Advances in Research

17(1): 1-9, 2018; Article no.AIR.32027
ISSN: 2348-0394, NLM ID: 101666096

Development of a Motorized Sheet Metal Rolling Machine

Olunlade Bankole Adeoye[1], Ogundola Jide[1], O. Odiba[1*] and Obaje Onuche[1]

[1]*National Agency for Science and Engineering Infrastructure, Prototype Engineering Development Institute (PEDI) Ilesa, Nigeria.*

Authors' contributions

The research work was carried out in collaboration between all the authors. Author OBA did the initial design while authors OJ, O. Odiba, O. Onuche did the modifications to the initial design. The manuscript was prepared together by authors OJ, O. Odiba, O. Onuche while author C managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2018/32027
Editor(s):
(1) Dr. Akash Dixit, Department of Mechanical Engineering, Oakland University, USA.
Reviewers:
(1) Yahuza Ibrahim, Abubakar Tafawa Balewa University, Nigeria.
(2) Hillol Joardar, C. V. Raman College of Engineering, India.
(3) Yong X. Gan, Mechanical Engineering Department, Cal Poly Pomona, USA.
(4) Ikubanni, P. Peter, Landmark University, Nigeria.
(5) Azuddin Mamat, University of Malaya, Malaysia.
Complete Peer review History: http://www.sciencedomain.org/review-history/26885

Original Research Article

Received 03 February 2017
Accepted 31 March 2018
Published 27 October 2018

ABSTRACT

This paper presents the design result for the development of a motorized sheet metal rolling machine. The aim of the research is to design a rolling machine that can roll metal sheets of up to 3 mm thickness. Sheet metal rolling is a process of converting a sheet of metal into a complete hollow cylinder. The machine consists of three rollers; slip roll, pinch roll and a back roll. The rollers are made of mild steel shaft 1500 mm long and 90 mm in diameter. The whole system is mounted on a metal frame made from mild steel plate also. The sheet metal is fed continuously between the upper and lower roller. The upper roller is an adjustable roller which slides in an upward and downward direction normal to the roller. The bending stress using analytical method is 545.45 Nmm^{-2} with deflection of 909.46 mm. A load of 1753.25 N is required to bend a mild steel sheet metal of 3 mm.

**Corresponding author: E-mail: oodiba@gmail.com;*

Keywords: Slip roll; pinch roll; back roll; mild steel; bending stress; deflection.

1. INTRODUCTION

Sheet metal fabrication plays an important role in the metal manufacturing world. Sheet metal is used in the production of materials ranging from tools, to hinges, automobile, boilers, pressure vessels, road tankers, storage tanks, silos, tubes and pipelines, pumps etc. Sheet metal fabrication ranges from deep drawing, stamping forming and hydro-forming to high energy-rate forming to create desired shapes [1,2]. Fascinating and elegant shapes may be folded from a single plane sheet of material without stretching, tearing or cutting. Shape rolling of sheet metal is the bending continually of the piece along a linear axis. This causes alteration of the original form of the sheet as it passes through a pathway of series of rollers. The present invention relates to plate bending machines of the type which operates with rolls. Such machines involve certain well – known difficulties in respect of bending plate into conical shape. In a plate bending machine, a frame, two parallel cylinder rolls rotatable mounted in side frame and adapted to be driven in the side direction, a third cylindrical roll situated substantially in the median plane between the two first – mentioned rolls and freely rotates, mounted in side frame in adjustable bearings permitting side third roll to be inclined relatively to the two first – mentioned rolls for producing conical bends, a tubular support mounted in fixed relation to said frame adjacent one end of said third roll and substantially perpendicularly to its axis, and a pin slid –ably mounted in said tubular support and movable into engagement with the periphery of said third roll to serve as an abutment for the edge of a plate when producing a conical bend [3]. The factor on which the sheet metal rolling machine is designed includes maximum thickness of sheet to be used, minimum and maximum diameter of hollow sheet cylinder which the company wants from rolling machine [4].

