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*Original Article*

# Computer-Aided Design (CAD) and Cost Implication of A Simple Laboratory Metal Extrusion Machine

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***Abstract*** *- This work presents a Computer Aided Design (CAD) and Cost Implication of a Simple Laboratory Metal Extrusion Machine. The concept is to have a laboratory metal extrusion that is capable of demonstrating metal extrusion processes and their applications. In the process of design and drawing, a solid work tool is used in the production of the parts and components of the machine. The machine is designed in accordance with design considerations that enable sourcing materials locally that fulfilled the design analysis and calculations. The materials are so selected to meet up with the required properties for components and parts. The cost estimate of the machine elements is done to serve as a guide in the actualization of the machine fabrication. The availability of this equipment will enhance academic research on metal extrusion and training of students on Simple extrusion processes.*

***Keywords*** *- Computer-Aided Design, Cost Analysis, Design Calculation, Design Drawing, Metal Extrusion Machine.*

## 1. Introduction

The metal was first heated and then forced into a die using a hand-driven plunger known as squirting in the 1800s to start the extrusion process (Rauwendaal, 2001). Concrete, metals, polymers, and ceramics may now all be extruded.

According to Mohammed (2014), an extrusion machine is a device that is powered by electricity or hydraulics and is used to push or pull cold metal billets, hot metals, molten metal, or plastics through a barrel-shaped cavity with a piston or screw conveyor. The material is forced out of the barrel through a die, which is a regular hole, to form a length shape that fits the die's shape. An extrusion machine's prime mover, plunger, piston, screw conveyor, barrel, and die are its main components. There had been some work done on the processes of extension.

Ghaemi et al. (2013) used an updated slab technique analysis to optimize the die profile for cold forward extrusion. The form of the die profile is one of the most crucial design factors in the extrusion process. In the study, slab analysis was used in a computational program to produce the ideal extrusion die profile. Furthermore, the ideal conical and curved die extrusion processes were carried out both experimentally and using the finite element method. It was shown that the friction situation and the work hardening characteristics of the material significantly influence the ideal streamlined die profile. Furthermore, from a metallurgical and manufacturing standpoint, the results demonstrated that the streamlined die profile created using the new approach is superior to the traditional conical dies.

As a result, the suggested technique is a trustworthy and effective instrument for creating simplified die profiles. As a result, the method can be applied to achieve desired outcomes in terms of die wear, extrusion force, and deformation homogeneity for both process and product quality.

An experimental and Finite Element Analysis (FEA) of the cold extrusion of high-grade (AA1100) aluminum was reported by Tiernan et al. (2005). Investigations were conducted into the effects of die land, reduction ratio, and die angle on the extrusion force during the extrusion process. For the experimental investigation, a forward extrusion die was created and produced. According to a report, the extrusion die's interchangeable parts allowed for quick adjustments of the extrusion parameters to achieve a high level of experimental flexibility. It was found that while a Linear Variable Differential Transformer (LVDT) offered automatic punch travel measurement during the extrusion cycle, a load cell integrated into the die design permitted accurate assessment of extrusion forces. Using a Personal Computer

(PC), all data acquired from the instruments were recorded and examined. The cold extrusion process was subjected to Finite Element Analysis (FEA) in tandem with the experimental program. FEA simulation was conducted using ELFEN, a finite element analysis application designed exclusively for metal forming simulation. For the analysis, a 2D asymmetric geometric model of the tooling and billet was created in this work.

According to Mohammed (2014), the intricate die design of the metal extrusion process results in a very complex type of metal flow and stress distribution. Using the commercial finite element code Deform-3D, a finite element simulation of Al-1100 rod extrusion was effectively accomplished in his work. The outcomes demonstrated that the stress distribution in the direct rod extrusion of Al-1100 could be accurately reproduced by the finite element model. In addition, the ideal die angle lessens the amount of effective, shear, and normal stresses. The study's findings indicate that the rod experiences the highest stresses at the exit stage when it is in touch with the die.

Friction Stir Extrusion is a novel direct-recycling process designed for metal machining chips, according to Dario et al. (2018). A revolving die is inserted into a cylindrical chamber that holds the recyclable material during the procedure. The die's churning action causes firm bonding, which permits a dense rod to be fully extruded from the back. The discontinuity of the process itself, which restricts the extrudate's volume to the chamber's capacity, is one of the primary weaknesses of this method. To get around that restriction, a specific extrusion fixture must be created while taking into consideration the simultaneous requirements of a continuous machine. In order to initiate the extrusion process and permit the continual loading of new charges, the die's design must guarantee appropriate pressure in the extrusion channel. In addition, for firm bonding to occur, the chips entering the chamber must find the right circumstances. The design difficulties of a continuous friction stir extrusion machine are discussed and examined in this work, along with potential solutions that take into consideration sensor equipment required for process monitoring and can be found through both experimental and numerical analysis. (Dario et. al., 2018).

Sunil Kumar and Rao P. S. focused on the extrusion process's impact analysis on product quality. In order to meet consumer demand, a significant number of producers encountered issues with the quality of their products when using the established extrusion pipe manufacturing technique. The current extrusion pipe manufacturing process requires the identification, control, and routine monitoring of all quality factors in order to guarantee product quality. A number of critical factors depend on the state of the process-related equipment, operational circumstances, pressures, temperatures, die quality, and materials employed. Manufacturers encounter numerous challenges in their efforts to reduce defects in finished goods, which has a direct impact on both product cost and lifespan. This paper's main goal is to examine the different extrusion process faults, assess how they affect product quality, and offer solutions and mitigations for enhancing the process to produce higher-quality and longer-lasting products. (Sunil and Rao, 2019).

