DEVELOPMENT OF A HIGH SPEED STAPLER PIN MANUFACTURING MACHINE

Sisira Priyantha Palagama

128813D

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Department of Electrical Engineering

University of Moratuwa

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Sisira Priyantha Palagama

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Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Industrial Automation

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Declaration

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Dr.A.G.B.P. Jayasekara

Signature: …………………….. Date: ……………….

Prof. N. Wickramarachchi

Abstract

Converting any kind of production system from discrete process to continuous process saves substantial time in production process enabling reduction of power consumption, reduction of space, utilized to increasing production capacity. That can be applied for development of existing manufacturing processes; here used for steel wire production processes.

Stapler pin was invented in late 1877’sfor binding of materials, popular due to simple form of use in the industry and now it has become an essential commodity in the market. In past decades, stapler pin manufacturing process have not been developed and used conventional manufacturing process all over the world which have limitations due to high energy consumption and high space requirement; therefore setting up such factories leads to high capital investments.

The objective of this study is to Development of High Speed Stapler Pin Manufacturing Machine to introduce to the local market and cope up the target. Total requirement of the stapler pins of different sizes for office uses and industrial uses are imported and distribute by various suppliers in Sri Lanka. No one can think of manufacturing stapler pins in Sri Lanka due to high capital investment and high operation cost and lack of own technology. Now many suppliers import base product and packet locally and distribute through super markets and retail markets. Stapler pin manufacturing process involves very simple mechanical functions of wire forming, feeding, cutting, bending, moving and gluing. Conventional stapler pin manufacturing is done by using round galvanized steel wire of different wire gauge from 18 to 26 based on the application.

Single or multiple wire which feed through set of rollers to straitening and forming it’s flat shape then gluing it by using gum. Then heated to dry and make wire flat strip. After it cut and bent to correct size to produce stapler pin by using mechanical actuator by aid of square shaped die and mold which moves up and down.

In this design mechanisms have completely changed to make its square shape by using rotary bending mechanism. Steel wire feed through freely rotating rollers by using rotational square bar then it cut by using rotating cutting tool while moving stapler pin forward. Cutting tool moving up and down enabling to produce two stapler pins at a time. In this Design of high speed stapler pin manufacturing machine addresses to save energy, time and space leads to convert factory manufacturing environment to domestic manufacturing environment. Use of time, space and energy saving strategy is most economical and applicable in modern industry accordingly manufacture of stapler pins can promote / emerge into the domestic industry and this product enabling to country economic development.

Two types of conceptual machines have been developed and relevant prototype models have been tested. Only one type of the conceptual design has been successful. Further improvements and developments have been incorporated to the successful model in order to produce stapler pins with correct shape and dimensions. Power requirements have been calculated by using theoretical approach by using formula and also experimental power requirement has also been calculated by experimental approach and observed that both power requirements are almost the same. Therefore the formulated equations can be used for further developments in the proposed process. Machine will be used in domestic manufacturing environment; hence certain safety precautions were concerned when selecting the power source, drive motor, heater and control system.

Acknowledgement

I wish to express my sincere gratitude to my supervisors, Prof. N. Wickramarachchi, Head of Department of Electrical Engineering and Dr.A.G.B.P. Jayasekara, Course Coordinator ,Senior Lecturer, Faculty of Engineering , University of Moratuwa for their continuous supervision, guidance and knowledge enabling me to successfully complete this report.

Furthermore, I would like express my heartiest thanks to non-academic staff of Electrical Engineering Department for their kind support.

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1.0 Introduction

Stapler pin was invented in late 1877's [1], was popular due to its simple form of use in the industry and now a days it has become an essential commodity in the market. It is made up of galvanized steel wire in different gauges, different sizes and shapes. Stapler pins are widely used in various industries for binding material in different applications. It is even used in the operation theaters for stitching injured human bodies. Due to high demand of stapler pin in various industries, manufactures have been interested in producing it in mass scale. Accordingly, stapler pin manufacturing process and related machines have been developed worldwide.

1.1 Application

Nowadays stapler pins have become a very useful commodity in many kinds of applications in the industries and in office use. Mainly it is used in office environments for fastening/collecting and binding papers. Also it is used in other day-to-day requirements and home made products such as preparing decorations, ornaments etc. Also it has become an essential item in the wood industry as well as in packaging industry.

1.1.1 Office Application

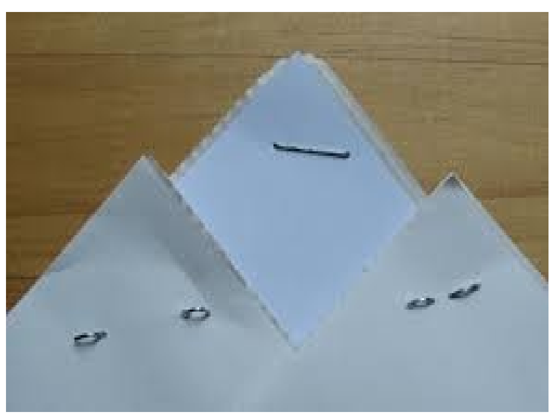


Figure 1-1: Office Use

Stapler pins commonly used for fastening more than one to many papers when handling letters. Binding papers when preparing books and leaflets shows in above Figure 1-1. In day to day applications in office environment it use for fixing papers on notice boards.

1.1.2 Decorations

Figure 1-2: Decorations

Staple pin is essential item used for binding or fixing material in decorations mostly used for wedding decorations and religious ceremonies, cultural activities in Sri Lankan contest viz “Poruwa”, “Thorana” etc.

1.1.3 Ornamental Items

Figure 1-3: Ornamentals

Stapler pin is a very much useful component for domestic manufacturing processes. Figure 1-3 shows it is being used for domestic bag manufacturing. Also used in many other hand made ornamentals

1.1.4 Wood Industry

Figure 1-4: Wood Industry

Another important area of using stapler pin is wood and carpentry works among many other applications. Figure 1-4 illustrate typical application of fastening wooden blocks. Also used for newly sewed wooden purling, girders to prevent expansion as well as distraught at the edges of it.

1.1.5 Upholstering Industry

Figure 1-5: Upholstering Work

Another different use of staple pin shows in Figure 1-5 .Upholstering chairs , settees and many other furniture manufacturing processes use various types and various sizes of stapler pins

1.1.6 Medical Application

Figure 1-6: Medical Applications

Nowadays stapler pin is used in operation theaters of which the material is a special stainless steel withstands for corrosion. Surgeons are using special type of stapler machines for this purpose.

1.2 Different Types, Shapes and Sizes

Different types, shapes and sizes of stapler pins are available in the markets which are widely used in various industries based on its applications as described in previous section.

1.2.1 Different Types

Figure 1-7: Different Shapes

Flat type pins are used in continuous photo copying in mass scale printouts binding. “U” shape pins are used in wood industry and in carpentry works. Air or electrically assisted machines are the equipment use for this application

1.2.2 Different Sizes

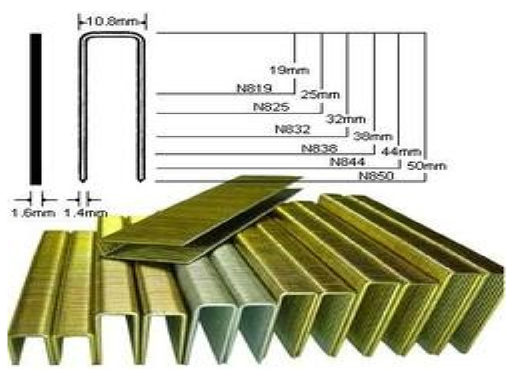


Figure 1-8 : Different Sizes

Different sizes are available depending on the requirements of the industries. Height and width of the pin vary according to the application.

2.0 Conventional Manufacturing Process

Conventional stapler pin manufacturing is done by using round galvanized steel wire of different gauges;18 to 26 based on the applications. Single or multiple round wires are fed through set of rollers to straightening and forming it's flat shape. Then gluing it by using adhesive and heated in order to dry it. Accordingly flat wire strips are produced to feed to the punching machine with a mechanical actuator and a square shaped die which moves up and down to cut and bend those wire strips to its correct size to produce stapler pins.

Mass scale production of stapler pins is achieved either by using multiple no of wires in conventional production process or using multiple no of machines.

Basic mechanism of the Conventional Manufacturing Process can be illustrated in following Figure 2-1.

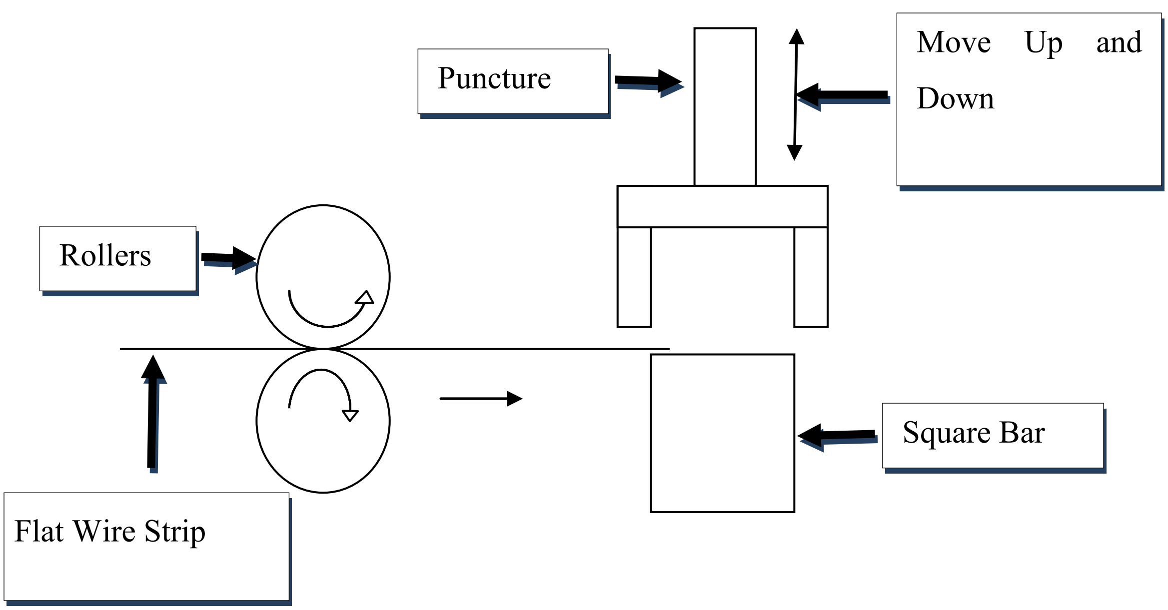


Figure 2-1: Conventional Mechanism of Producing Stapler Pin

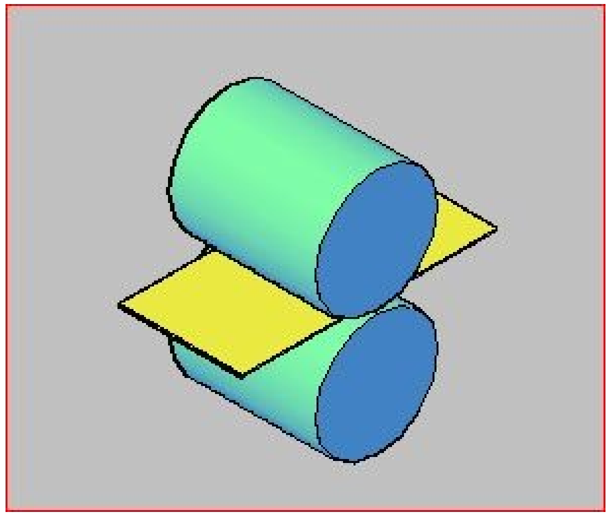


Figure 2-2: Rollers

Drive Rollers used for wire straightening and form flat shape from round shape same as in conventional process. But the actual manufacturing process use more than one set of rollers in order to maintain smooth, continuous operation and to minimize tendency to tensile failure of the individual wires passing through the rollers.