Rolling process can be used to deform a sheet or plate into hollow shapes of constant (cylindrical or elliptical) or varying cross sections like cone frustum. Cylindrical and conical sheets are the basic compound used for the various engineering applications. Several shapes can be made or folded from a single sheet of plane material without having to neither stretch, tear nor cut if folding is incorporated into the design [5,6]. The process can be performed using many materials such as carbon and alloy steels, aluminum alloys and titanium alloys. Rolling machines with both three and four rolls are indispensable to the production of cylinders with various curvatures. The rolling process is usually performed by a three roll bending machine. The entire process of the roll bending may be divided into three steps [7]:

1. Positioning of blank sheet or plate
2. Lowering of the centre roller
3. Feeding of the plate.

Shape rolling of sheet metals involves a continuous folding along a linear axis of a sheet and this alters the original form of the material as it is passed through the folding rollers. But in forming or rolling the sheet into the various shapes, there is a need for them to satisfy tight tolerances compared to the desired geometry [8].

In Nigeria, local artisans and craftsmen are the major producers of simple farm tools needed on the farm while the small and medium scale welders are known to be the highest group with the most production potential in the production of farm tools and equipment for the farm [9], so there is a need to develop capacity in the production of machines and equipment needed for these group of people in the country to carry out their functions. The need for local capacity in local production and improved work tools and machines for the local artisans and welders can never be overemphasized. Bello [10] did a critical appraisal of locally available sheet rolling machines which indicated the necessity of improving on the ergonomic design, system complexity and cost.

2. MACHINE DESCRIPTION

The major design component consists of three rollers supported on bearing blocks mounted on a frame, the upper roller provides the required driving force and the front end roller bends the metal according to the set radius of bend.

2.1 Design Consideration

To achieve bending, the work material must be subject to two major forces; frictional force which causes a no slip action when the metal and roller come in contact and a bending force acting against the forward speed and the torque applied to move the material.

At least, two rollers are involved in flat rolling depending on the thickness and the properties of the material while three or multiple roller system is required in shape rolling.

A work material under bending load is subjected to some forms of residual stress and deformation as it bends. The outer bend radius of the material undergoes tensile plastic deformation while the material at the inner bend radius undergoes compressive plastic deformation. The width along the bend radius will reduce in length based on Poisson's ratio, and if the end radius is too small, the plastic deformation at the outside of the bend will result in a fracture.

2.2 Machine design and analysis

The calculation of load and stress acting on the sheet [6];

For mild steel sheet

t = 3 mm
b = 1250 mm
L = 2450 mm

$$W = {}^{4EI}/_{RL} \quad (1)$$

where; W is the Load, E is the Modulus of elasticity of compression, I is the Moment of inertia of sheet, R is the Radius of curvature, L is the Length of the sheet and E is taken as 210 x 10^3 MPa or N.mm^2

$$\mathrm{I} = {}^{\mathrm{bh}^3}/_{12} \quad (2)$$

Where; h is also the thickness of the sheet.
Using a radius of curvature R of 550, we have;
W = 1753.5 N

Bending stress

$$\sigma = {}^{MY}/_{I} \quad (3)$$

Where; M is the Bending moment and Y the Perpendicular distance of the neutral axis.

σ = 584.41 N/mm^2

Deflection of sheet at mid span to obtain required radius of curvature

$$\delta = {}^{wl^3}/_{48EI} \quad (4)$$

$$\delta = 909 \cdot 46\, mm$$

2.3 Shaft Diameter Subjected to Twisting and Bending Moment

With a load (W) of 1753.25 N and considering a factor of safety (FoS) of 2, we have the working load as [10];

$$Working\ load = load\ \times FoS \quad (5)$$
$$Working\ load = 3506.49\ N$$

Now, considering a shaft of length 1.5 m,

$$Bending\ moment\ (M) = F \times d\ (Nm) \quad (6)$$

Bending moment (M) = 5259.74Nm

$$Twisting\ moment\ (T) = F \cdot r\ (Nm) \quad (7)$$

$where\ r = {}^{d}/_{2}$ (Shaft radius), F is the force and d the perpendicular distance

Twisting moment (T) = 1753.23d

$$T_e = \sqrt{M^2 + T^2}\ = {}^{\pi}/_{16} \cdot \tau \cdot d^3 \quad (8)$$

The shaft is assumed to be made of mild steel with an allowable stress of 42 N

$$\sqrt{M^2 + T^2} = {}^{\pi}/_{16} \cdot \tau \cdot d^3$$

Resolving the equation using standardized polynomial function and inserting values, we get

$$d = 86.05\ mm$$

The diameter, d of the shaft is assumed to be 90 mm from the above result rounding up to the next whole number.

