Design Analysis of a Nail Production Machine

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Abstract: This paper describes the design analysis of a nail making machine which can be used to enhance nail productionfor the cottage industry.
It is also designed to manufacture special shaped nails such as linoleum nails, roofing nails, double cap nails, shaped nails, concrete nails, etc.. with low noise generation and vibration. Galvanized steel is used in the mounting of L-section beams and frame sections due to its composition.
The designed equipment also consists of lubricating system and driving system
With over all dimension of1588mm length x635mm width x 804mm height and a weight of 200kg including shear force and bending moment calculations. The designed machine uses a motor of 1.5kw and with a production output of 351pieces of nails/min. Also the cost of the designed equipment is cheaper when compared to other existing machines in the nailmarket.The design implementation will boost local production of nails for cottage industry and our local economy since the cash inflow from the nail sales is also calculated through the tabulation ofoperational cost and initial investment which was found to yield a payback period of investment dividends within three months of operations,
Keywords: Bendingmoment, Shear force, Nail production machine, cutting die lever, bending stress.

I. Introduction

Nails are pin-shaped. Sharp objects of hard metals or alloy used as fasteners, typically made of steel, often dipped and coated to prevent corrosion in high conditions or improve adhesion. Nails are driven into wood by a hammer, nail gum or an explosive charge and it holds material together by friction in the axial direction, and shear strength but mostly used in the industry ranging from building and construction to carpentry. In Nigeria nail production has not been embraced fully as the nail production machine is not affordable due its cost and high exchange rate in terms of purchase from other foreign countries but with the demand for housing amid rising population; the production of locally made nail production machine cannot be nipped in the bud. The nail making process consist of wire drawing through a series of dies to reduce it to a required diameter. The end of the wire is gripped and punched in a die with the shape of the nail head. It forms a head which is knurled for easy hitting while driving it into the work piece to be fastened. After this, depending on the length of the required nail in inches; the wire is severed with a die that is formed with the shape of the sharp point. The complete nail at this stage goes through a collecting tray and other coating processes to improve hardness and corrosion resistance. The designed nail making machine has the power driving system, wire feeding system, head forming system, nail cutting system, machine fixture system and nail exit system. The total initial investment, cost of operation and cash flow per month for the nail making machine are presented in table 4.1, 4.2 and 4.3 respectively. Also the detailed design of the nail making machine and its parts are presented in the appendix.

II. Materials and Method

Design Considerations
The design of the nail production machine must be in compliance with standard specifications. Machine dimensions are 1588mm length by 635mm width by 804mm length. Machine speed is 1400rpm, Weight is 200kg and a motor of 1.5kw and frame.

Design Components
Components used for the design are frame, slidingroller, cutting die lever, wiregripper, rail guide, nail head punch cover, dieblock, nail feeder support, cam,rollers,connecting rod,bearings,crankshaft,pulleys,flywheel, motor,nail collector, fastener material,etc

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Shear force and bending moment calculations.

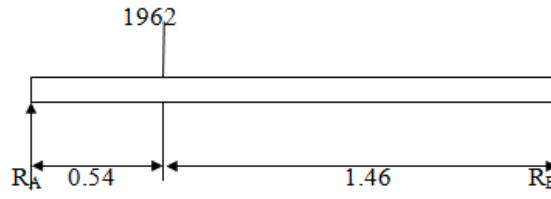$M_{machine}$ = 200kg

M_{load}=200kg $\times$ 9.81 =1962N

1962

Fig 3.1 F.B.D of bottom frame

$\sum F+$

$W = R_A + R_B$.............................. (3.1)

$\sum M = 200 \times 9.81 \times 0.54 - R_B \times 2$

$R_B = \frac{200 \times 9.81 \times 0.54}{2}$ =529.74N

$W=R_A+R_B$

$R_A=W-R_B$......................... (3.2)