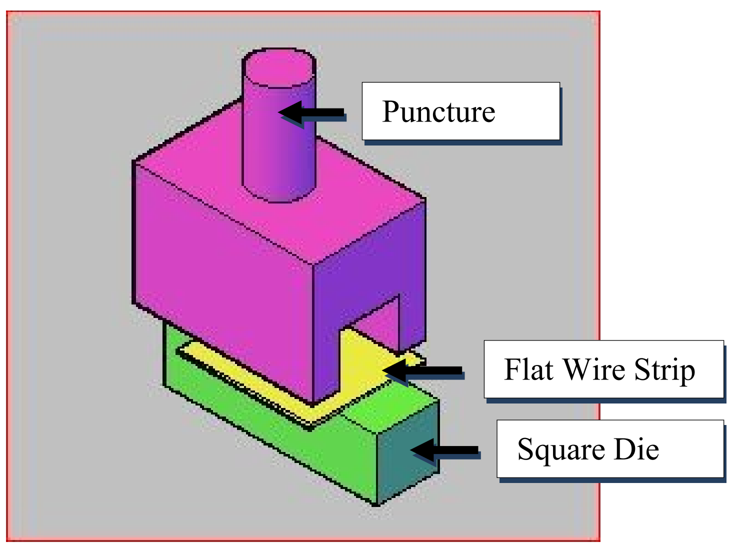


Figure2-3: Punching

Hydraulically or pneumatically operated actuator moves up and down while wire strips are cut and bent to the stapler pin shape. Die keeps stationary in practical reason. Stapler pin automatically removes from die after completing the task and fallen to the conveyor.

2.1 Production Flow Chart- Conventional Process

Following flow chart can be developed based on the manufacturing process for multiple wire process in Figure2-4

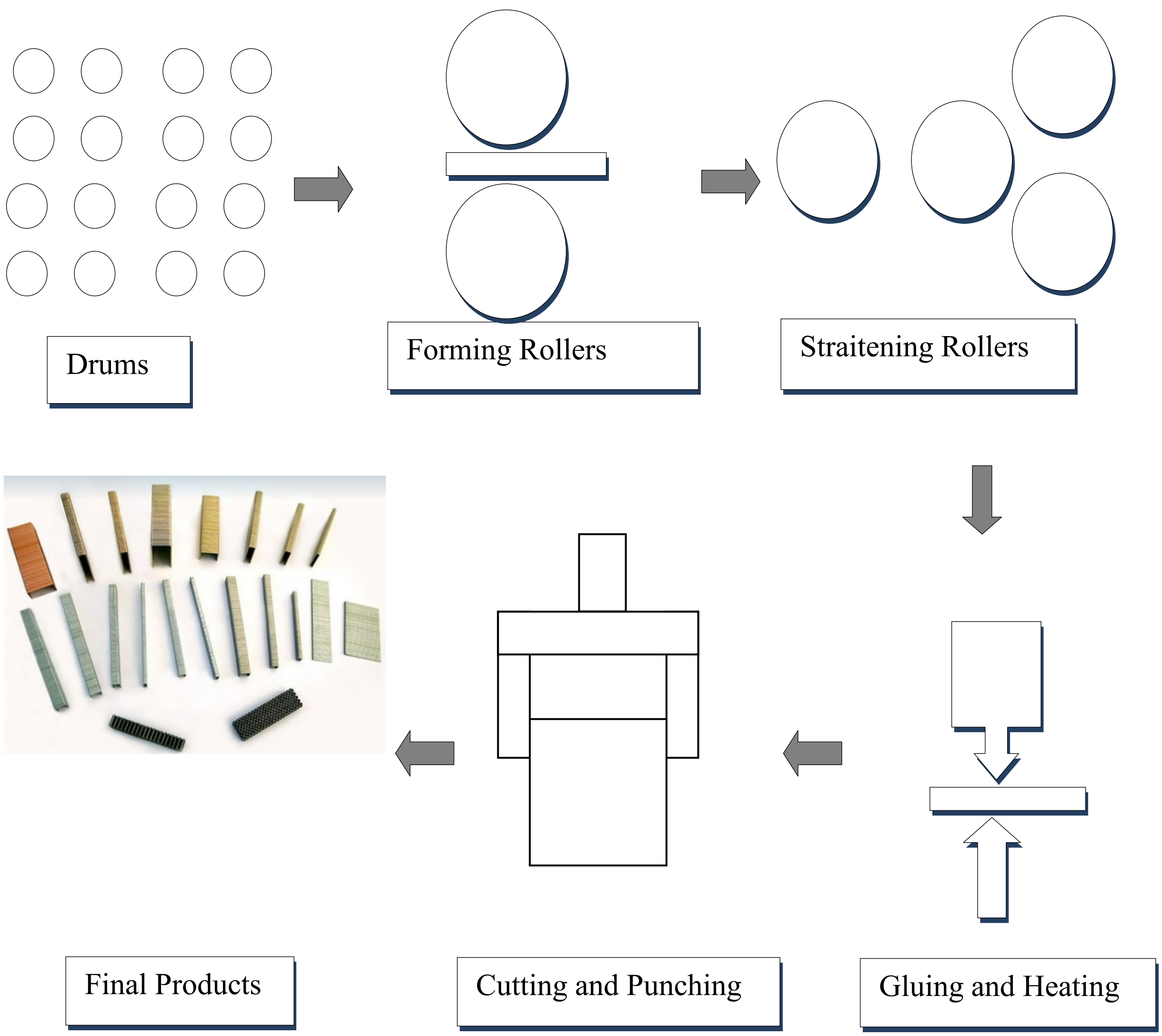


Figure 2-4: Production Flow Chart

2.2 Manufacturing Process

Stapler pin manufacturing process involves very simple mechanical functions of wire forming, feeding, cutting, bending, moving and gluing. Production floor of mass scale factory of multiple galvanized wires [2] illustrated in following Figure 2-5 including all stations in the process. Individual functions, components and operation are discussed in sub topics in proceeding topics with help of Figures 2-6 to 2- 13 in the video [2].

Figure 2-5: t= 0.37s: Production Floor of a Factory

2.2.1 Wire Drums

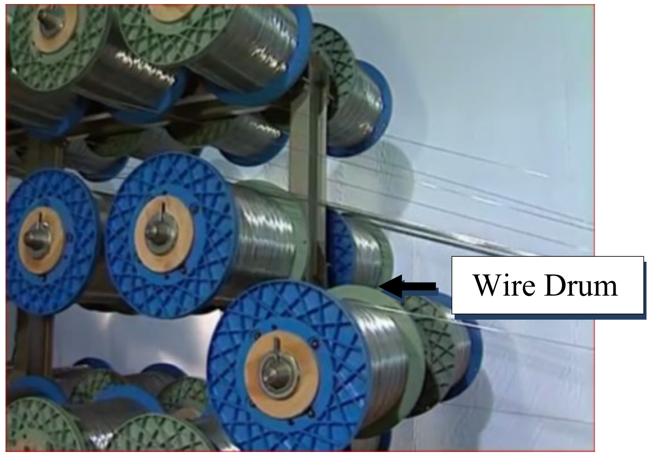


Figure 2-6 : t=0.51s: Wire Drums

Galvanized steel wire (raw material) used for a day's production is stored in individual wire drums. Please see Figure 2-6. It is continuously fed to the next working station for wire strip making. All the drums are freely rotating and number of drums depends on the width of the wire forming strip. Generally 50numbers of drums are used.

2.2.2 Wire Forming Rollers

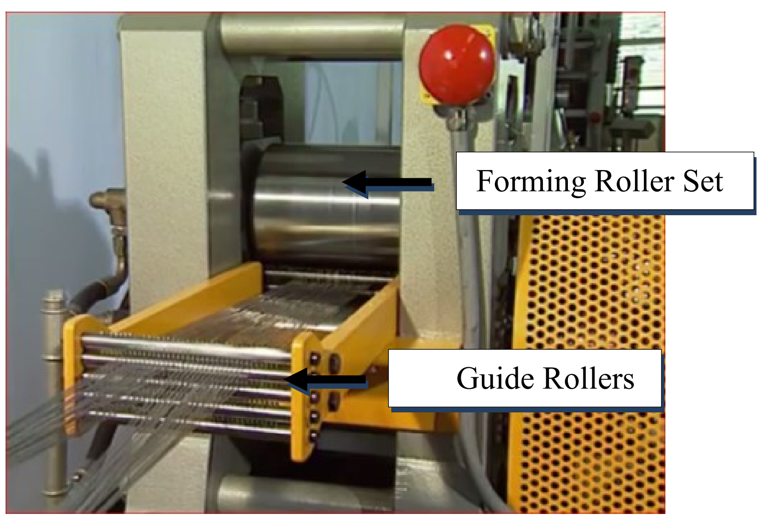


Figure 2-7 : t=1.05s:Wire Forming

Straightened wires pass through double drum roller set enabling wires to deform to flat strip. Guide roller sets are also accommodated in order to securely feeding to the forming roller set. It can be easily understood by above Figure 2-7.

2.2.3 Wire Straightening Rollers

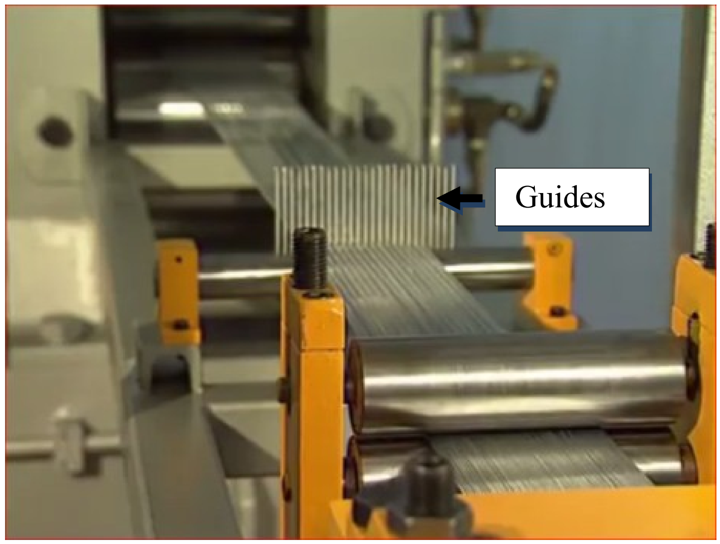


Figure 2-8 t=1.13s: Straightening

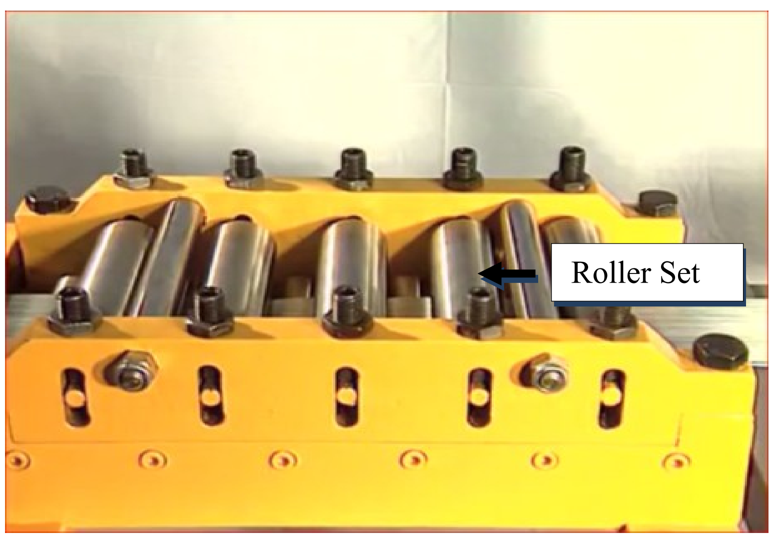


Figure 2-9 t=1.16s: Straightening

Galvanized steel wires may deformed for uneven shapes when handling it at various places. All wires straightened by using set of guides and rollers fixed vertically as well as horizontally before making the wire strip. Please refer Figure 2-8 and 2-9. All wires pass thorough these rollers and guides enabling wire to make itself straight.