2.4 The shape rolling mechanism

From Fig. 1, A is the slip roll, B is the back roll and while C is the pinch roll. T is the torque (Nm), W (N) is the load, t (mm) is the thickness of the material and S is the slip roll direction.

2.4.1 The pinion drive motor parameters

Assuming a speed of 60 rpm and centre –to – centre of wheel and pinion gears to be 100mm (0.1 m)

The required pitch line velocity from the rolling shaft is [9];

$$V_p = {}^{\pi DN}/_{60} \quad (9)$$

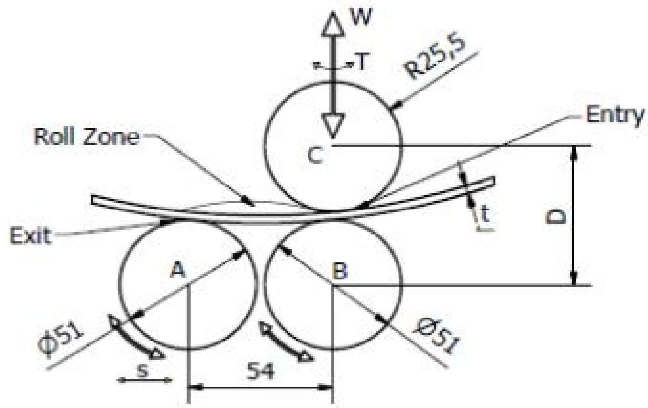


Fig.1. Pinch roll arrangement

And in putting values we get

V_p = 0·2827 m/s

Where N is the speed of the motor

The required power for the rolling shaft is obtained from the relation

$$P = F \times V_p \tag{10}$$

And since the pinion gear drives the three rollers, the required power by the pinion then becomes

$$P = 3 \cdot F \times V_p$$

$$P = 1.49\ kW$$

Using a factor of safety of 1.2, effective power (E_p) is given as

$$E_p = 1.2 \times P \tag{11}$$

$$E_p = 1.78\ kW$$

And resolving this in terms of horse power (Hp)

$$Hp = {}^{E_p}\!/_{0.746} \tag{12}$$

$$= 2 \cdot 39\ Hp$$

Hence, from the calculated value, we select a preferred motor of 2·5 Hp.

$$N_p = 60\ rpm$$

$$\varphi = 20°\ (pressure\ angle\ of\ the\ gear)$$

$$Gear\ ratio = 2:1$$

$$G = {}^{T_w}\!/_{T_p} \tag{13}$$

$$ {}^{T_w}\!/_{T_p} = {}^{D_w}\!/_{D_p} = 2 \tag{14}$$

Where, T_w is the number of teeth on the wheel, T_p is the number of teeth on the pinion, D_w is the wheel diameter and, D_p is the diameter of the pinion.

$$L = 0.1\ m$$
$$P = 1.78\ kW$$

The minimum number of teeth on the pinion in order to avoid interference is given as;

$$T_p = \frac{2 \cdot A_W}{G\left[\sqrt{1+{}^1\!/_G({}^1\!/_G+2)Sin^2\varphi}-1\right]} \tag{15}$$

Where: A_w = Fraction by which the standard addendum for the wheel should be multiplied

G = Gear ratio or velocity ratio given as

$$ {}^{T_G}\!/_{T_p} = {}^{D_G}\!/_{D_p} \tag{16}$$

φ = Pressure angle or angle of obliquity.