Rahul et al. investigated the metal extrusion method used to make items with a predetermined cross-sectional shape. A substance is forced through a die with the required cross-sectional area. The contributions made by earlier researchers in the field of the extrusion process have been succinctly reviewed. Researchers mostly employ steel and aluminum alloys as the die and billet materials in the extrusion process. In most cases, axisymmetric conditions are used in the FEM modeling of the extrusion process. The most common method for meshing the workpiece is to use axisymmetric quadrilateral pieces. Tools used in the construction of the extrusion process, as well as the experimental setup, are shown and discussed. Punch force and stroke variations are seen in the FEM results. (Rahul et al., 2018)

## 2. Design and Methods

Using Solid Works tools, the work is completed based on the detailed drawings and the design analysis provided by Khurmi and Gupta, 2005. The design drawings are used to determine the machine elements' cost implications.

### *2.1. Design Analysis and Calculations*

*2.1.1. Design Analysis of Extrusion*

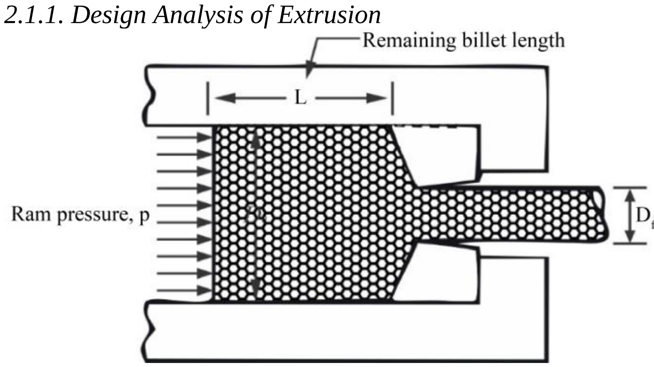



**Fig. 1 Pressure and other variables in direct extrusion**

Using Figure 1 as a reference in discussing some of the parameters in extrusion. The diagram of the extrudate and billet are both assumed to be circular in the diagram. The extrusion ratio, often known as the reduction ratio, is one crucial component. The definition of the ratio is:

$$r_x = \frac{A_0}{A_f} \quad (1)$$

Where,

$r_x = extrusion\ ratio$

$A_0 = cross - sectional\ area\ of\ the\ starting\ billet\ (m^2)$

$A_f = final\ cross-sectional\ area\ of\ the\ extruded\ section\ (m^2)$

The ratio applies for both direct and indirect extrusion; the value of $r_x$ can be used to determine true strain in extrusion, given that ideal deformation occurs with no friction and no redundant work:

$$\boldsymbol{\mathcal{E}} = Inr_x = In\frac{A_0}{A_f} \quad (2)$$

Under the assumption of ideal deformation (no friction and no redundant work), the pressure applied by the ram to compress the billet through the die opening depicted in our figure can be computed as follows:

$$P = \bar{y}_f\mathcal{E} = \bar{y}_f Inr_x \quad (3)$$

$\bar{y}_f = average\ flow\ stress\ during\ deformation\ (MPa)$

As the billet compresses and travels through the die aperture, friction develops between the die and the work. Friction also occurs in direct extrusion between the billet surface and the container wall.

Johnson provided the following empirical formula to estimate extrusion strain under friction conditions:

$$\boldsymbol{\mathcal{E}}_x = a + bInr_x \quad (4)$$

Where,
$\boldsymbol{\mathcal{E}}_x =$ = extrusion strain; and
a and b are empirical constants for a given die angle.

Typical values of these constants are $a = 0.8$ and $b = 1.2\ to\ 1.5$. Values of $a$ and $b$ tend to increase with increasing die angle.

The friction between the billet and container walls in direct extrusion results in higher ram pressure than in indirect extrusion. Ram pressure in direct extrusion can be calculated using the formula below:

$$P = \bar{y}_f\left(\boldsymbol{\mathcal{E}}_x + \frac{2L}{D_0}\right) \quad (5)$$

Where the term $\frac{2L}{D_0}$ accounts for the additional pressure due to friction at the container–billet interface. L is the portion of the billet length remaining to be extruded, and Do is the original diameter of the billet. Note that P is reduced as the remaining billet length decreases during the process.
Ram force in indirect or direct extrusion

$$F = PA_0 \quad (6)$$

Where,
$F = Ram\ force$
$P = Extrusion\ pressure$
$A_0 = Area\ of\ the\ billet(m^2)$

$$\bar{y} = K\mathcal{E}^n \quad (7)$$

Where,
$\bar{y} = Extrusion\ constant$
$K = Strength\ coefficient\ of\ aluminium$
$n = Strain-hardening\ exponent\ of\ aluminium$

According to Hosford, the strength coefficient K of aluminium lies between 400MPa and 550MPa (Hosford, 2005). Also, common values of the strain-hardening exponent are between 0.2 and 0.3 (Mohammed, 2014).