2.2.4 Wire Gluing Machine

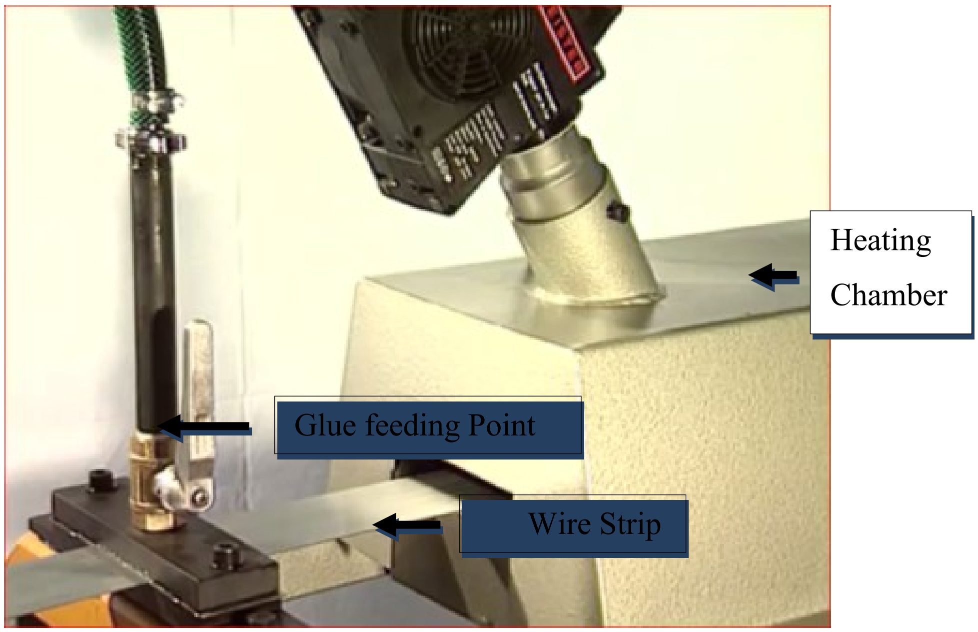


Figure 2-10: t=1.26s: Gluing

Flat wire strips need to be fixed together by using adhesive to prevent separation of individual pins and make slabs of stapler pins. Figure 2-10 shows essential components of gluing.

Glue flows on to the wire strip freely and distributed evenly and fed to the heating chamber in order to dry it. Substantial time is required for drying it; therefore length of the heating chamber is high.

2.2.5 Wire Feeding Machine

Figure 2-11 t=2.02s:Feeding

Wire strip feeding machine is used for feeding wire to the punching machine. It moves back and fro along wire moving direction. Gripping mechanism is also accommodated in to the system to grip the wire strip. Power is supplied by the aid of hydraulic actuators.

2.2.6 Wire Punching Machine

Figure 2-12: t=2.11s: Punching

Final operation is punching of wire strip to produce stapler pin slab while it moving up and down. Different set of dies are used for this operation to make different shapes, types and sizes. Hydraulic actuators are used to ensure smooth operation of the moving parts.

2.2.7 Final Product

Figure 2-13 t= 2.42s:Final Product

Many kinds of stapler pins can be produced in this production process by changing the dies in appropriate shapes. Final product falls on the conveyor to be transported to packing stations. In this particulate production process following types and shapes of stapler are manufactured

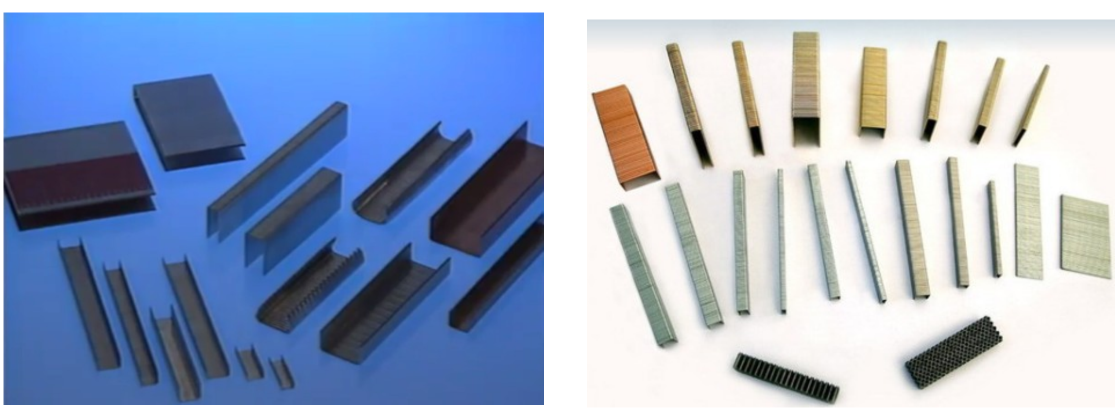


Figure 2-14: Types and Shapes

3.0 Proposed Manufacturing Mechanism

In this design, conventional mechanism has been completely changed to make its square shape by using a rotary bending mechanism. Rotary bending mechanism is a typical operation utilized for bending of wires.

Steel round wire kept under tension is fed through freely rotating rollers enabling wire to make it's flat shape while wrapping around the rotational square bar. Then it moves along the square bar with the aid of nut and bolt principle. Then it is cut from opposite two sides by using a rotating cutting tool while moving forward on the square bar around which the wire is wrapped in square shape forming the shape of stapler pins. Cutting tool moves up and down while rotating with the aid of cam mechanism enabling to produce two stapler pins at a time. Instead of using multiple wires, a single wire is used in the proposed process.

Basic function of the Proposed Manufacturing Process described above can be illustrated in following Figure1.4 and1.5

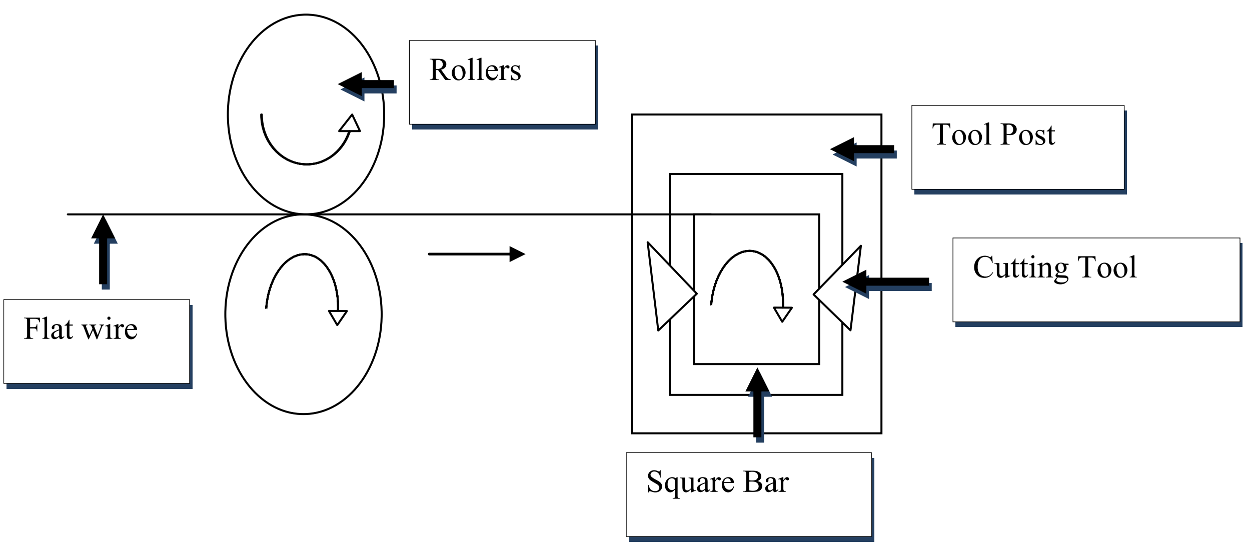


Figure 3-1: Proposed Manufacturing Mechanism

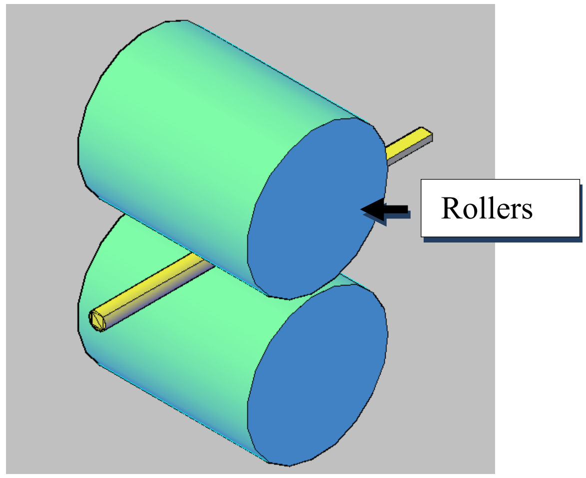


Figure 3-2: Free Rollers

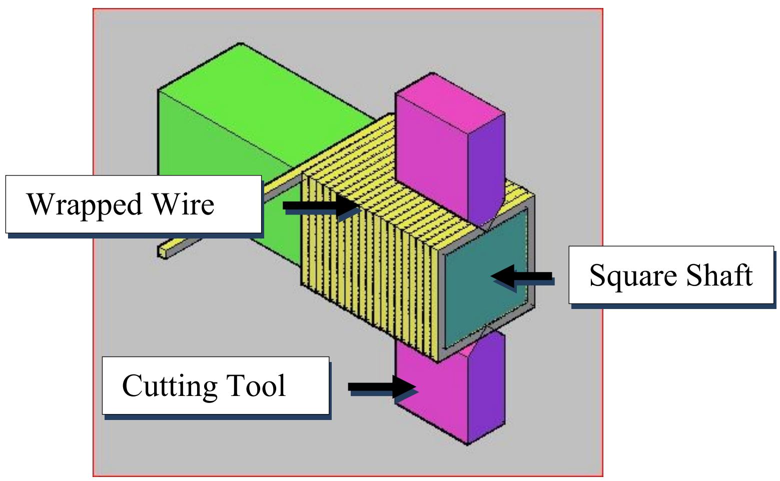


Figure 3-3: Wrapping and Cutting Mechanism

3.1 Novel Production Process and Motivation

Stapler pin manufacturing process has not been developed further and used conventional manufacturing process all over the world which has limitations due to high energy consumption and massive space requirement, therefore any manufacturer has to setup factory which leads to high capital investment.