The nearest standard module if no interference is to occur is given as [9];

$$T_p = \frac{2}{G\left[\sqrt{1+{}^1\!/_G({}^1\!/_G+2)Sin^2\varphi}\ -1\right]} \tag{17}$$

Feeding values into the above relation, we got the T_P to be 14.

Total number of teeth on gear (T_G) is given as the product of G and T_P which gives us a value of 28 teeth on the gears.

$$L = {}^{D_G}/_2 + {}^{D_p}/_2 = {}^{2D_p}/_2 + {}^{D_p}/_2 = {}^{3D_p}/_2 = 1.5D_p \quad (18)$$

Where: D_P is the pitch circle diameter of the pinion

$L = 1.5\ D_p$ and
$D_p = 0.066$

We also know that

$D_p = M \cdot T_p$

Where; M is the required number of module and T_p is the number of teeth on the pinion

$$M = {}^{D_p}/_{T_p} = 4.714 \quad (20)$$

We pick 4 as the number of required modules (i.e. M = 4) and this because rounding to the nearest whole number value will reduce the number of teeth on both the pinion and gear which will have an effect on the rolling process.

2.4.2 Number of teeth on each wheel [11]

We know that the number of teeth on the pinion T_p is given as

$$T_p = {}^{D_p}/_M = 16 \quad (21)$$

And the number of teeth on the gear T_G is given as

$$T_G = G \times T_p = 32 \quad (22)$$

2.4.3 The necessary width of the pinion [11]

The torque, T, acting on the pinion is;

$$T = {}^{P \times 60}/_{2\pi N_p} \quad (23)$$

$$T = 284\ Nm$$

the tangential load, W_T is given as

$$W_T = {}^{T}/_{{}^{D_p}/_2} = 8.6\ kN \quad (24)$$

and the normal load, W_N on the tooth is given as

$$W_N = {}^{W_T}/_{Cos\ \varphi} = 9158.33\ N \quad (25)$$

since the normal pressure between the teeth is 175 Nmm^{-1}, therefore, the necessary width of the pinion is;

$$b = {}^{W_N}/_{175} = 52.33\ mm \quad (26)$$

2.4.4 The load on the bearings of the wheels [11]

We know that the radial load on the bearings W_R due to the power transmitted is given by the relation

$$W_R = W_N \cdot Sin\ \varphi = 3.13\ kN \quad (27)$$

The tangential velocity V, is

$$V = {}^{\pi D_e N_e}/_{60} = 3.82\ m/s \quad (28)$$

The nominal power is

$$Nominal\ power\ = \frac{estimated\ power}{design\ factor} \quad (29)$$

With a design factor of 0.95, we will be able to entertain losses of power such as friction in bearing and air resistance. This nominal power can be calculated from the *relation* above and gives our nominal power as 1.57 kW.

2.4.5 Tension in the belt

The tension T_1 acting on the tight side of the belt and tension T_2 acting on the slack side of the belt can be calculated using

$$T_1 - T_2 = {}^{60 \cdot W}/_{\pi D_e N_e} \quad (30)$$

$$T_1 - T_2 = 409.43\ N$$

Where: D_e is the diameter of the pulley on the motor, N_e is the speed of the motor and Fx is the service factor and equals 1.2 (medium duty machine)

$$T_1 + T_2 = {}^{60 \cdot W}/_{\pi D_e N_e} \times Fx \quad (31)$$

$$T_1 + T_2 = 491.316$$

Resolving the above relations gives; T_1 = 450.38 N and T_2 = 40.95 N.

2.5 Mechanical Power

2.5.1 Power transmitted, P_T (power per belt)

$$P_T = (T_1 - T_2)V \tag{32}$$

$$P_T = 1564.84\ W$$

2.5.2 Design power

$$Design\ power = Norminal\ power \times Service\ factor \tag{33}$$

$$Design\ power = 1878.2\ W$$

2.5.3 Required number of belt

$$Number\ of\ belts\ required = \frac{Designed\ power}{Power\ per\ belt} = 1.28 \tag{34}$$

So, the number of belts required is approximately 2.