$R_A=200 \times 9.81-529.74$

$R_A=1432.26N$

SHEAR FORCE

$SF_A=R_A=1432.26N$

$SF_B=R_A= W$

$SF_B=1432.26-200 \times 9.81$

$SF_B= -529.74N$

$SF_C=R_A-W+R_B$

$SF_C=1432.26-200 \times 9.81+529.74$

$SF_C=0$

BENDING MOMENT

$BM_A=0$

$BM_B=R_A \times 0.54$

$BM_B=1432.26 \times 0.54$

$BM_B=773.42$

$BM_C=R_A \times 2-W \times 1.46$

$BM_C=1432.26 \times 2-200 \times 9.81 \times 1.46$

$BM_C=0$

Nail head punch

The function of this is to hit the wire tip hence making it conform to the required shape of the nail head. Its tip is knurled to form the surface necessary for providing friction while using the nail. It is made of high carbon, heat-treated steel for strength and durability. The heat treatment helps prevent chipping or cracking caused by repeated blows on the cut wire. It needs to be strong and sturdy. It should be hard to prevent cracking and chipping during hitting. It is connected to a support which transfers motion from the crankshaft through the connecting rod.

Figure 3.2 Nail head punch

The auxiliary components which support and guide the nail head punch include; die block, wire gripper, nail guide and the nail head punch cover.

Force required to forge the nail head can be calculated as below:-
Stress, σ is given by $\sigma = \frac{Force}{Area}$
Making force the subject of the formula, $Force = Stress * Area$
Area of wire acted upon by the force of the nail head punch is given by:
$Area = \frac{\pi d^2}{4}$, where d is the diameter of the wire $= 2 \times 2.54 \times 10^{-2}$

$$Area = \frac{\pi(2 \times 2.54 \times 10^{-2})^2}{4} = 2.03 * 10^{-3} m^2$$

The yield strength of mild steel is, $\sigma = 248$ MPa
Therefore, the force P $= 248 * 10^6 * 2.03 * 10^{-3} = 503440$N
The density of the nail head punch material is 7.85g/cm^3
The linear speed of the nail head punch can be calculated as follows: -
The motor speed is 1400 rpm
From $\omega = \frac{2\pi N}{60}$
N = 1400 r.p.m
Then $\omega = \frac{2 * \pi * 1400}{60} = 146.6 \ rad/sec$
From v = ωr
r = 1.5 x 2.54 x 10^{-2} = 0.0381m
The linear speed of the nail head punch is v =146.6x0.0381 = 5.585m/s
The momentum of the nail head punch is given by
Momentum = mv,   where m = mass
v = linear velocity
The mass of the nail head punch can be estimated as follows.
Mass = ρV,   where ρ = density
V = volume
The minimum force required to forge the nail is 503440N as determined above. Putting a safety factor of 2, the actual force imparted on the nail wire is 503440X2 = 1006880N

Cutting die lever
This is to drive the nail cutting dies. They push the cutting dies to the cutting position and are themselves pushed back by the return spring.
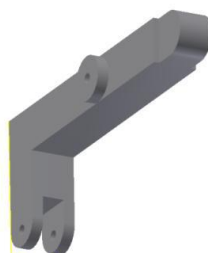
Fig3.3 Cutting die lever

The Stress due to the Bending Moment that the cutting die levers must overcome is calculated as follows:
The bending stress is given by $\sigma_{bending} = \frac{M}{I} * \frac{d}{2}$
Where M=the maximum bending moment, I= the moment of inertia
And d=the thickness of the beam
The moment of inertia I is given by,
$$I = \frac{bd^3}{12} = \frac{2 \times 2.54 \times 10^{-2} \times (2 \times 2.54 \times 10^{-2})^3}{12} = 5.24 \times 10^{-7}$$
Computing the stress due to the bending moment:
The cutting die lever can be modeled as a simply supported beam as illustrated in the diagram below:
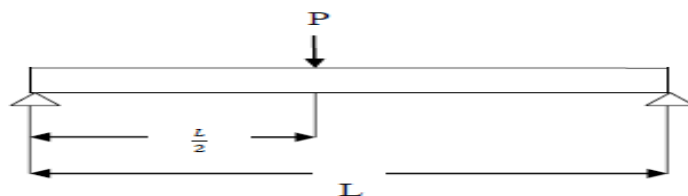
Figure 3.4: Cutting die lever analysis