This design of high speed stapler pin manufacturing machine focuses on saving energy, time and space leads to convert factory manufacturing environment to domestic manufacturing environment.

Use of time, space and energy saving strategy is more economical and applicable in modern industry. Accordingly manufacture of stapler pin scan promote / emerge into the domestic industry contributing to country's economic development.

3.2 Objectives

Total requirement of the stapler pins of different sizes for office uses and industrial uses are imported and distributed by various suppliers in Sri Lanka Island wide. No one has thought of manufacturing stapler pins in Sri Lanka due to high capital investment and high operation cost and lack of own technology. Now many suppliers imports base product and packaging locally and distributed through super markets and retail markets.

This research attempts to develop a new technology and methodology for producing any kind of stapler pins for office use as well as industrial use in domestic manufacturing environment enabling substantial income for the new small scale manufacturing entrepreneurs. Accordingly following set of objectives to be achieved in order to produce new technology.

- Derive equations for calculating total power requirement for manufacturing process
- Develop machine to convert factory manufacturing environment to domestic manufacturing environment by optimal using of time, energy and space.
- Using computer aided design and simulation of mechanical components of new machine by using CAD software
- Producing hand driven machine and compare machine specifications with real values at slow speed for various wire gauges of different sizes of stapler pins
- Electrically powered machine and testing performance

4.0 Conceptual Process Design

Certain operations used in conventional manufacturing process such as forming, gluing etc. too are included in the new design;however the method and the mechanisms have been changed for each operation in order to easy setup and compact accommodation of the systems within a limited space coping up with the design concept.

4.1 Production Flow Chart- Novel Process

Each operation is shown in following flow chart.

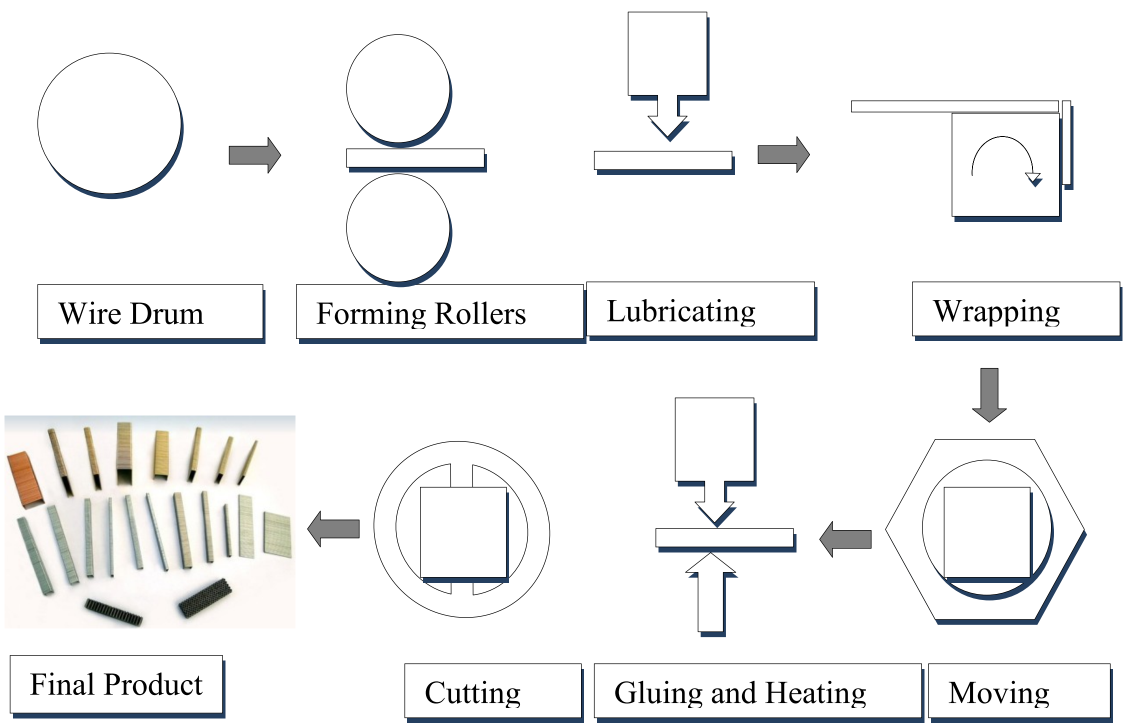
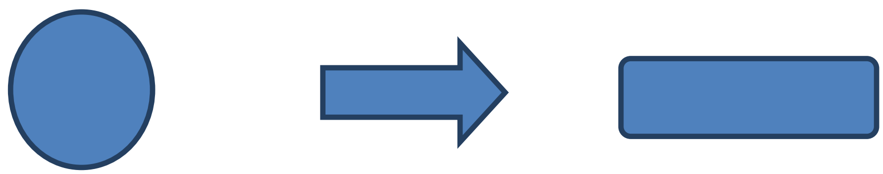
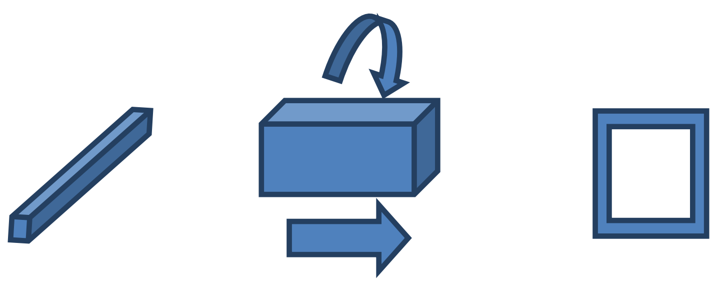


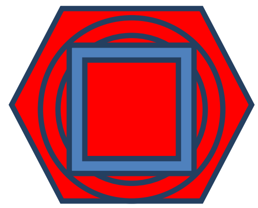
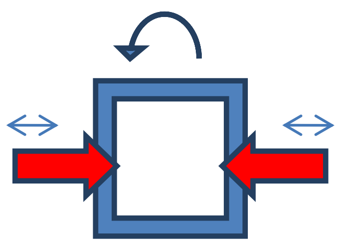
Figure 4-1: Proposed Concept Flow Chart

In this concept production capacity directly depends on the rotational speed of the wrapping square shaft.

Details of the conceptual production process in new concepts are shown in following table no 4-1 to produce square type stapler pin of any size and gauge of metal wire used. Dimensions stated in the table are particularly used for office.

Table4-1: Description of Individual Process

Process	Method/ Mechanism
Forming and lubricating	0.5588 mm (Gauge 24) diameter wire passes through two free rollers kept at 0.4mm distance forms wire to flat shape. At the same time lubrication oil is applied to the two rollers enabling wire to move at less friction.
	
Feeding & Bending	Flat shape wire of 0.6 mm x 0.4mm wraps around square die shaped shaft driven by induction motor and bends due to applied tension by adjustable free rollers
	
Moving	Square, spiral shape wire acts as a square bolt and enters into the threaded nut kept stationary and centered to the square shaft. When square shaft rotates, the wrapped wire in square spiral shape moves along the square shaft

Process	Method/ Mechanism
	
Gluing and Cutting	Cutting tools rotate on a stationary circular guide post with a square bar and cutting tool moves up and down by using cam mechanism. While rotating, cutting of wire takes place and at the same time heated adhesive/glue is fed to the rotating square bar through stationary circular guide post
	
Parting off	Number of rotations of shaft is counted by using an encoder fitted to the shaft and actuate parting off tool at correct position and the length of produced stapler rail of 50 no stapler pins with the help of linear motor with a controller
Motor control	Power variation required for the wire bending and cutting operations is controlled by the variable speed induction motor controller

4.2 Novel Machines Configurations

Engineering drawings have been developed for two types of machines by using AUTO CAD to run the machine by electrical driven motors to produce multiple stapler pins at a time. Configurations of these machines are shown in following Figure 4-2and Figure 4-3.

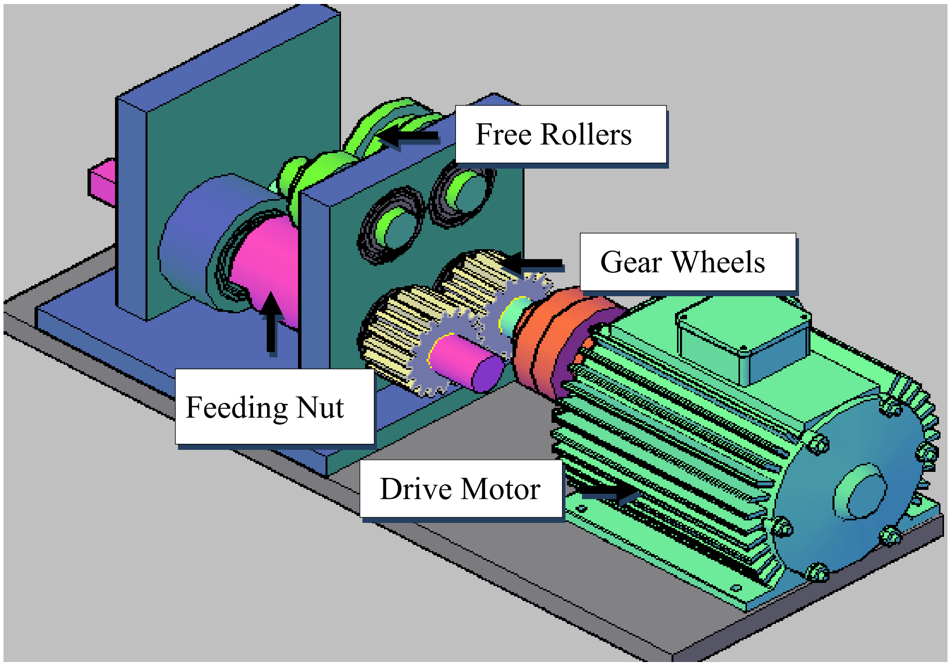


Figure 4-2: Configuration – Type 1

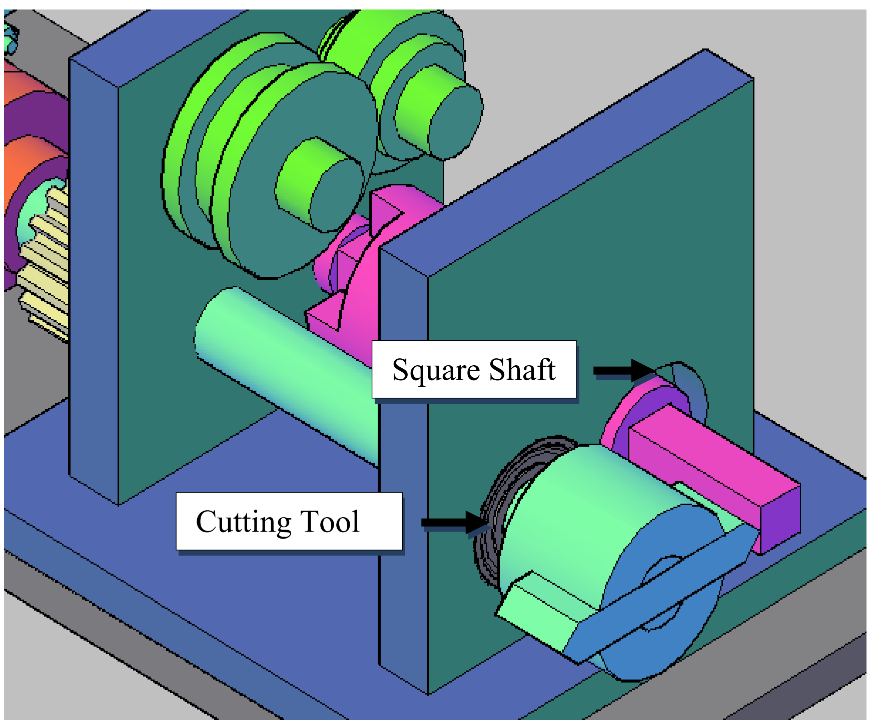


Figure 4-3 : Rear View – Type 1

Variable speed single phase induction motor directly couple to the drive shaft. One rotation of shaft produces two stapler pins at a time

Here uses two shafts mechanism and synchronized by using two ideal gear wheels. Also two shafts rotate in opposite directions. One shaft is for mounting bending and moving mechanism and other shaft is use for mounting cutting mechanism.