2.5.4 Centre distance [12]

The centre distance can be calculated using the formulae below

$$C = 3R_1 + R_2 \tag{35}$$

Where, R_1 is the radius of the smaller pulley and R_2 is the radius of the larger pulley and C from our design has a value of 0.33 m.

2.5.5 Belt length [13]

With diameter of the larger pulley D_s = 0.5 m, D_e = 0.05 m and C = 0.33 m, the length, L can be calculated from

$$L = 2C + \pi(R_1 + R_2) + {(R_2 - R_1)^2}/{C} \tag{36}$$

$$L = 1.67\ m$$

2.5.6 Length of straight section of a belt

On the small pulley, the length of a straight section of belt can be calculated using the formulae

$$a = (C^2 - (R_2 - R_1)^2)^{1/2} \tag{37}$$

$$a = 0.2345\ m$$

2.6 Working Principle of the Rolling Mechanism

The sheet metal to be rolled is shaped at the edge by hammering in other to start the operation easily and to avoid flats at the beginning and end of the rolled form. In rolling cylindrical shapes, a gradual curve is formed rather than sharp bends. The sheet metal is introduced between the top and the bottom rolls, the gap between the top and bottom rolls are adjusted to the required diameter by regulating the screw rods.

The rollers are arranged with two sets of rollers below and one above. The top roller provides the bending force, the back bottom roller provides the required driving force while the front end roller performs the bending operation according to the set radius of bend. An adjuster on each block assembly ensure loading of workpiece and adjustment to the required radius of bend. Bores on each bearing blocks provide an adjustment for the roller gap variability. The top roller provides the bearing load (bending force) and also compliments the driving roller when working on thick materials. The lower back roller provides the necessary driving force while the slip roller does the bending and material delivery.

3. RESULTS AND DISCUSSION

In this design, a sheet of thickness 3 mm was used with a standard metal sheet of dimension 1250 x 2450 mm. The power is gained by the rollers through the gear drive system and this load is applied on the metal sheet. The principle being a metal sheet passing between the upper and the lower roller is rolled to the curvature; this process is sustained until the desired curvature is achieved.

A load (W) of 1753.25 N was used in this design, which yielded a bending stress (σ) of 584.41 Nmm-2 and a deflection of sheet at mid span to obtain the required radius of curvature (δ) of 909.49 mm. Considering our W with a factor of safety (FoS) of 2, our working load came to 3506.49 N.

A shaft length of 1.5 m is used and the bending moment (M) is 5259.74 Nm. The shaft is assumed to be made of mild steel with an allowable stress of 42 N and so, the shaft diameter is gotten to be 90 mm.

The tension (T_1) acting on the taut side of the belt is 450.38 N while T_2, the tension acting on the slack side of the belt is 40.95 N. The power transmitted (P_T) per belt is 1564.84 N with a design power of 1878.2 N and from the design calculation, a total of 2 belts will be required.

4. CONCLUSION

The sheet metal rolling machine has been designed, the force required for bending was determined analytically. Compared to the manually operated sheet rolling machine in terms of productivity and efficiency, power operated sheet rolling machine is more efficient. The time involved in sheet rolling is less. From the design, it is determined that a load of 1753.25 N is required to bend a sheet metal of 3mm thickness with a bending stress of 584.41 Nmm^{-2}. The deflection of sheet at mid span to obtain the required radius of curvature is 909.46 mm. The final circular product surface finish is largely determined by the skill of the operators. This research work will help in building local capacity.

COMPETING INTERESTS

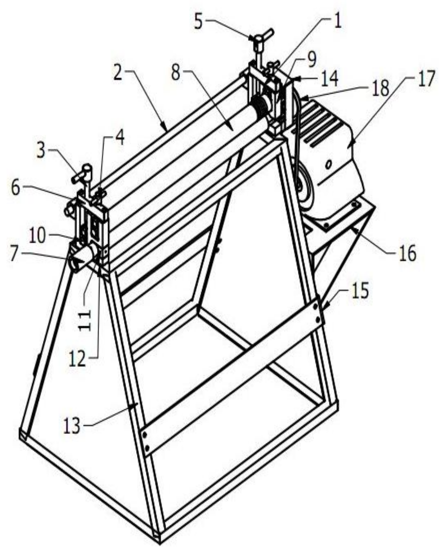
Authors have declared that no competing interests exist.