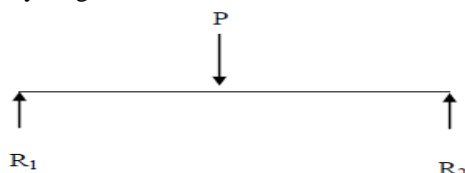This can be represented in a free body diagram as follows

Figure 3.5: Cutting die free body diagram

R1 and R2 are the reactions at the ends due to the central load P
From the balance of clockwise and anti-clockwise moments, R1 and R2 are found to be:
$R_1 = R_2 = 503440N$
The resulting bending moment will be maximum at the center where P acts and is given by:
$\mathbf{M_{max}} = 503440 \times 8 \times 2.54 \times 10^{-2} = 102299 Nm$
The stress due to the maximum bending moment experienced at the centre of the cutting die levers is given by,
$\sigma_{\text{bending max}} = \frac{M}{I} \times \frac{d}{2} = \frac{102299}{5.24 \times 10^{-7}} \times \frac{2 \times 2.54 \times 10^{-2}}{2} = 4959 \times 10^6 \cong 4959\ MPa$
The cutting die levers should be designed to overcome this stress i.e. the levers should have higher bending stress strength so that the nail machine does notfail.

III. Results and Discussions
With the objective of designing a nail making machine suitable for the cottage industry in Nigeria, it is of paramount importance to get a machine which can be fabricated locally. Having made an investment for the nail making machine, the payback period can be computed as below.

The following equation can be used in the calculation:- $\frac{1}{\sum_{p=0}^{n} R_P - D_P} = 1$

Where R_p is the income during the period p;
D_p is the operating cost during the period p;
n is the payback period; and
*I*is the initial investment made in period 0.
Total initial investment (I) is given by:

Table 4.1: Total Initial investment

ITEM	COST
Nail making machine	288,950
Land and buildings	575,900
Vibration isolators	38,300
Wire coil stand	10,600
Weighing scale	12,200
Installation	75,800
TOTAL	**1,001,750**

Operating costs (D_p) can be computed as follows:

Table 4.2: Operation costs

ITEM	COST
Nail wire	244000
Packaging material	31000
Operator	60,700
Labour	62,000
Mechanic	15200
Security	15000
Transport costs	90,900
Electricity	20700
Water	2000
TOTAL	**541,500**

Cash inflow can be calculated as shown below as follows:

Production rating of the nail making machine innovation = 350 nails per minute.
Total number of nails produced per month assuming 7 working hours per day and 20 working days per month = 350x60x7x20 = 2,940,000 nails.
Number of nails in kilograms per month assuming a kg is approximately 481 nails = 6,112.3kg.
Income from sale of nails produced per month assuming NGN. 250 per kilogram = NGN. 1,528,075.
Cash flow is tabulated as follows:

Table 4.3: Cash flow per month

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Cash inflow (Rp)	697,140	1,060,860	1,389,500	1,389,500	1,389,500	1,389,500
Cash outflow (Dp)	515,900	538,650	538,650	538,650	538,650	538,650
Net cash inflow	181,260	523,000	850,890	850,890	850,890	850,890
Cumulative cash flow	181,300	703,510	1,554,400	2,405,270	3,256,150	4,107,050

From the formula above, $I = \sum_{p=0}^{n} R_P - D_P$, when n=1 month, I=337,940

$\sum_{p=0}^{n} R_P - D_P = 59,800 < I \; therefore \; n \neq 1$, when n=2 months, I=337,900

$$\sum_{p=0}^{n} R_P - D_P = 232,100 < I \; therefore \; n \neq 2, when \; n = 3 \; months, I = 337940$$