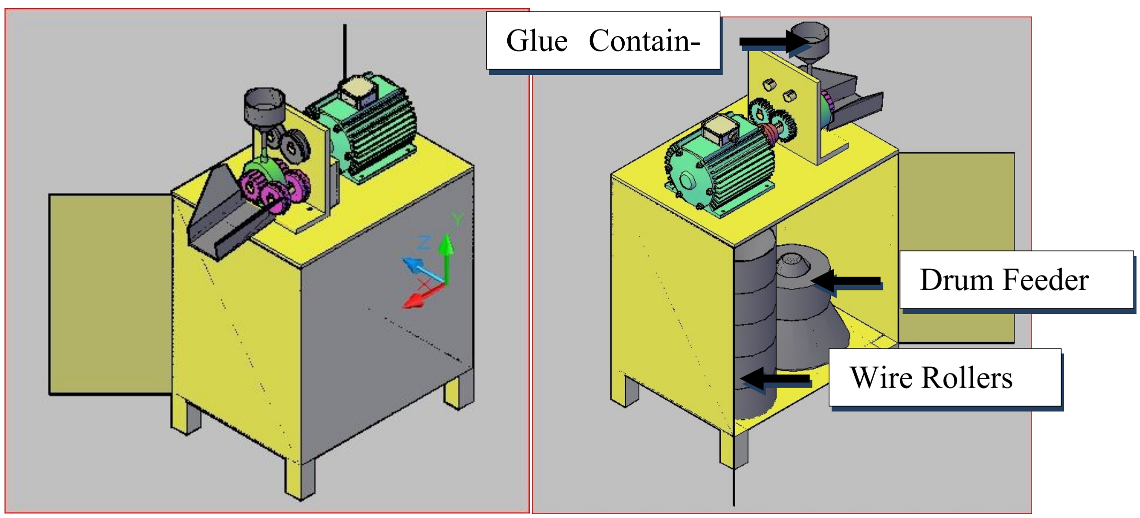


Figure 4-4: Configuration – Type 2 Front Side and Rear Side

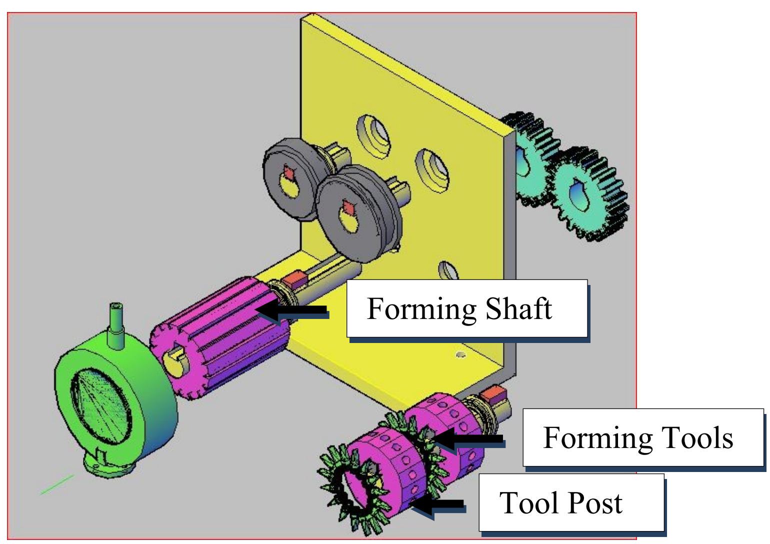


Figure 4-5: Exploded View

5.0 Theoretical Approach and Mathematical Modeling

Power requirement for conceptual process of the novel machine is analyzed by mathematical modeling of individual operations described in the sequence of flow chart shown in Figure 4-1. For this analysis, only significant mechanical power requirements selected from individual operations have been considered.

5.1 Wire Forming Process

Initial step of the process is to obtaining flat shape of the staple pin using round shape galvanized wire. In this operation, wire should pass through two rollers. Typical arrangement of the Rolling as shown in Figure5-1 then round wire forming to the flat shape and flattening of the wire takes place. Gap of the rollers are adjustable to the required thickness of the staple pin. This operation is known as Rolling Mill Operation [3].

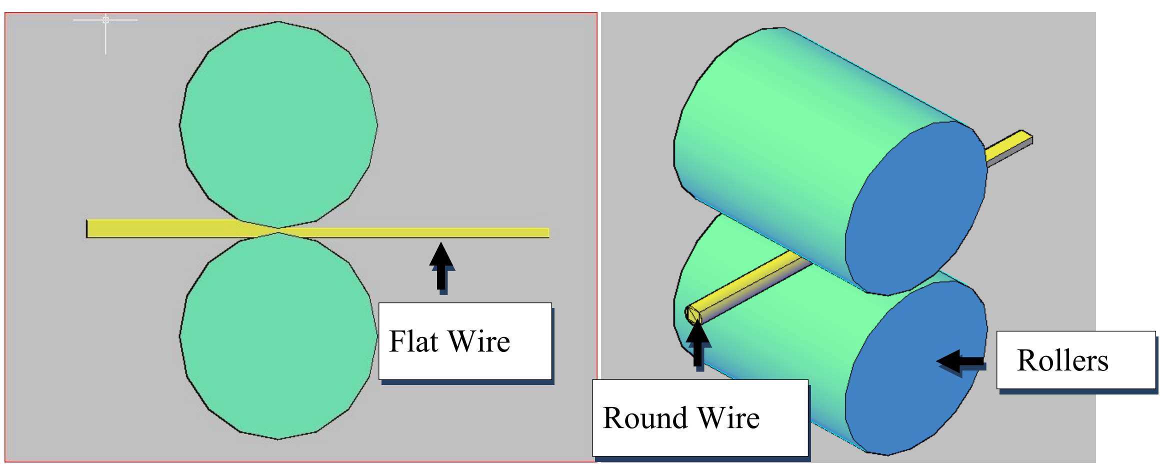


Figure 5-1: Wire Forming Operation

Power requirement for this forming operation is identical to the Rolling Mill operation. In the paper Firoj U. Pathan, Santosh N. Shelke [3] in their article for Design of Cold Rolling Mill Components calculated the rolling power.

The rolling power is given by following equations

$$P_r = \sigma_0 \, bh_1 \left\{\frac{1-r}{1-0.5r}\right\} v\ln\left(\frac{h_1}{h_2}\right) \text{...Equation 5-1}$$

$$P_r = \sigma_0 bh_1 \left\{\frac{1-r}{1-0.5r}\right\} v\ln\left(\frac{1}{1-r}\right) \text{..Equation 5-2}$$

From the elementary physics, $\sigma_0 = \frac{T_b}{bh}$...Equation 5-3

If the pulling tension is known, rolling power can be calculated. Tension of the wire is calculated in following topic under wire bending process.

5.2 Wire Bending Process

Figure 5-2 shows the typical arrangement of bending operation of conventional method. Work piece rests on the die and puncture pushes downward, then work piece bent to the shape of the angle of the die. In the proposed method bending operation takes place when rotating the square shaft while the flat wire is under tension as shown in Figure 5-3.

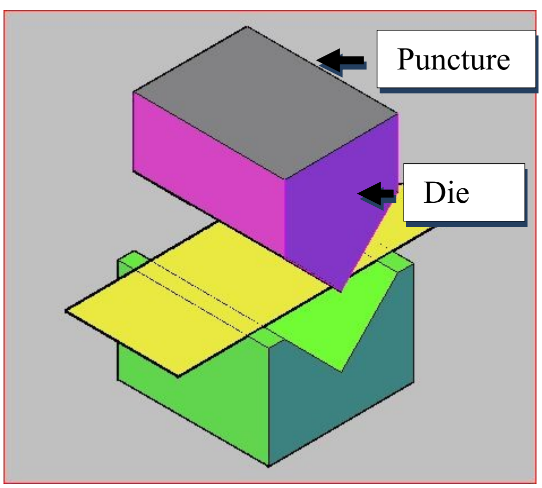


Figure5-3: Bending Operation 3D

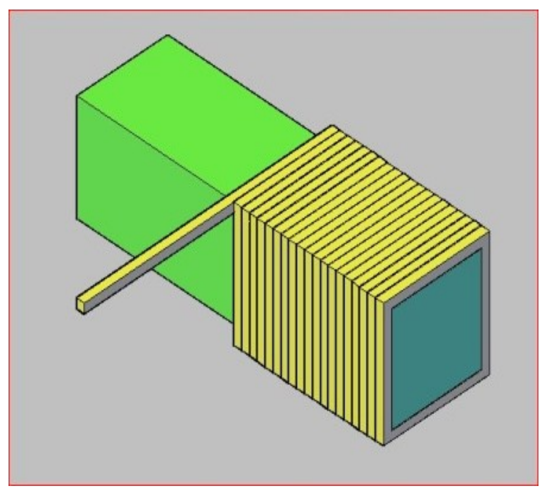


Figure5-2:Wrapping Operation

This method is known as rotary bending. Type of Rotating bending has been discussed byStoychev1 B. I., S. H. Stefanov [4]. The word “Rotary bending” used by A.R. Pelton, J. Fino Decker, L. Vien, C. Bonsignore, P. Saffari, M. Launey, M.R. Mitchell [5]

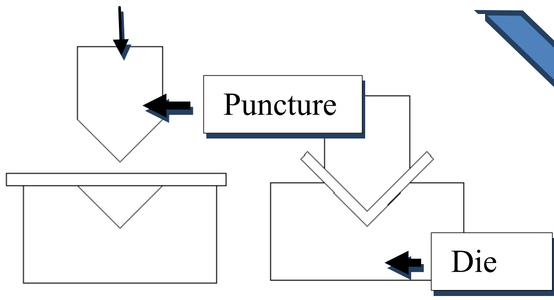


Figure 5-4:Bending Operation 2D

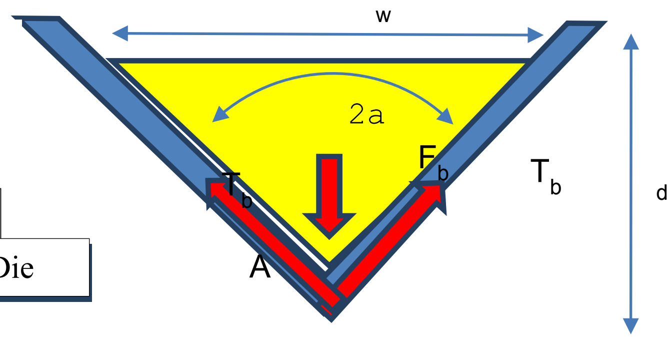


Figure 5-5:Force Diagram

Bending force is given by the equation below [6] for the V bending using punch and die

$F_b = K\sigma_T \frac{hb^2}{w}$...Equation 5-4

K is a constant that accounts for differences encountered in actual bending process and is 1.33 for V- bending [6]. Therefore similar method and equation can be used for calculating rotary bending force used for wire bending in the novel process.