$$A_0 = \frac{\pi d^2}{4} \quad (8)$$

Where,
$d = diameter\ of\ the\ billet\ (m)$
Strain-hardening of aluminium = 0.2
Strength coefficient of aluminium = 175 MPa

$$V = \frac{2\pi \times r}{60} \times N \quad (9)$$

Where,
$V = linear\ velocity\ (m/s)$
$r = radius\ of\ the\ ram\ (m)$
$N = angular\ velocity\ (rpm)$

$$Shaft\ power, P_s = FV \quad (10)$$

Also, to get the required torque,

$$P_s = \frac{2\pi NT}{60} \quad (11)$$

Then,

$$T = \frac{60P_s}{2\pi N}$$

Where,
$N = Torque\ (Nm)$
$P_s = Shaft\ power\ (W)$
$N = angular\ velocity\ (rpm)$

*2.1.2. Determination of the Required Extrusion Force*

*Extrusion force required for O-Shaped Die*

Considering the diameter of the O-shape die, where its diameter is 15mm, the area is calculated thus;

$$A = \frac{\pi d^2}{4},$$

$$A_1 = \frac{3.142 \times 0.015^2}{4} = 0.0001767m^2$$

$$A_0 = \frac{\pi d^2}{4}, \text{where d} = 16\text{mm, which is the diameter of the ram/piston}$$

$$A_0 = \frac{3.142 \times 0.016^2}{4} = 0.0002011m^2$$

$$r_x = \frac{A_0}{A_1} = \frac{0.0002011}{0.0001767} = 1.1381$$

$$\boldsymbol{\mathcal{E}} = Inr_x = In1.1381 = 0.1294$$

$$\bar{y} = K\mathcal{E}^n$$

Taking K to be 400MPA and n to be 0.2

$$\bar{y} = 400000000 \times 0.1294^{0.2} = 265733829.7$$

$$P = \bar{y}_f \mathcal{E} = 265733829.7 \times 0.1294 = 34385957.57N/m^2$$

$$F = PA_0 = 34385957.57 \times 0.0002011 = 6915.02N$$

Assuming the low angular velocity of 150rpm

$$V = \frac{2\pi \times r}{60} \times N = \frac{2 \times 3.142 \times 0.008}{60} \times 150 = 0.12568m/s$$

*2.1.3. Determination of the Required Extrusion Power*
*Extrusion power required for O-shape Die*

$$P_s = FV = 6915.02 \times 0.12568 = 869.08W$$

For electrical horsepower,

$$1Hp = 746Watt$$

$$P_s = \frac{869.08}{746} = 1.16 \approx 2Hp$$

*2.1.4. Determination of the Required Extrusion Torque*

$$T = \frac{60P_s}{2\pi N} = \frac{60 \times 869.08}{2 \times 3.142 \times 150} = \frac{52144.8}{942.6} = 55.32Nm$$

