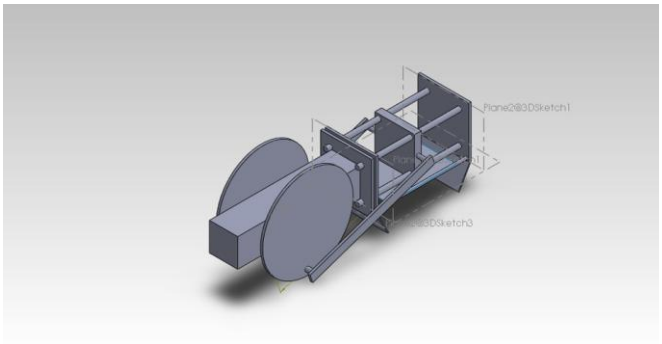


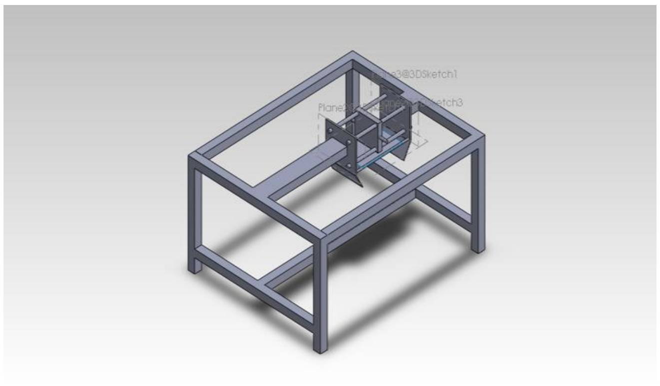




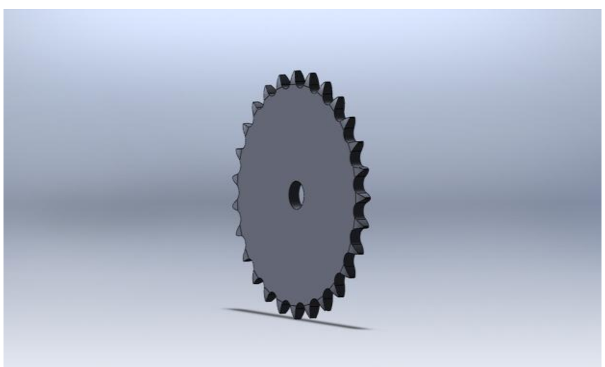
Crusher Mechanism



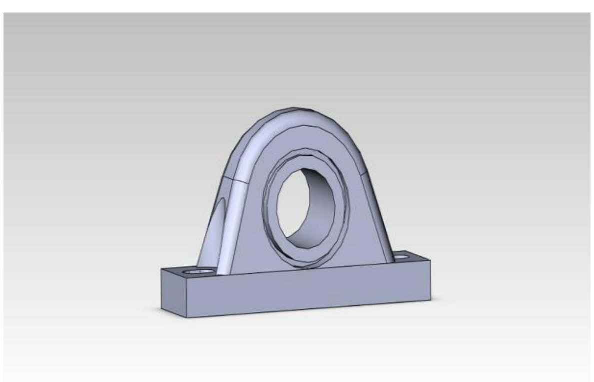




Casing



Sprocket



Bearing Block

Fig. 3. Different parts and components of a Can Crusher.

V. DESIGN OF COUPLINGS

A mechanical device that permanently connects two rotating shafts is called a coupling. Coupling is most frequently used to unite the shafts of two independently constructed or purchased units to create a new machine. To lift water from a well, for instance, a coupler connects the engine's output shaft to the hydraulic pump's input shaft. In industrial machinery, a coupling connects an input shaft of a gearbox to the output shaft of an electric motor. An electric motor's rotating shaft and a compressor's input shaft are connected through a coupling. The distinction between a clutch and a coupling is that a clutch allows the operator to join or separate two shafts, whereas a coupling is a persistent contact.

Rigid or flexible couplings are utilized when the axes are in the same line or collinear. A stiff coupling lacks the facilities necessary to tolerate a slight misalignment among the shafts, but a flexible coupling does.