Force diagram for the rotary bending operation is illustrated in Figure 5-4.

Bending force and the moving distance of the puncher known, from the elementary principles of physics, bending power can be derived from equation no 7 below

$P_b = F_b\, d$...Equation 5-5

Considering the equilibrium of point at A, from elementary principles of physics tension of wire given by following equations

$F_b = 2T_b \mathrm{Cos}\alpha$...Equation 5-6

$T_b = \frac{F_b}{2\cos\alpha}$……………………………………………...……………..Equation 5-7

5.3 Wire Cutting Process

Typical arrangement of the cutting operation is shown in Figure 5-7. Cutting tools move up and down by using spring loaded cam mechanism and thereby the cutting operation takes place

Force diagram for flat wire cutting operation is illustrated in Figure5-6

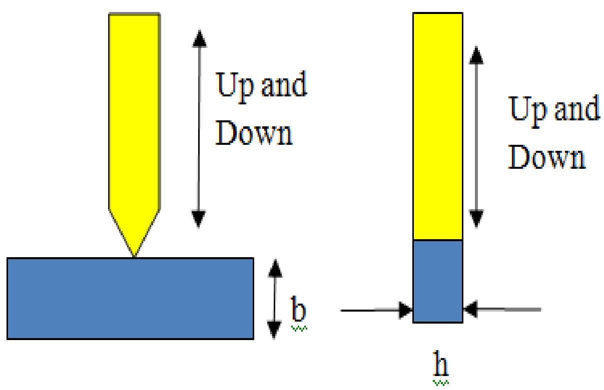


Figure 5-6: Cutting Force Diagram

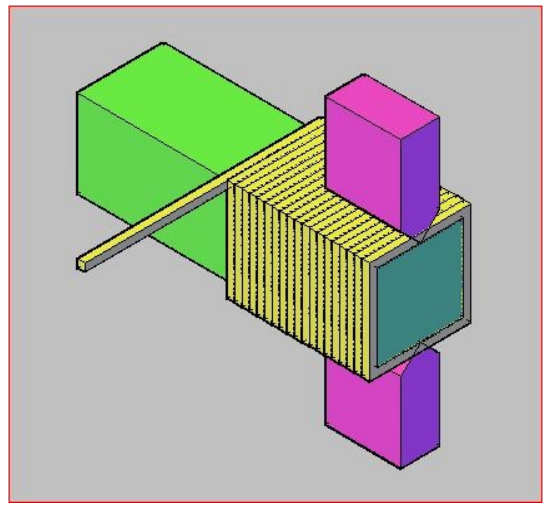


Figure 5-7: Cutting Operation

Considering the shear stress of the wire, from elementary principles of physics cutting force of the cutting tool is given by following equation

$F_c = \sigma_s hb$…………………………………………………………….....Equation 5-8

Cutting force, thickness of the wire and the moving distance of the cutting tool under cutting force are known; from the elementary principles of physics, cutting power can be derived from equation no 5- below

$P_c = \sigma_s hb^2$……………………………………………………………Equation 5-9

5.4 Wire Moving Process

Moving force to the wrapped wire is applied by using the threaded nut kept stationary. Flat wire wrapped around the square bar acts as a threaded bolt only at four corners of the shaft. When rotating the square shaft, the wrapped wire comes out while rotating in square shape along the square shaft.

Typical arrangement of wrapping operation is shown in Figure5-6 and Force diagram of the square shaft is illustrated in Figure5-7

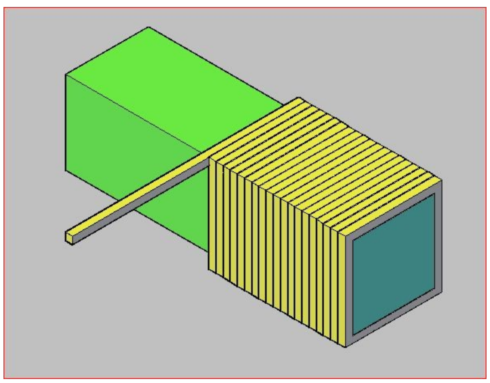


Figure 5-6 : Moving Operation

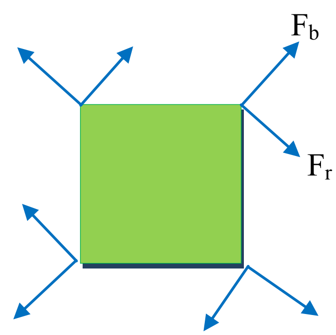


Figure 5-7: Moving Force Diagram

By using elementary principles following equations can be derived

$F_r = \mu F_b$ ....Equation 5-10

Torque required for n_t number of turn of the nut to push the wire along the four edges is given by

$T = rn_c n_r F_r = rn_c n_t \mu F_b$ ....Equation 5-11

Torque required by the nut and the rotational speed of the shaft known, from the elementary principles of physics, moving power can be derived in the equation no 5-12 below

$P_m = T\omega = rn_c n_t \mu F_b \omega$ ....Equation 5-12

5.5 Power for Rotating Parts

Power required for rotating all revolving parts can be represented in a single rotating mass. Diagram for the rotating parts are illustrated in Figure5-8

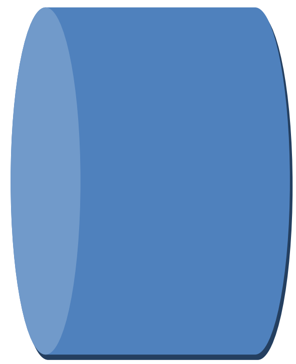


Figure 5-8: Equivalent Mass of Rotating Part

Power required for the rotating parts is given by

$I = \frac{mr^2}{2}$……………………………………………………………Equation 5-13

$P_R = I\omega^2$……………………………………………………………Equation5-14

$P_R = \frac{mr^2\omega^2}{4}$……………………………………………………………Equation 5-15

5.6 Total Power

According to the above derivations total power can be calculated by adding all calculated power for different individual mechanical components discussed above

$P_T = P_b + P_c + P_r + P_m + P_R$…………………………………………….Equation 5-16

6.0 Theoretical Power Calculation

All parameters for calculating total power for novel method of operation can be obtained from above derived 16 no of equations. Power calculation for the novel staple pin manufacturing process for six types of wire gauges viz. Gauge 20, Gauge 22, Gauge 23 , Gauge 24, Gauge 25 and Gauge 26 is shown in following tables. Sizes and dimensions of the wire have been taken from the standard wire gauge table[7] and the practical measurements taken after the practical testing of wire rolling process and the assumption taken as the cross sectional area of the wire has not been change after deformation of steel wire in the rolling process as shown in following table.

Table 6-1: Dimensions of the Wire

Gauge	Diameter/mm	Thickness/mm	Width/mm (With Assumption)	Width/mm (Measured)
20	0.9144	0.4	1.6409	1.5
22	0.7112	0.4	0.9926	1.0
23	0.6096	0.4	0.7293	0.8
24	0.5588	0.4	0.6128	0.6
25	0.5080	0.4	0.5065	0.5
26	0.4572	0.4	0.4102	0.4

6.1 Calculation of Bending Force and Tension of Wire

From the equation no 4 and 7 given below, bending force and tension of wire has been calculated and shown in table no 6-2

$F_b = K\sigma_T \left(\frac{hb^2}{w}\right)$……………………………………………..…………...Equation 6-1

$T_b = \frac{F_b}{2\cos\alpha}$………………………………………………...……..………..Equation 6-2

Table 6-2 : Bending Force and Tension of Wire Gauge 20,22 and 23

Parameter	Description	Units	G 20	G 22	G 23
σ_T	Tensile strength of steel wire	Mpa	440.00	440.00	440.00
α	Die angle	Degrees	45.00	45.00	45.00
b	Width of steel wire	m	1.64	0.99	0.72
h	Height of steel wire	m	0.40	0.40	0.40
w	Width of die opening	m	17.00	17.00	17.00
K	Constant		1.33	1.33	1.33
Apply above values to the equations					
F_b	$K\sigma_T\left(\frac{hb^2}{w}\right)$	N	37.07	13.56	7.32
T_b	$\frac{F_b}{2\text{Cos}\alpha}$	N	35.28	12.91	6.97

Table 6-3 : Bending Force and Tension of Wire Gauge 24,25 and 26

Parameter	Description	Units	G24	G 25	G 26
σ_T	Tensile strength of steel wire	Mpa	440.00	440.00	440.00
α	Die angle	Degrees	45.00	45.00	45.00
b	Width of steel wire	m	0.61	0.50	0.41
h	Height of steel wire	m	0.40	0.40	0.40
w	Width of die opening	m	17.00	17.00	17.00
K	Constant		1.33	1.33	1.33
Apply above values to the equations					
F_b	$K\sigma_T\left(\frac{hb^2}{w}\right)$	N	5.17	3.53	2.31
T_b	$\frac{F_b}{2\text{Cos}\alpha}$	N	4.92	3.36	2.20

6.2 Velocity of the Wire

Calculation to determine the velocity of the wire considering the wrapping of steel wire around the square shaft of 12mm width of each side at 1500rpm speed is given below

Velocity of the wire , v = 4x12x1500/60 mm/s= 1200 mm/s = 1.2 m/s

6.3 Calculation of Wire Forming Power

Wire forming power is calculated from the below given equations no 1,2 and 3 and tabulated in table no 6-4 and table no 6-5.

$$P_r = \sigma_0 \, bh_1 \left\{\frac{1-r}{1-0.5r}\right\} v\ln\left(\frac{h_1}{h_2}\right) \qquad \text{Equation 6-3}$$

$$P_r = \sigma_0 bh_1 \left\{\frac{1-r}{1-0.5r}\right\} v\ln\left(\frac{1}{1-r}\right) \qquad \text{Equation 6-4}$$

$$\sigma_0 = \frac{T_b}{bh} \qquad \text{Equation 6-5}$$

Table 6-4:Wire Forming Power Gauge 20, 22 and 23

Parameter	Description	Units	G 20	G 22	G 23
Tb	Tension of wire	N	35.28	12.91	6.97
b	Width of steel wire	m	1.64	0.99	0.72
h	Height of steel wire	m	0.40	0.40	0.40
$\sigma_0 = \frac{T_b}{bh}$	Average stress of wire	Mpa	53.76	32.52	23.89
h1	Inlet thickness of wire	m	0.91	0.71	0.60
h2	Outlet thickness of wire	m	0.40	0.40	0.40
b	Width of wire	m	1.64	0.99	0.72
$r = \frac{(h_1 - h_2)}{h_1}$	Reduction ratio		0.56	0.43	0.34
$ln(1/(1-r)$			0.82	0.57	0.42

Parameter	Description	Units	G 20	G 22	G 23
v	Velocity of wire at 1500rpm	m/s	1.20	1.20	1.20
Pr	Power for rollers	w	48.71	11.41	4.25
$P_r = \sigma_0 b h_1 \left\{\frac{1-r}{1-0.5r}\right\} v \ln\left(\frac{1}{1-r}\right)$					