### *2.2. Design Drawings*

*2.2.1. The isometric view of the Metal Extruder*

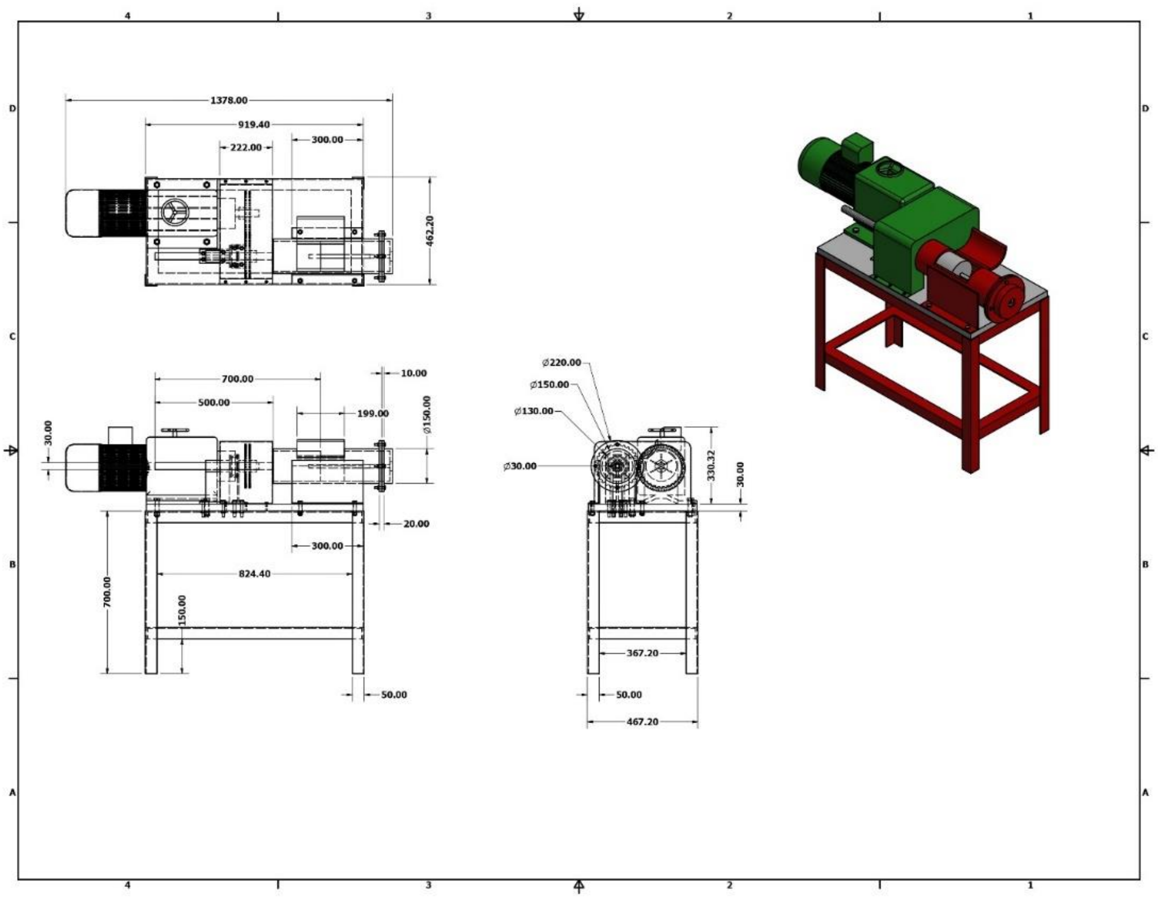
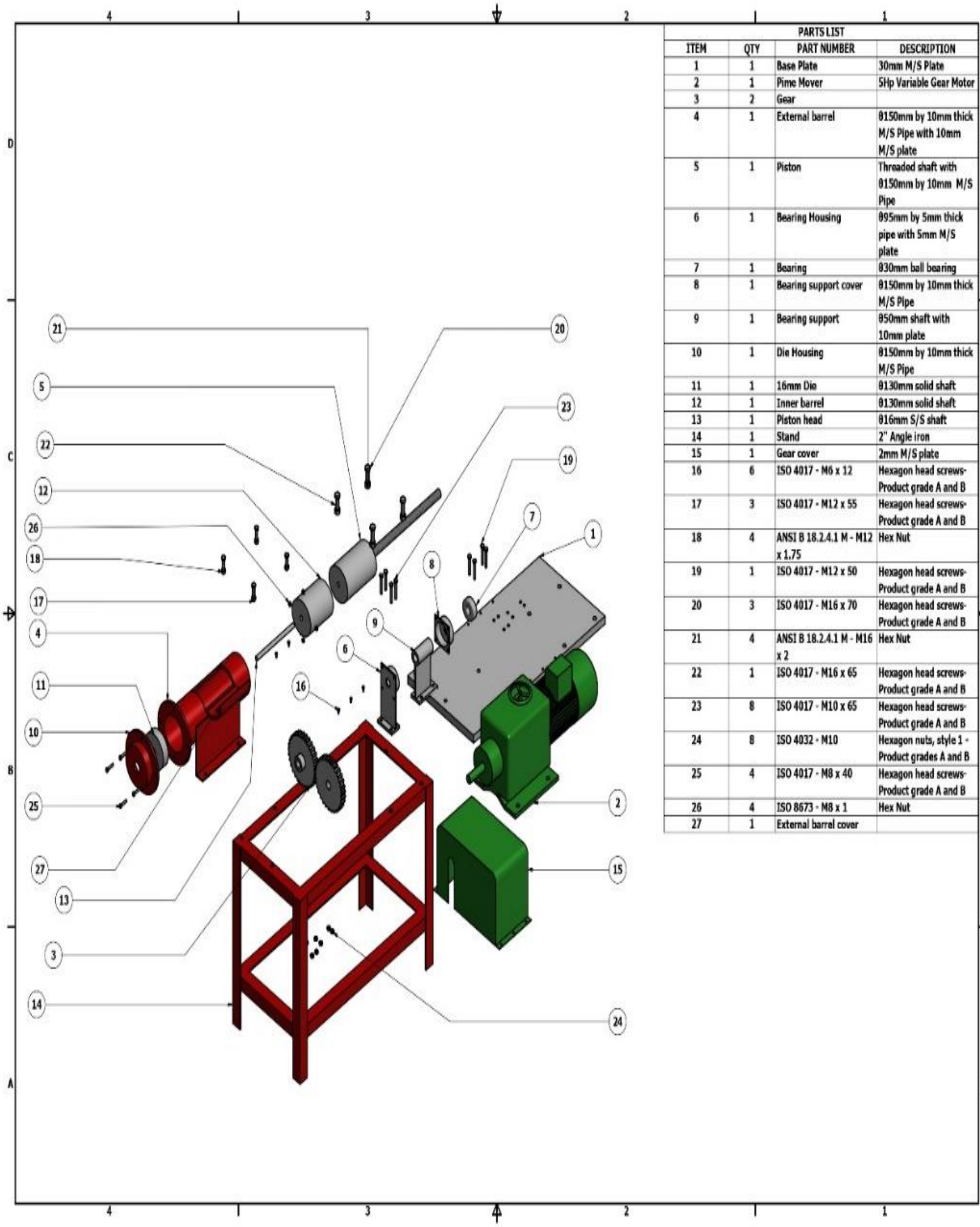