$$\sum_{p=0}^{n} R_P - D_P = 512,823 > I \; therefore \; n = 3$$

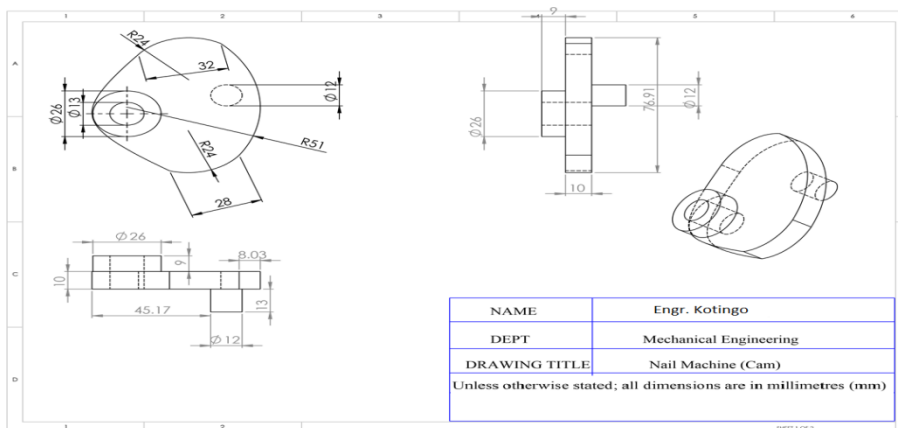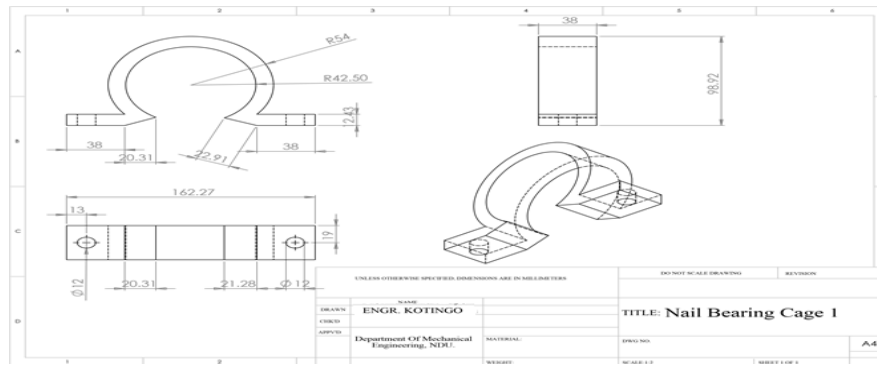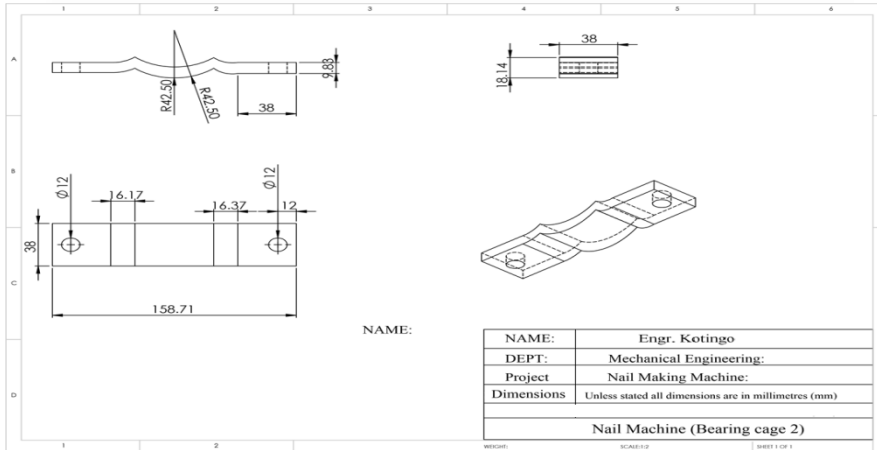This