Table 6-5:Wire Forming Power Gauge 24, 25 and 26

Parameter	Description	Units	G 24	G25	G 26
T_b	Tension of wire	N	4.92	3.36	2.20
b	Width of steel wire	m	0.61	0.50	0.50
h	Height of steel wire	m	0.40	0.40	0.40
$\sigma o = \frac{T_b}{bh}$	Average stress of wire	Mpa	20.07	16.59	11.02
h_1	Inlet thickness of wire	m	0.55	0.50	0.45
h_2	Outlet thickness of wire	m	0.40	0.40	0.40
b	Width of wire	m	0.61	0.50	0.41
$r = \frac{(h_1 - h_2)}{h_1}$	Reduction ratio		0.28	0.21	0.12
$ln(1/(1-r)$			0.33	0.23	0.13
v	Velocity of wire at 1500rpm	m/s	1.20	1.20	1.20
P_r	Power for rollers	w	2.30	1.07	0.30
$P_r = \sigma_0 b h_1 \left\{\frac{1-r}{1-0.5r}\right\} v \ln\left(\frac{1}{1-r}\right)$					

6.4 Calculation of Wire Bending Power

Equation no 5 given below calculates wire bending power tabulated in table no 6-6table no 6-7

$P_b = F_b d$……………………………………………………………...Equation 6-6

Table 6-6:Wire bending Power Gauge 20, 22 and 23

Parameter	Description	Units	G20	G 22	G 23
F_b	Bending force	N	37.07	13.57	7.32
d	Distance moved of die	m	9.50	9.50	9.50
$P_b = F_b d$	Bending power one bend	Nm	0.35	0.13	0.07
n_c	No of corners of one turn		4.00	4.00	4.00
$Pb = n_c F_b d25$	Bending power at 1500rpm	w	221.19	80.94	43.69

Table 6-7:Wire bending Power Gauge 24, 25 and 26

Parameter	Description	Units	G 24	G 25	G 26
F_b	Bending force	N	5.17	3.53	2.32
d	Distance moved by die	m	9.50	9.50	9.50
$P_b = F_b d$	Bending power one bend	Nm	0.05	0.03	0.02
n_c	No of corners of one turn		4.00	4.00	4.00
$Pb = n_c F_b d25$	Bending power at 1500rpm	w	30.85	21.07	13.82

6.5 Calculation of Wire Cutting Power

Wire cutting power tabulated in table no 6-8and table no 6-9 have been computed from equation no 9 given below,

$P_c = \sigma_s hb^2$……………………………………………………………Equation 6-7

Table 6-8:Wire Cutting Power Gauge 20, 22,and 23

Parameter	Description	Units	G 20	G 22	G 23
σ_s	Shear strength of steel wire	Mpa	440.00	440.00	440.00
b	Cutting thickness of wire	m	1.64	0.99	0.73
h	Width of wire	m	0.40	0.40	0.40

Parameter	Description	Units	G 20	G 22	G 23
$F_c = \sigma_s hb$	Cutting force	N	288.80	174.71	128.35
$P_c = \sigma_s hb^2$	Cutting power one cut	Nm	0.12	0.07	0.05
n_c	No of cuts per one turn		2.00	2.00	2.00
$P_c = n_c \sigma_s hb^2 (25)$	Cutting power at 1500rpm	w	36.27	21.94	16.12

Table 6-9:Wire Cutting Power Gauge 24 25,and 26

Parameter	Description	Units	G24	G 25	G 26
σ_s	Shear strength of steel wire	Mpa	440.00	440.00	440.00
b	Cutting thickness of wire	m	0.61	0.51	0.50
h	Width of wire	m	0.40	0.40	0.40
$F_c = \sigma_s hb$	Cutting force	N	107.85	89.14	88.00
$P_c = \sigma_s hb^2$	Cutting power one cut	Nm	0.04	0.04	0.04
n_c	No of cuts per one turn		2.00	2.00	2.00
$P_c = n_c \sigma_s hb^2 (25)$	Cutting power at 1500rpm	w	13.55	11.20	11.05

6.6 Calculation of Wire Moving Power

Equation no 11 and 12 below has been used in calculating wire moving power and the same is tabulated in table no6-10table no 6-11

$T = rn_c n_r F_r = rn_c n_t \mu F_b$……………………………………………..Equation 6-8

$P_m = T\omega = rn_c n_t \mu F_b \omega$………………………………………………...Equation 6-9

Table 6-10 : Wire Moving Power Gauge 20, 22 and 23

Parameter	Description	Units	G 20	G 22	G 23
μ	Friction coefficient		0.60	0.60	0.60
F_b	Bending force	N	37.07	13.57	7.32

Parameter	Description	Units	G 20	G 22	G 23
$F = \mu F_b$	Moving force	N	22.24	8.14	4.39
r	Radius of nut	m	8.50	8.50	8.50
n_c	No of effective corners of bend		4.00	4.00	4.00
n_t	Number of thread of the nut		10.00	10.00	10.00
T	Torque given by nut	Nm	7.56	2.77	1.49
P_m	Power to move wire at 1500rpm	W	1,187.43	434.54	234.55

Table 6-11 : Wire Moving Power Gauge 24, 25 and 26

Parameter	Description	Units	G 24	G 25	G 26
μ	Friction coefficient		0.60	0.60	0.60
F_b	Bending force	N	5.17	3.53	2.32
$F = \mu F_b$	Moving force	N	3.10	2.12	1.39
r	Radius of nut	m	8.50	8.50	8.50
n_c	No of effective corners of bend		4.00	4.00	4.00
n_t	Number of thread of the nut		10.00	10.00	10.00
T	Torque given by nut	Nm	1.05	0.72	0.47
P_m	Power to move wire at 1500rpm	W	165.61	113.11	74.21

6.7 Calculation of Power for Rotating Parts

Power for rotating parts has been calculated using equation no 13 and 14 and tabulated below; table no 6-12

$I = \frac{mr^2}{2}$……………………………………………………….………………Equation 6-10

$P_R = I\omega^2$………………………………………………..………………Equation6-11

$P_R = \frac{mr^2\omega^2}{4}$………………………………..……………………………Equation 6-12

Table 6-12 : Power for Rotating Parts

Parameter	Description	Units	Value
m	Effective mass of the rotor including all rotating components	Kg	5.00
r	Effective radius of the rotor including all rotating components	m	0.10
ω	Rotational speed	rev/Second	25.00
$P_R = \frac{mr^2\omega^2}{4}$	Power required to rotate at 1500rpm	W	1.96

6.8 Calculation of Total Power

According to the above derivations total power can be calculated by adding all calculated individual power requirements for different mechanical components discussed above and tabulated in table no 6-13 and table no 6-14

$P_T = P_b + P_c + P_r + P_m + P_R$ ……………………………………………Equation 6-13

Table6-13 : Total Power Gauge 20, 22 and 23

Parameter	Description	Units	G 20	G 22	G 23
P_b	Bending power at 1500rpm	w	221.19	80.94	43.69
P_c	Cutting power at 1500rpm	w	36.27	21.94	16.12
P_r	Power for rollers	w	48.71	11.42	4.26
P_m	Power required to move wire at 1500rpm	w	1,187.43	434.54	234.55
P_R	Power required to rotating components at 1500rpm	w	1.96	1.96	1.96

Parameter	Description	Units	G 20	G 22	G 23
P_T	Total power for wire processing at 1500rpm	w	1,495.57	550.81	300.59

Table6-14 : Total Power Gauge 24, 25 and 26

Parameter	Description	Units	G 24	G 25	G 26
P_b	Bending power at 1500rpm	w	30.85	21.07	13.82
P_c	Cutting power at 1500rpm	w	13.55	11.20	11.05
P_r	Power for rollers	w	2.30	1.08	0.31
P_m	Power required to move wire at 1500rpm	w	165.61	113.11	74.21
P_R	Power required to rotating components at 1500rpm	w	1.96	1.96	1.96
P	Total power for wire processing at 1500rpm	w	214.27	148.42	101.36

7.0 Experimental Approach and Problems Encountered

When comparing the type 1 in Figure 4-3 and type 2 in Figure4-4,type 1 is simple for construction and operation and easy for testing. Also it consumed minimum power which can match for domestic application and limited to maximum $0.5x0.5x0.5m^3$ space requirement for the process. Therefore initial attempt has been made to test above processes by using hand driven machine with slight changes of the machine components as designed in Auto Cad in above Figure4-3. Purpose of hand driven machine is to verify whether the conceptual operation is practically viable and proven and the power requirement complies with the theoretical calculation.

7.1 Selection of Stapler Pin

All machine components fabricated and machined in this research is to manufacture industrial and office use stapler pins widely available in the market using galvanized steel wire of gauges 20, 22, 23, 24, 25 and 26 to comply all requirements for the manufacturing and related operations for the testing purpose. Figure 7-1 shows the type and shape of the stapler pin selected for the production and testing process.

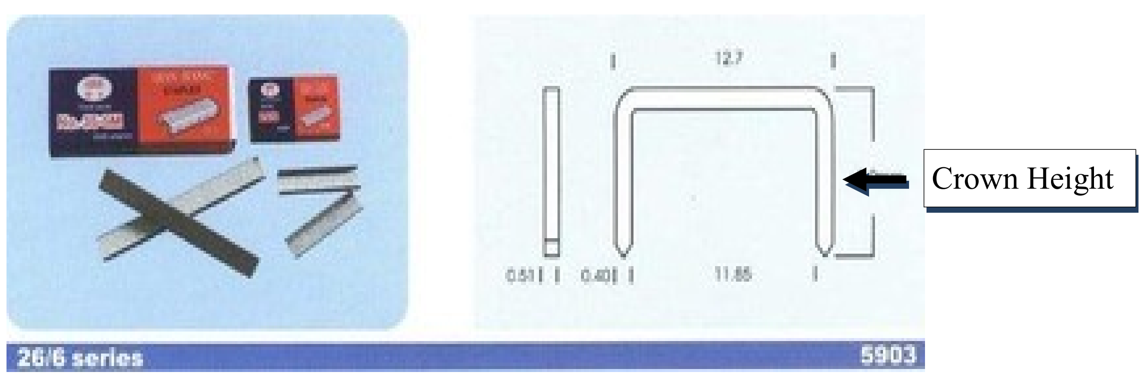


Figure 7-1: Proposed Shape and Dimension of Stapler Pin

The manufacturing industry uses various standards and notations for identifying the stapler pins particularly used by manufacturers and the vendors. Figure 7-1 shows the stapler pin designated as 26/6,of which 26 denotes the gauge of the steel wire and 6 denotes crown height of the stapler pin. Novel manufacturing process has planned to produce any kind of stapler pin in the square shape therefore selected all gauges of wire (20, 22, 23, 24, 25 and 26)and respective designation of products shall be 20/6, 22/6, 23/6, 24/6, 25/6 and 26/6. Therefore the size of square bar shown in Figure 7-4 is fabricated into 12mmx12mm dimension.

7.2 Fabrication and Operation of Hand Driven Machine

In this process several attempts have been made for developing mechanical components in order to satisfy the proposed manufacturing concept and the operation. Mainly to confirm the continuous feeding of steel wire without interruption and tensile failure from the initial stage and to the final stage, to produce final product of stapler pin in accordance with the proposed size and dimensions of the selected stapler pin.

7.2.1 First Attempt on Developing Mechanical Components

This attempt planned to verify and confirm the continuous feeding of wire without any kind of failure from the beginning to end of the production process. Accordingly components fabricated and used for this purpose are shown in following Figure 7-2.