**Fig. 2 Details of Isometric view of the Metal Extruder**

*2.2.2. The Exploded View of the Extruder*



| PARTS LIST | | | |
|---|---|---|---|
| ITEM | QTY | PART NUMBER | DESCRIPTION |
| 1 | 1 | Base Plate | 30mm M/S Plate |
| 2 | 1 | Pime Mover | 5Hp Variable Gear Motor |
| 3 | 2 | Gear | |
| 4 | 1 | External barrel | Ø150mm by 10mm thick M/S Pipe with 10mm M/S plate |
| 5 | 1 | Piston | Threaded shaft with Ø150mm by 10mm M/S Pipe |
| 6 | 1 | Bearing Housing | Ø95mm by 5mm thick pipe with 5mm M/S plate |
| 7 | 1 | Bearing | Ø30mm ball bearing |
| 8 | 1 | Bearing support cover | Ø150mm by 10mm thick M/S Pipe |
| 9 | 1 | Bearing support | Ø50mm shaft with 10mm plate |
| 10 | 1 | Die Housing | Ø150mm by 10mm thick M/S Pipe |
| 11 | 1 | 16mm Die | Ø130mm solid shaft |
| 12 | 1 | Inner barrel | Ø130mm solid shaft |
| 13 | 1 | Piston head | Ø16mm S/S shaft |
| 14 | 1 | Stand | 2" Angle iron |
| 15 | 1 | Gear cover | 2mm M/S plate |
| 16 | 6 | ISO 4017 - M6 x 12 | Hexagon head screws-Product grade A and B |
| 17 | 3 | ISO 4017 - M12 x 55 | Hexagon head screws-Product grade A and B |
| 18 | 4 | ANSI B 18.2.4.1 M - M12 x 1.75 | Hex Nut |
| 19 | 1 | ISO 4017 - M12 x 50 | Hexagon head screws-Product grade A and B |
| 20 | 3 | ISO 4017 - M16 x 70 | Hexagon head screws-Product grade A and B |
| 21 | 4 | ANSI B 18.2.4.1 M - M16 x 2 | Hex Nut |
| 22 | 1 | ISO 4017 - M16 x 65 | Hexagon head screws-Product grade A and B |
| 23 | 8 | ISO 4017 - M10 x 65 | Hexagon head screws-Product grade A and B |
| 24 | 8 | ISO 4032 - M10 | Hexagon nuts, style 1 - Product grades A and B |
| 25 | 4 | ISO 4017 - M8 x 40 | Hexagon head screws-Product grade A and B |
| 26 | 4 | ISO 8673 - M8 x 1 | Hex Nut |
| 27 | 1 | External barrel cover | |