REFERENCES

1. Cloutier M. Sheet metal fabrication. ME 353 Instructor: Jesse Adams, 2000. Smf.pdf. Modified May 15th. 2010;1-18.
2. Bello RS. Development and evaluation of metal rolling machine for small-scale manufacturers. Eng. Int: CIGR Journal. 2013;15(3):80-85.
3. Kulkarni A, Pawar M, Yadav P, Patil A, Jagtag C. Sheet metal bending machine. International Journal of Innovations in Engineering Research and Technology. 2015;2(3):1-2.
4. Vishwakarma P, Bankar V. Design and analysis of M.S roller in sheet metal rolling machine. International Journal of Engineering Research and General Science. 2016;4(2). ISSN: 2091-2730
5. Martin Kilian, Simon Flory, Zhonggui Chen, Niloy J. Mitra, Alla Sheffer, Helmut Pottmann. Curved Folding. ACM transactions on graphics (TOG). 2008;27: 3.
6. Wertheim M. Cones, curves, shells, towers: He made paper jump to life. The New York times; 2004.
7. Padghan NP, Deshpande DP, Sakhale CN. Force analysis of metal sheet in bending operation on sheet bending machine. International Journal of Engineering Research and Technology (IJERT). 2015;4(01):267-270. ISSN 2278-0181
8. Behrouzi M, Shakeri B, Mollaei Dariani. Inverse analysis of springback in sheet metal forming by finite element method. EngOpt 2008 – international conference on engineering optimization. Rio de Janeiro, Brazil; 2008.
9. Yilep TP. Characteristics of major Agricultural tools manufacturing artisans in northern Nigeria. Journal of Agricultural Engineering and Technology. 2012;7:45-52.
10. Bello RS. Workshop technology and practice. South Carolina, US: Createspace; 2012.
11. Khurmi RS, Gupta JK. Machine design. 1st Multicolored ed. Eurasia Publishing House (PVT.) Ltd; 2005. ISBN: 81-219-2537-1.
12. Aaron D, Deutschman Walter J. Michels Charles R. Wilson. Machine design theory and practice. 1st ed. Macmillan; 1975.
13. Virgil M. Faires. Design of machine elements. 3rd ed. Macmillan; 1965.