shows that the payback period for the investment will be achieved in the third month of operation.
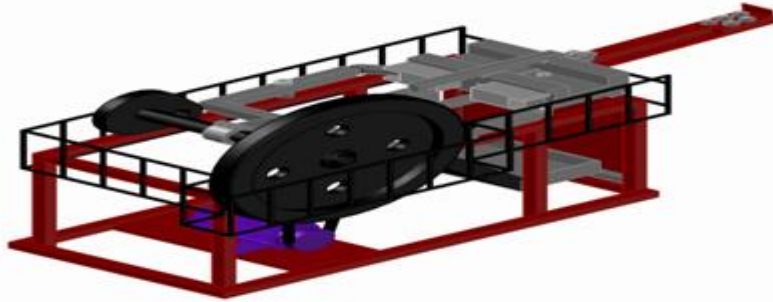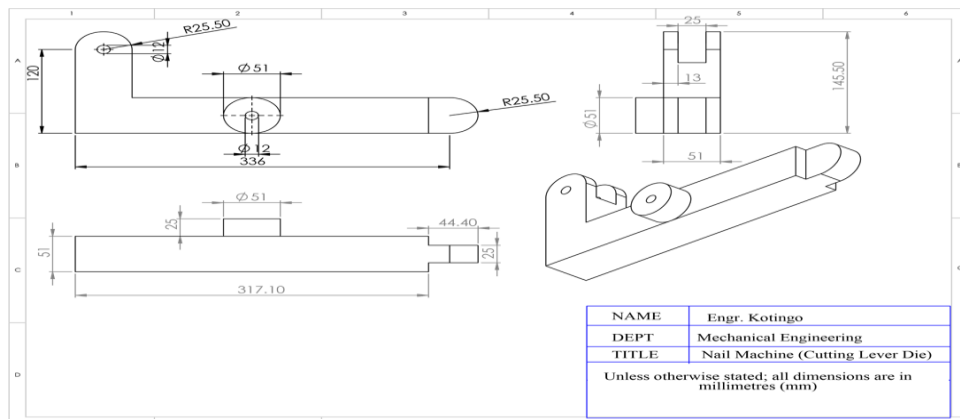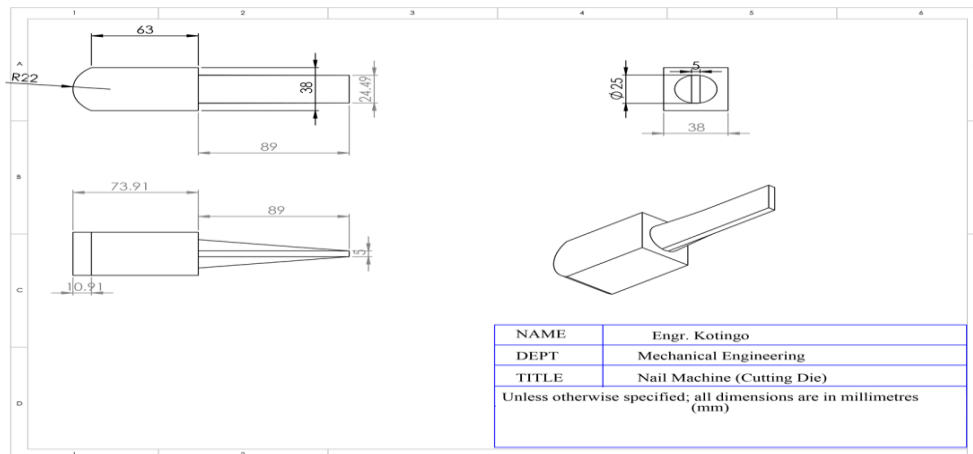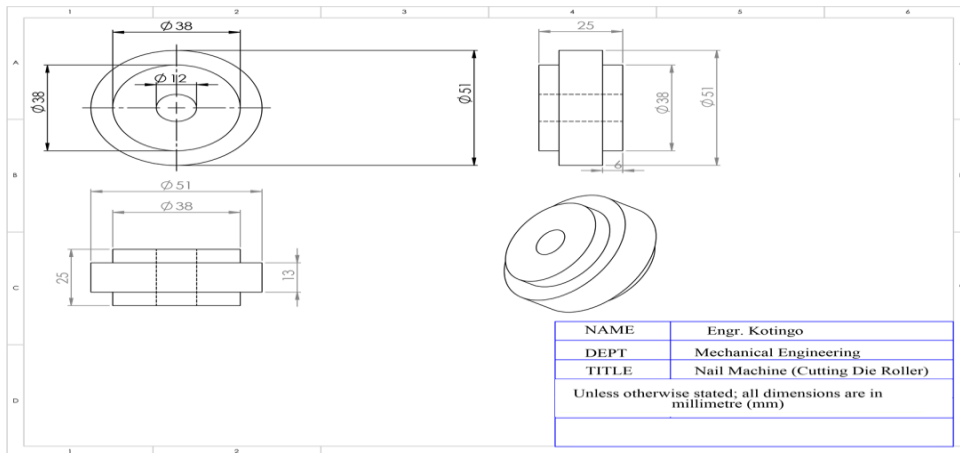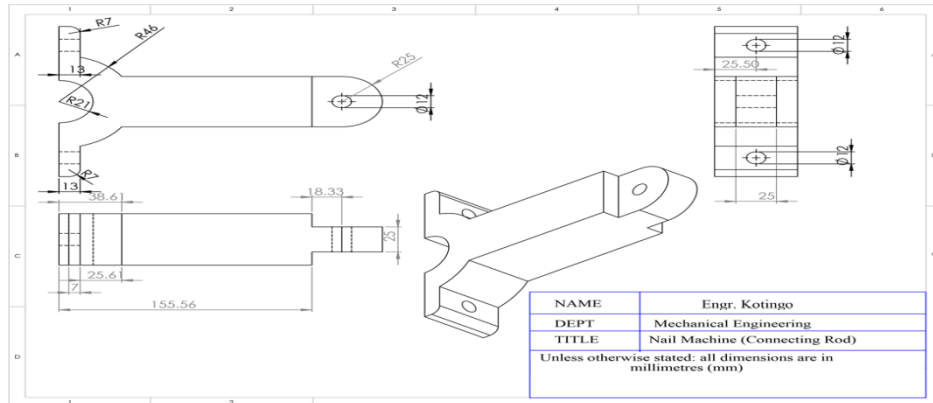
IV. Conclusion