**Fig. 3 Exploded view of the extruder**

### 2.3. Working Drawings

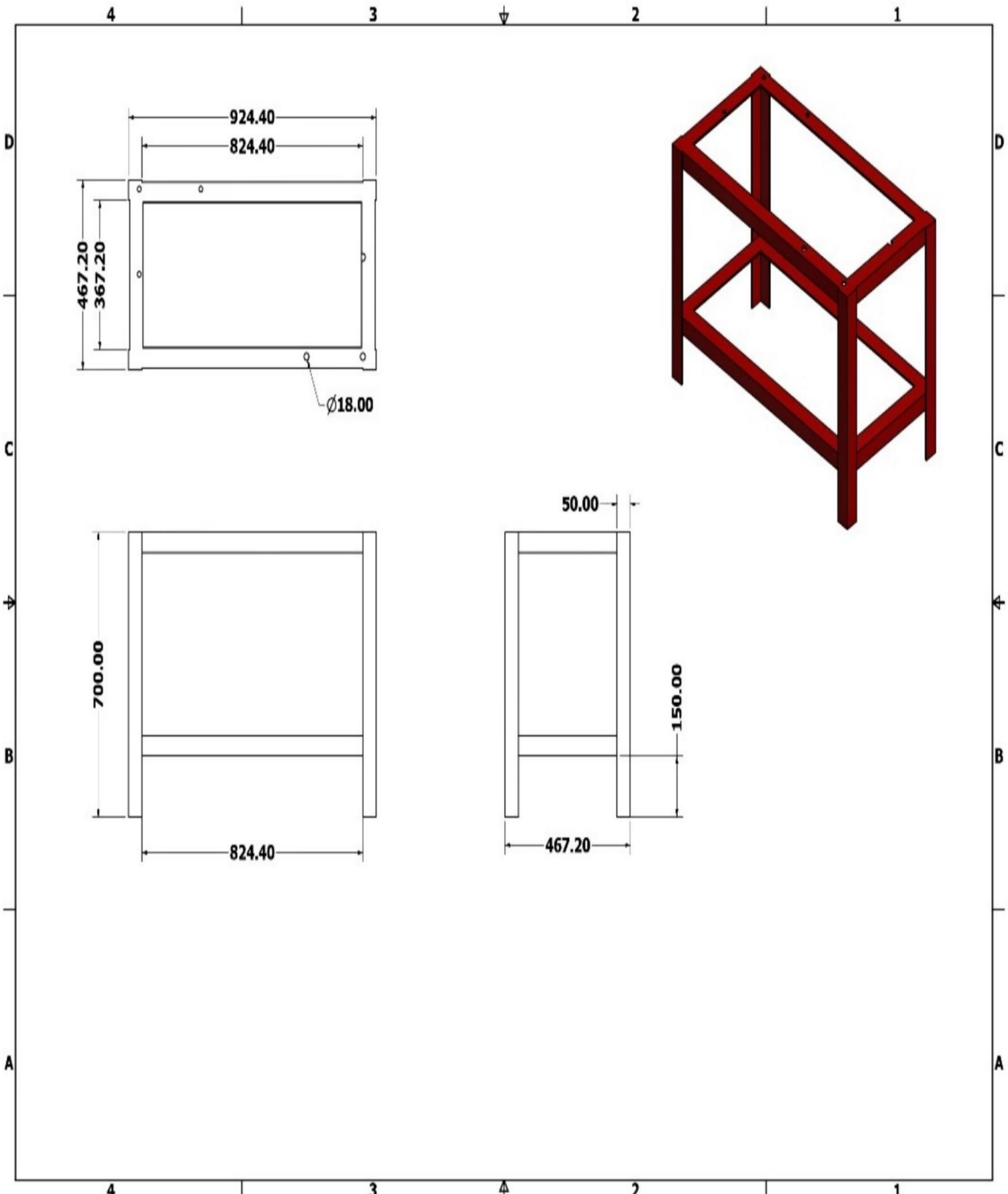



**Fig. 4 The frame**

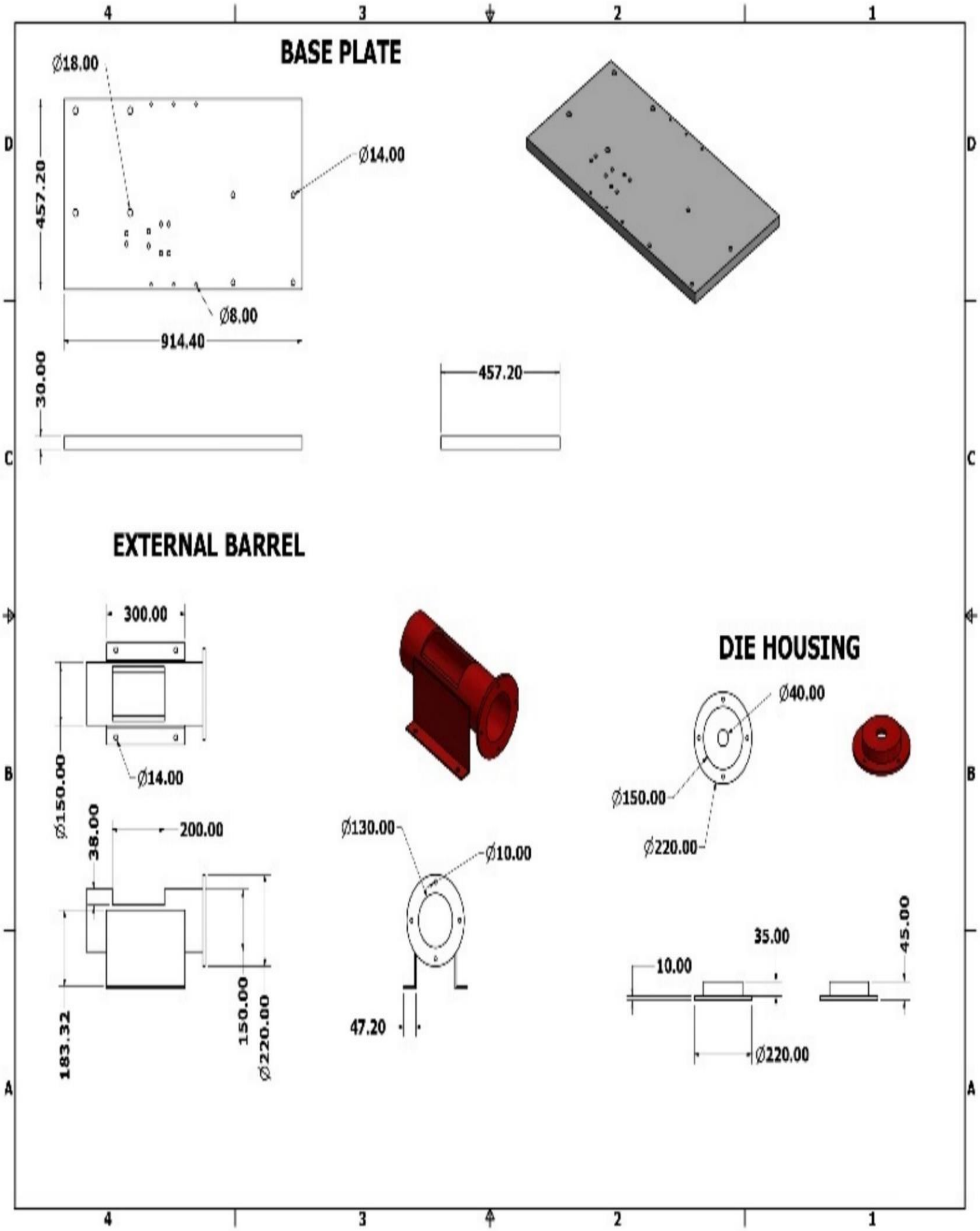



**Fig. 5 base plate and barrel**

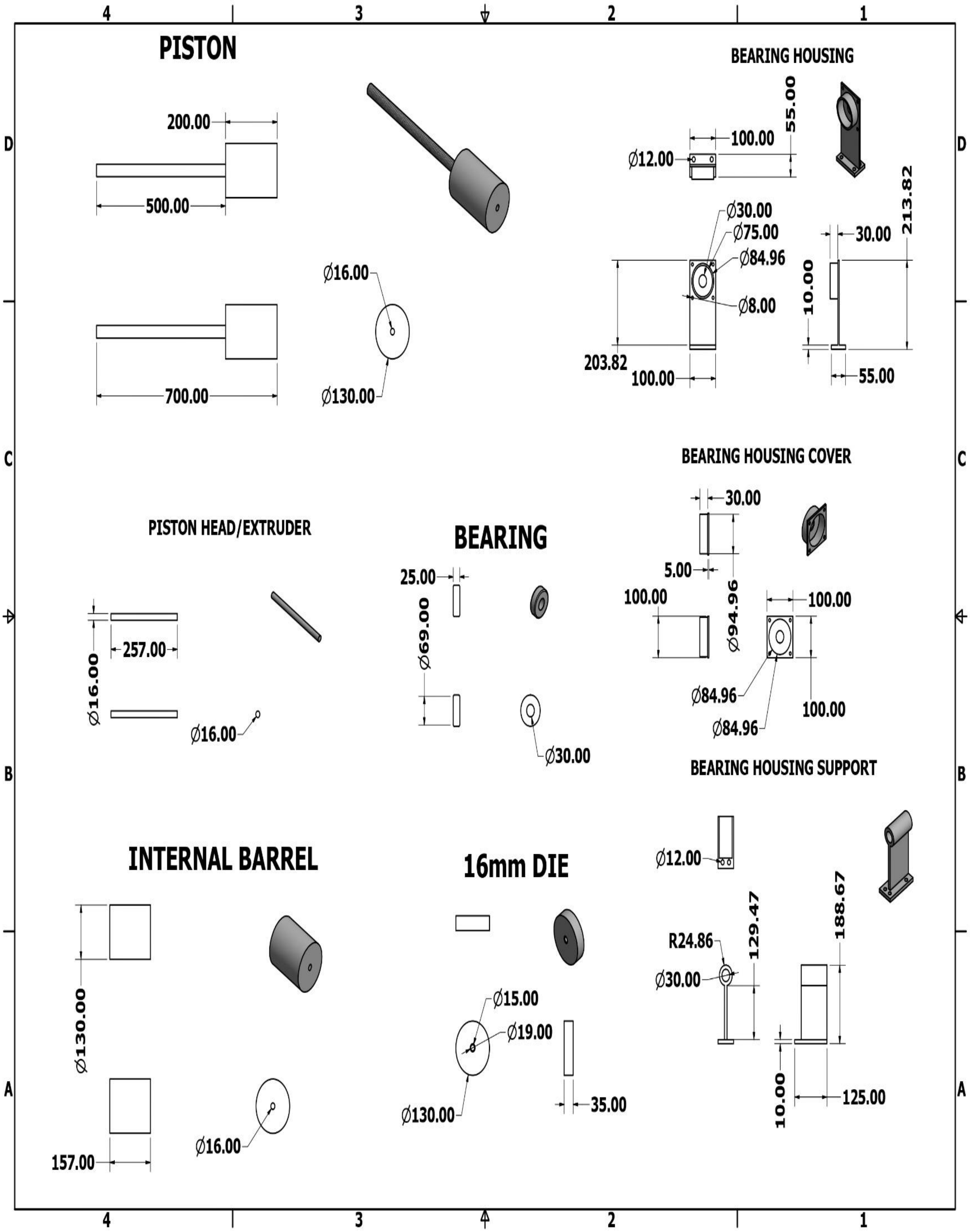



**Fig. 6 The Piston, Beaming and Internal Barrel**

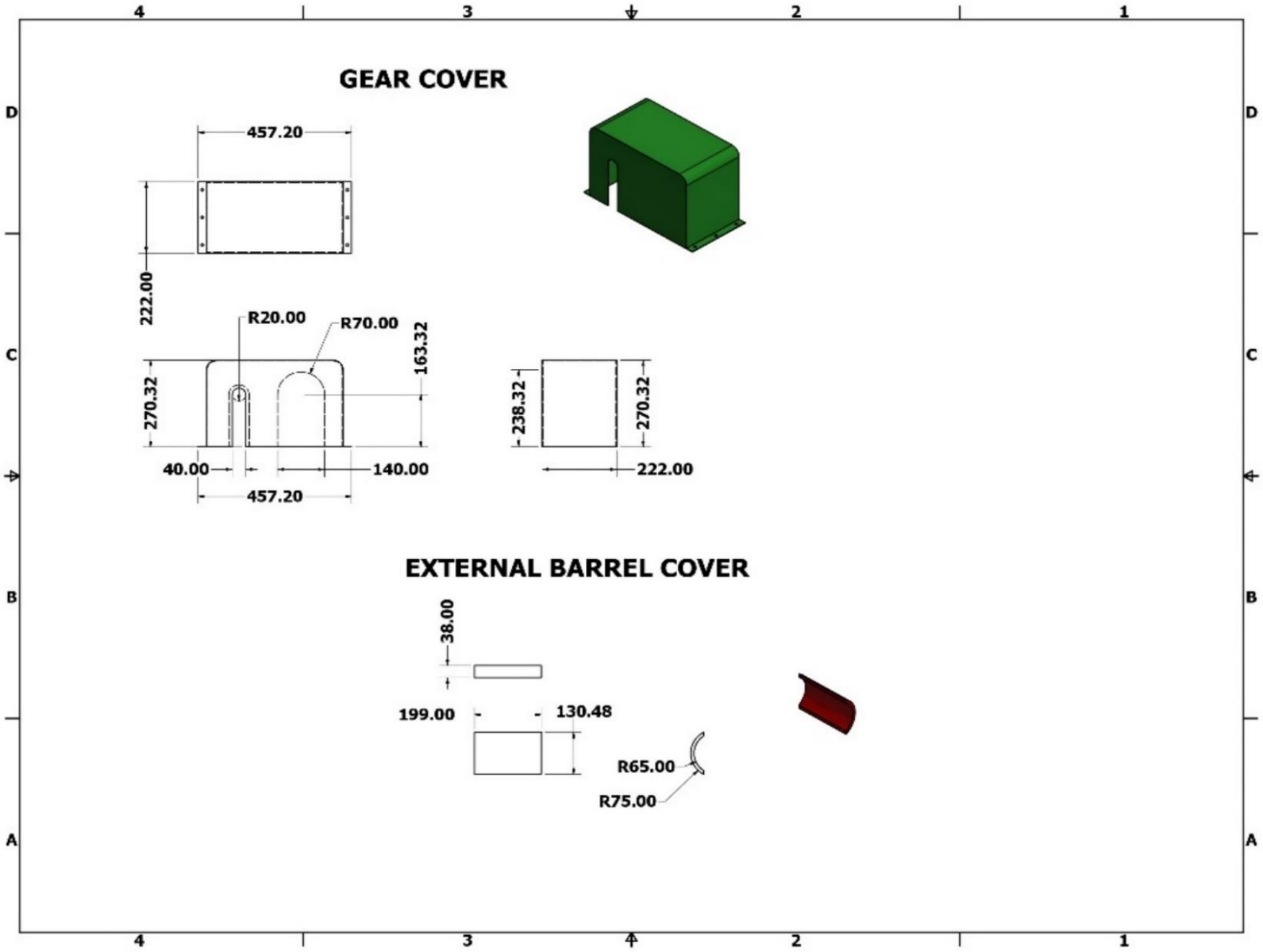



**Fig. 7 Gear cover and barrel cover**

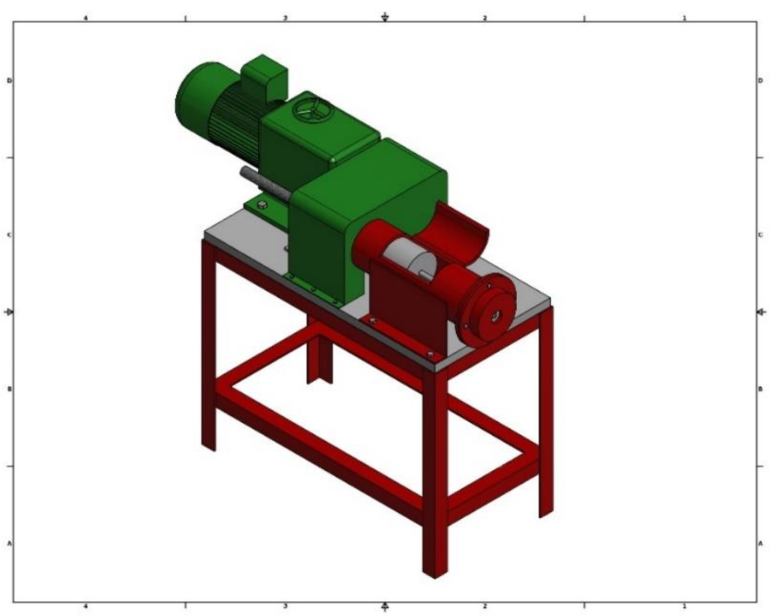


**Fig. 8 Isometric view of the metal extruder**

## 3. Cost Analysis

The cost analysis covered here includes the cost of materials and the cost of production (labor). This is a rough estimate of the Metal Extrusion Machine's cost for this specific manufacturing. As more machines are created, the cost per piece will decrease. Even so, the research provides a ballpark estimate of the machine procurement cost for a basic laboratory experimentation aluminum extrusion method. It will also function as a manual for those who wish to enhance the design work.