The difference between rigid and flexible coupling is as follows:

A rigid coupling cannot tolerate misalignment between the axes of the shafts. It is only applicable when two shafts are precisely aligned. The flexible coupling, on the other hand, can withstand 5mm of axial misalignment and 0.5 degrees of angular misalignment between the shafts since it has flexible components like a bush or disk.

Shocks and vibrations are absorbed by the coupling's flexible components. In stiff coupling, such a provision does not exist. Only in situations where there are no shocks or vibrations may it be employed.

The following criteria should be met by a good coupling, whether it is rigid or flexible:

- It must be able to transfer torque from the driving shaft to the driven shaft.
- It must maintain the two shafts in the correct alignment.
- For repairs and modifications, the coupling should be simple to build and disassemble.

The material used for the flexible coupling is EN-GJS-800-2, which is grey cast iron with lamellar graphite with a yield strength of 1000-1100 MPa.

A. Design

Procedure for Flexible Coupling

Selection of material-

SHAFT-

Yield strength of material 1100 MPa

Factor of safety = 1

PINS-

Yield strength of material = 400 MPa (plain carbon steel 30C8)

Factor of safety = 1

1. **Permissible stresses:**

- **SHAFT-**

Torsional shear stress = (0.5* yield strength)/factor of safety

= (0.5*1100)/1 = 550Mpa.

- **PINS-**

Torsional shear stress = yield strength/factor of safety =400/1 = 400.

2. **Diameter of Shafts:**

The motor's starting torque is 125% of the rated torque. Therefore,

M = (60*10^6*0.745694*1.25) / (2*3.14*18) = 494043.4692

Torsional shear strength=(16M/(3.14*d^3)

D = 15.78mm or d = 16mm.

3. **Dimensions of Flanges:**
   - Outside diameter of hub = 2d = 32mm.
   - Length of hub = 1.5d = 24mm.
   - Pitch circle diameter of pins = 3d or 4d = 48mm.
   - Thickness of output flange=0.5d = 8mm.
   - Thickness of protective rim = 0.25d = 4mm.

Torsional shear strength Mr/J

M = 0.5*3.14*4*d^2x t x torsional shear strength

M = 843958.627

Torsional shear strength = 65.586 MPa <400 MPa

So, the stresses in the flange are within the limit.

4. **Diameter of Pins:**

Number of pins selected, N=3

Diameter of pins = (0.5*d)/sq. root N = 4.618mm = 8mm (as per standardization)

Shear stress in the pin = (8*M)/(3.14*d^2*D*N) =328.044 Mpa. <400 MPa

Therefore, based on shear resistance, its structure is secure.

B. Design Procedure for the Hub

1. **Selection of material-**

- **SHAFT-**

Yield strength of material = 690 MPa (High-strength alloy ASTM A514)

Factor of safety=1.

- **PINS-**

Yield strength of material = 400MPa (plain carbon steel 30C8)

Factor of safety =1.

Permissible stresses-

SHAFT-

Torsional shear stress = (0.5* yield strength)/factor of safety = (0.5*690)/1 = 345Mpa.

PINS-

Torsional shear stress=yield strength/factor of safety =400/1 = 400

Diameter Of Shafts

The starting torque of the motor is 125% of the rated torque. Therefore,

M = (60*10^6*0.745694*1.25) / (2*3.14*18) = 494043.4692

Torsional shear strength=(16M/(3.14*d^3))

d = 19.393mm or d = 20mm.

3. **Dimensions Of Flanges-**

- Outside diameter of hub = 2d = 40mm
- Length of hub =1.5d = 30mm
- Pitch circle diameter of pins = 3d or 4d = 80mm
- Thickness of output flange = 0.5d = 10mm
- Thickness of protective rim = 0.25d = 5mm

Torsional shear strength = Mr/J

M = 0.5*3.14*4*d^2xtxtorsional shear strength

M = 433539.7862.

Torsional shear strength = 36.8 MPa <400 MPa

So, the stresses in the flange are within the limit.

5. **Diameter of Pins**

Number of pins selected, N = 4

Diameter of pins = (0.5*d)/sq. root N = 5mm = 8mm (as per standardization).

Shear stress in the pin=(8*M)/(3.14*d^2*D*N) =138 Mpa. <400 MPa

So, the shear strength of the design makes it safe.