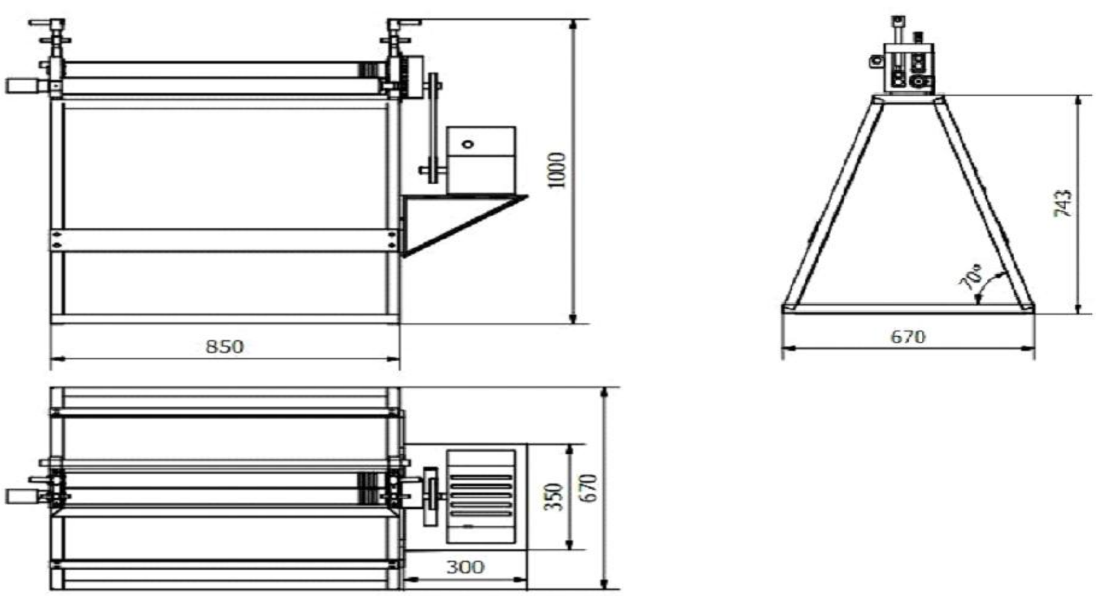
APPENDIX

Appendix 1: Detailed component drawing of the rolling machine

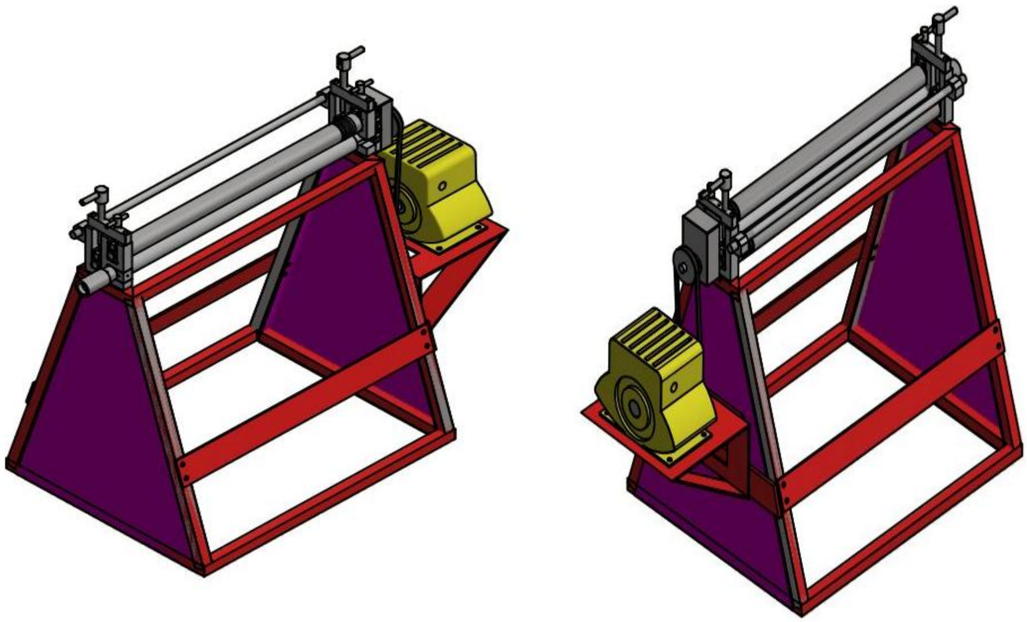


PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	BEARING BLOCK HOLDER 2	Mild steel block
2	1	Tie Rod	Mild steel rod
3	1	Adjust Screw Holder Ass Left1	Mild steel
4	1	Adjust Screw Holder Ass Left2	Mild steel
5	1	Adjusting screw holder right	Mild steel
6	1	Adjusting screw holder leftt	Mild steel
7	1	SLIP ROLL ASS	Mild steel shaft
8	1	PINCH ROLL	Mild steel shaft
9	1	BEARING BLOCK HOLDER 1	Mild steel block
10	1	BACK ROLL	Mild steel shaft
11	1	SWING BLOCK	Mild steel block
12	1	Base plate	Mild steel plate
13	1	Stand Ass.	Mild steel plate
14	1	GEAR COVER	Mild steel plate
15	1	side braze	Mild steel plate
16	1	motor seat	Mild steel bar
17	1	Motor	
18	1	V-Belt	

Appendix 2: 2 Dimensional drawing of the rolling machine



Appendix 3: 3 Dimensional drawing of the rolling machine



Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/26885