**Table 3.1. Bill of engineering materials and evaluation**

| ITEM NO | DESCRIPTION | UNITS | SIZE | QTY | UNIT PRICE (#) | TOTAL COST (#) |
|---|---|---|---|---|---|---|
| 1 | Electric variable gear motor | - | - | 1 | 250,000 | 250,000 |
| 2 | 10mm thick Ø75mm internal Mild Steel Pipe | Feet | 1 Foot | 1 | 25,000 | 25,000 |
| 3 | 10mm thick Ø50mm internal Mild Steel Pipe | Feet | 1 Foot | 1 | 15,000 | 15,000 |
| 4 | Threaded shaft | Φ35mm | | 1 | 7000 | 7000 |
| 5 | Extrusion die (30mm thick) | - | - | 6 | 8000 | 48,000 |
| 6 | 50 x 50mm Angle iron of 3mm thickness | Feet & mm | 18 Feet | 2 | 2,700 | 5,400 |
| 7 | Bolt and nuts | mm | M16 | 10 | 80 | 800 |
| 8 | Cutting disc | - | - | 8 | 2,000 | 16,000 |
| 9 | Grinding disc | - | - | 2 | 900 | 1,800 |
| 10 | Electrode | - | $G_{12}$ | | 2,500 | 5000 |
| 11 | Aluminium billets | - | - | - | - | 25,000 |
| 12 | 30x914x457 plate m/s | mm | - | 1 | 70,000 | 70,000 |
| 13 | Purchase Transportation | - | - | - | - | 21,500 |
| 14 | Delivery Transport | - | - | - | - | 15,000 |
| 15 | Service charges | - | - | - | - | 65,000 |
| 16 | Logistics | - | - | - | - | 10,000 |
| 17 | Design drawing | - | - | - | - | 20,000 |
| 18 | Finishing | - | - | - | - | 15,000 |
| **TOTAL** | | | | | | **615,500** |

## 4. Conclusion

The successful completion of this project will provide extensive knowledge and expertise in the field of manufacturing engineering, specifically in the area of the extrusion process.

Its use in the creation of some shapes will be helpful in the lab for extrusion demonstration and basic experimentation.

## 5. Acknowledgement

The authors acknowledge the support of the Olusegun Obasanjo Centre for Engineering Innovation and the Federal Polytechnic Ado Ekiti for providing a conducive environment and necessary equipment for the work.

## Conflict of Interest

The research is carried out basically on the financial contribution of the Authors, and the processes involved are of their own effort.

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