C. Sprocket Design:

1. Selection of the Diameter:

Diameter of the sprocket attached to the Gear Box (Sprocket 1) = 100mm

RPM available at the output of the Motor = 1440

Gear Ratio of the Gear Box = 40:1

Therefore,

RPM available at the output of the Gear Box, i.e., at the sprocket 1= 1440/40 = 36.

RPM required at the crank = 18.

Therefore

Diameter of the Sprocket attached to the shaft will be = (36 / 18) x 100 = 200 mm.

Material of the Sprocket – Tempered and Case-Hardened Steel

Strength of the Sprocket material- 900 MPa

Assuming, FOS = 1.3

Available strength of the Sprocket material = 900/1.3 = 700 Mpa.

2. Selection of Pitch and Pitch Circle Diameter:

Since the RPM at the Sprocket 1 is 36 (low-speed applications) Therefore,

The selected pitch is **13mm**

PCD of sprocket 1= 80mm

PCD of sprocket 2= 170mm.

D. Chain Design:

The strength of the chain material should be higher than that of the sprocket material; otherwise, there would be a lot of wear and tear on the teeth of the sprocket.

Therefore

Strength of the Chain material = 1500MPa

Material of the Chain – Alloy Steel.

E. Bearing Design:

We have selected Ball Bearing due to the following advantages-

- Due to the point contact, there would be low friction.
- It can sustain axial and radial load simultaneously.
- It has a high load-carrying capacity.

RPM of the shaft = 18
Radial load on the bearing = Weight of 2 sprockets
Weight of shaft + Additional weight
= 80+80+40+40 = 240 N
Axial load on the bearing = Zero
Therefore
Equivalent load on the bearing, P = **240 N.**
Now,
Diameter of the shaft = 20mm (as the ID of the sprocket is 20mm)
Life required = 60000 hours.
Therefore,
L 10 = (60xNxL) / 1000000
= (60x18x60000) / 1000000 = 62.4 million revolutions.
Therefore
Dynamic load carrying capacity, C = P (L10) ^0.33 = 240x (62.8) ^0.33 = **950 N.**

Available Bearing ---- 61804
Dynamic load carrying capacity **=** 2700 N.

F. Design of Gear Box

Worm reduction gear unit under driven type is required to drive a sprocket and chain, medium loaded, operating 24 hrs per day at 36 rpm, transmitting 0.746 KW. The gear unit is directly driven by a coupling by a 1440 rpm electric motor. The ambient temperature is 30 degrees on the machine.

STEP 1:
Ratio required = Input speed/Output speed = 1440/36 = 40:1.
STEP 2:
From Table 1
Driven machine- sprocket chain (medium loaded)
Type of load- moderate shock
From Table 2
Mechanical service factor (Fm)= 1.50 for 24 hr/day continuous operation.

STEP 3:
Equivalent output power (mechanical) = 0.746*1.5 = 1.119 KW.
Equivalent output torque (mechanical) = (9550*1.119)/36 = 296.845Nm
From catalogue
Refer rating at input speed 1440 rpm, ratio 40:1
Gear unit size 12, ratio 40:1, having output torque (mechanical) = 296.845Nm
Input power (mechanical) = 62 KW.

STEP 4:
From table 3, thermal service factor (Ft) = 1.16
For an ambient temperature of 30 degrees
Equivalent output power (thermal) = 0.746*1.16 = 0.86536 KW = (9550*1.119)/36 = 296.845 Nm.

STEP 5:
From the catalogue, rating at input 1440 ratio- 40:1for 12-inch size
The Output torque (thermal) = 296.845Nm,
Which is less than the calculated equivalent
The Output torque (thermal) = 280 Nm
Required input power = (calculate equivalent output torque(mechanical)* Rated power(mechanical) / (rated output torque *Fm)

VI CONCLUSION AND FUTURE SCOPE

The working and performance of any robust system depend on the material used, its design parameters, and manufacturing considerations as per the applications. After proper design of each part and component, the research work leads us to the conclusion that it can be employed in mass production because it smashes the cans satisfactorily in a short amount of time, which leads to high recycling ability to crush the cans. After a robust design, a can crusher was successfully constructed utilising a single slider crank mechanism. The can crusher is well designed with robust parts and components and has been tested. The theoretical design seems well established, but it can be improved by applying some design software, so that the fabrication process and design parameters can be improved.

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