The current design of the nail making machine has overall dimensions of 1588mm length, 635mm width and 804mm height with an output of 351Pcs/min and a weight of 200kg. Designed to yield a payback period of investment within three months of operation. Motion of nail cutting machine is conveyed from the crankshaft to the nail head punch via a connecting rod and the nail head punch in turn drives the rest of the components. Sufficient lubrication makes it air-cooled without a cooling system. The nail making machine requires a trained operator. The cottage industry stands to experience gains as jobs will be created to boost the Nigerian economy and also reduce the overall cost of nails in the market.
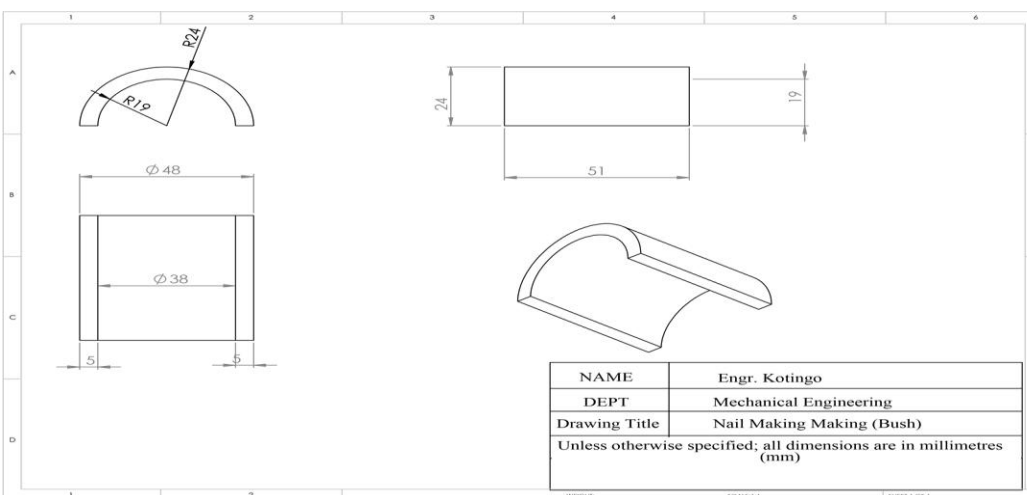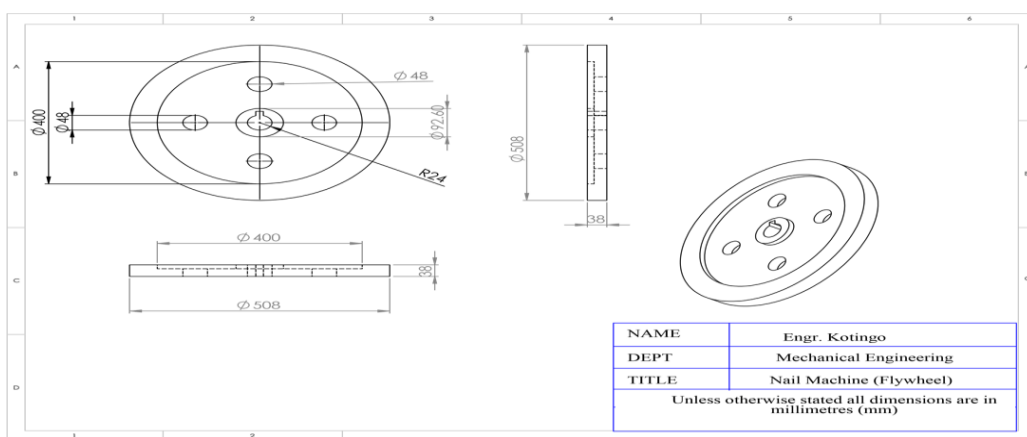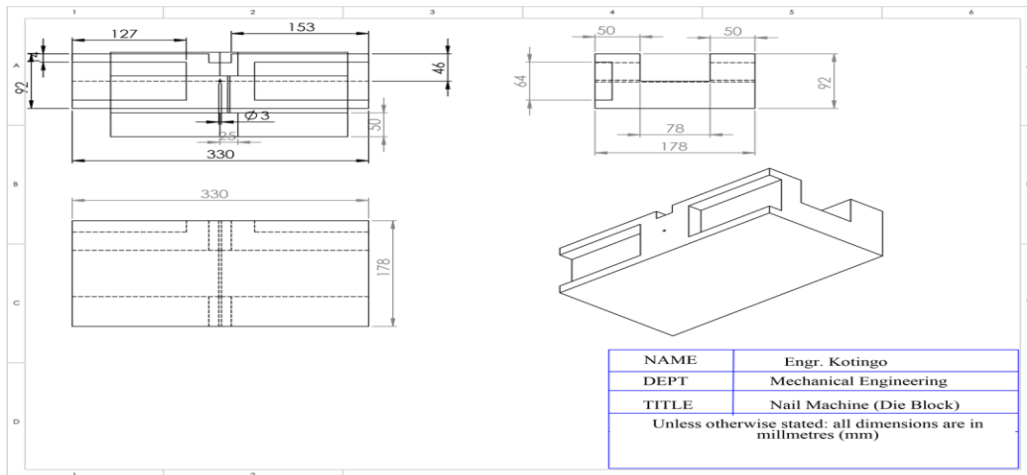
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APPENDIX

NAME	Engr. Kotingo
DEPT	Mechanical Engineering
TITLE	Nail Machine (Connecting Rod)

Unless otherwise stated: all dimensions are in millimetres (mm)

NAME	Engr. Kotingo
DEPT	Mechanical Engineering
TITLE	Nail Machine (Cutting Die Roller)

Unless otherwise stated; all dimensions are in millimetre (mm)

NAME	Engr. Kotingo
DEPT	Mechanical Engineering
TITLE	Nail Machine (Cutting Die)

Unless otherwise specified; all dimensions are in millimetres (mm)

NAME	Engr. Kotingo
DEPT	Mechanical Engineering
TITLE	Nail Machine (Cutting Lever Die)

Unless otherwise stated; all dimensions are in millimetres (mm)

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