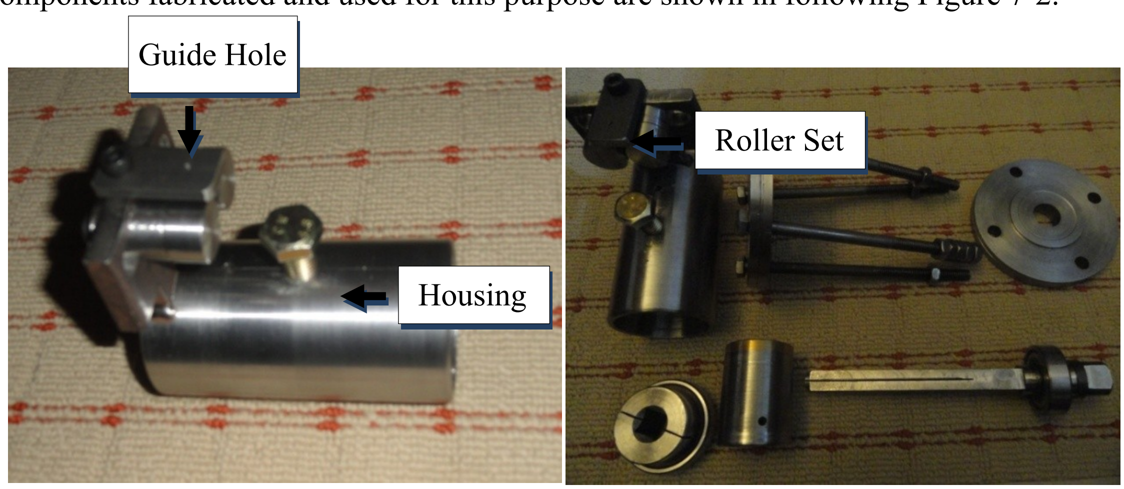


Figure 7-2 Mechanical Component of Hand Driven Machine

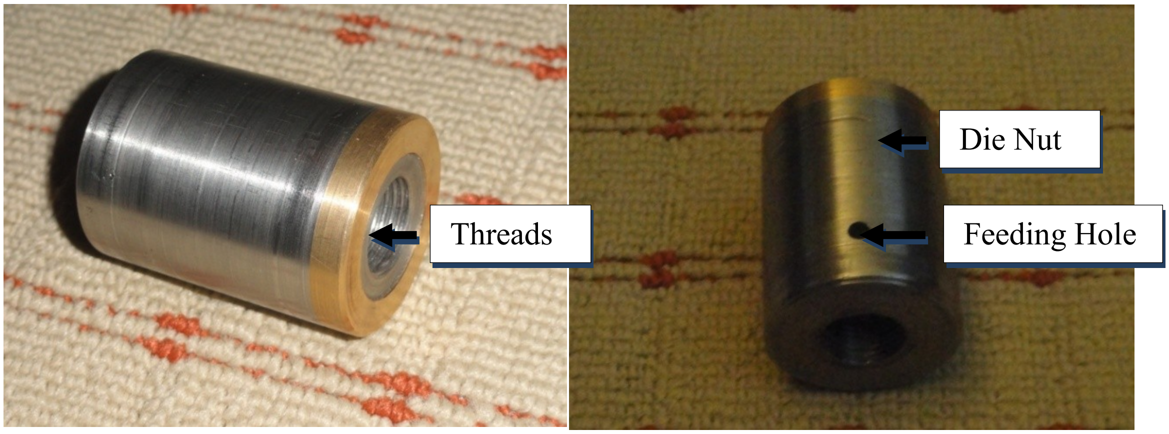


Figure 7-3 - Mechanical Component – Die Nut

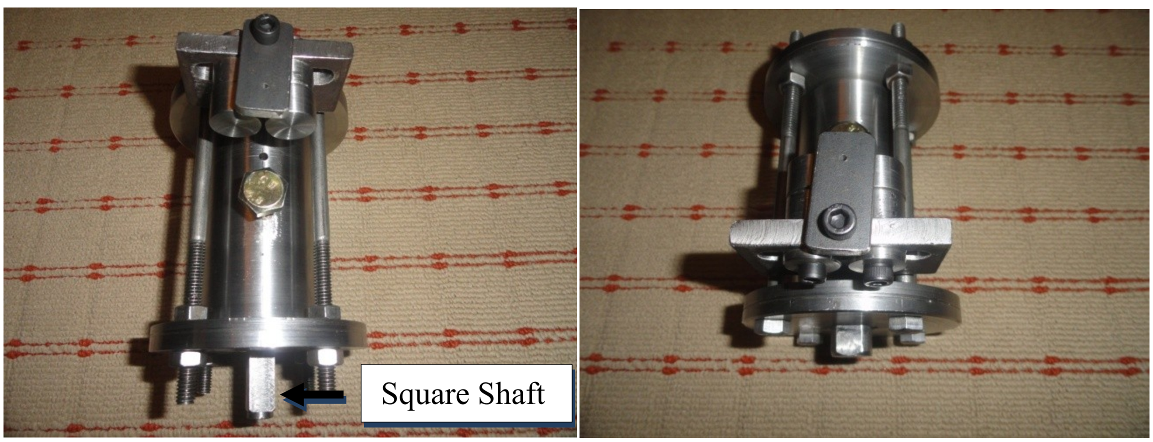


Figure 7-4: Hand Driven Machine Front Viewand Rear View

Figure 7-4 shown the hand operated machine utilized in the experimental testing process. Wire is fed through tiny guide hole through adjustable roller set which used to form its flat shape and entered to the feeding hole of die nut accommodated in the housing and securely fixed by the hexagonal bolt. Shaft is mounted on two bearings fixed to the two flanges at two ends. Provision is kept for rotating square bar by using wrench.

7.2.2 Test Results in First Attempt

Testing of process by hand operation made by using wrench of size 19mm rotating with approximately 0.1kg force at rotational speed of 1 turn per second for a period of 2 minutes. During the rotating of square bar force exerted to the wrench increased gradually and reached to 5kg force approximately. Result of the primary testing of prototype model failed for continuous operation as all the material went inside did not come out and stuck inside the machine. Results of basic operations were as follows.

- Feeding of wire to the rollers tested and completed successfully
- Forming of wire by rollers tested and completed successfully
- Feeding of wire to the bending die nut tested and completed successfully
- Bending of wire by square shaft tested and completed successfully
- Moving of bent wire through rotating square shaft tested and it was unsuccessful

7.2.3 Calculation of Experimental Power

By using Force excreted through wrench in above testing Power and Torque required for rotating square bar can be calculated by using following equation formulated from elementary principal`s in physics. Please refer following Figure 7-5

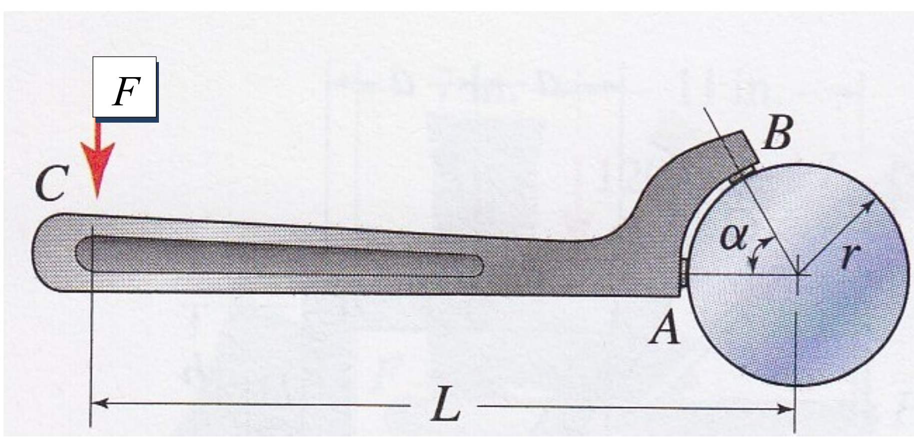


Figure 7-5: Method of Applying Torque

$T = FgL$……………………………………………………………………Equation 7-1

$P = T\omega$ ……………………………………………………………………Equation 7-2

Force exerted through wrench in above testing and power and torque calculated and tabulated in following table no 7-1

Table 7-1: Power Consumption for First Attempt – Gauge 24 Wire

No of turn	L	F	T = FgL	Power at 1 Rev/S(P)	Power at 25 Rev/s (P)
	m	Kg	Nm	W	W
1.00	0.24	0.5	1.18	7.39	184.63
20.00	0.24	0.5	1.18	7.39	184.63
40.00	0.24	0.7	1.65	10.34	258.48
60.00	0.24	0.8	1.88	11.82	295.41
80.00	0.24	0.9	2.12	13.29	332.34
100.00	0.24	1	2.35	14.77	369.26
120.00	0.24	2	4.70	29.54	738.53
140.00	0.24	3	7.06	44.31	1,107.79
160.00	0.24	5	11.76	73.85	1,846.32

This power is utilized for forming, bending and pushing against friction force however cutting operation has not taken place in this instant of the manual testing of manufacturing process.

Accordingly following graphs in Figures 7- 6 to 7-8 are drawn in order to analyze performance of the prototype machine with practical measurements.

Exponential pattern represents in the graph as a result of increasing the torque continuously.

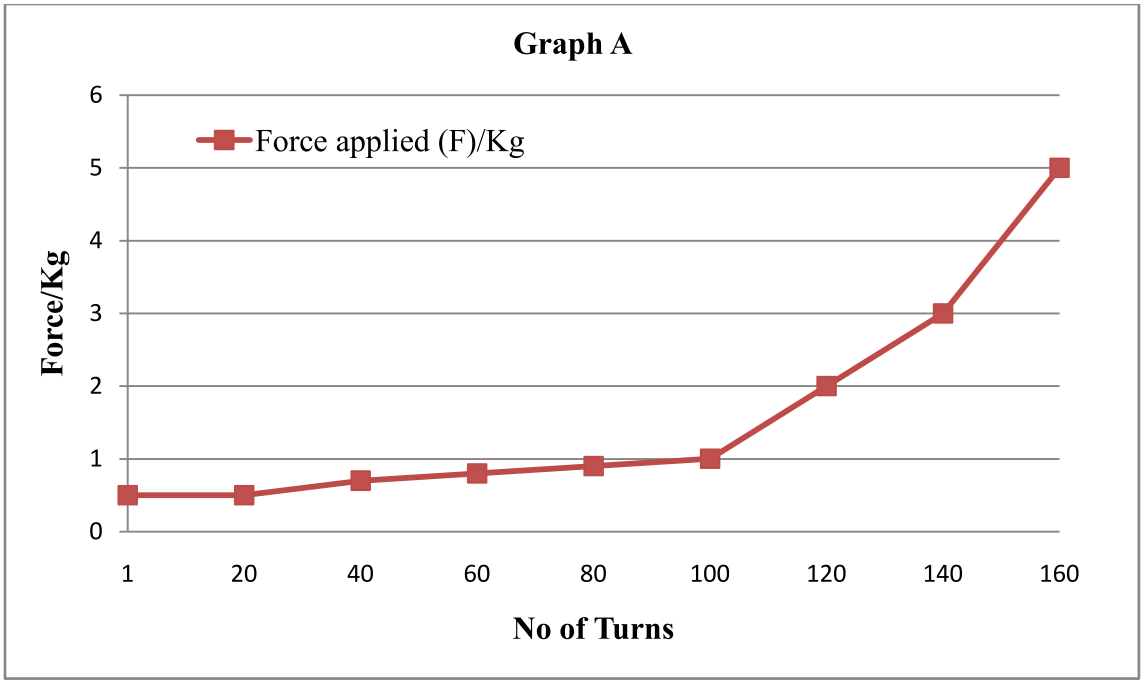


Figure 7-6 : Force

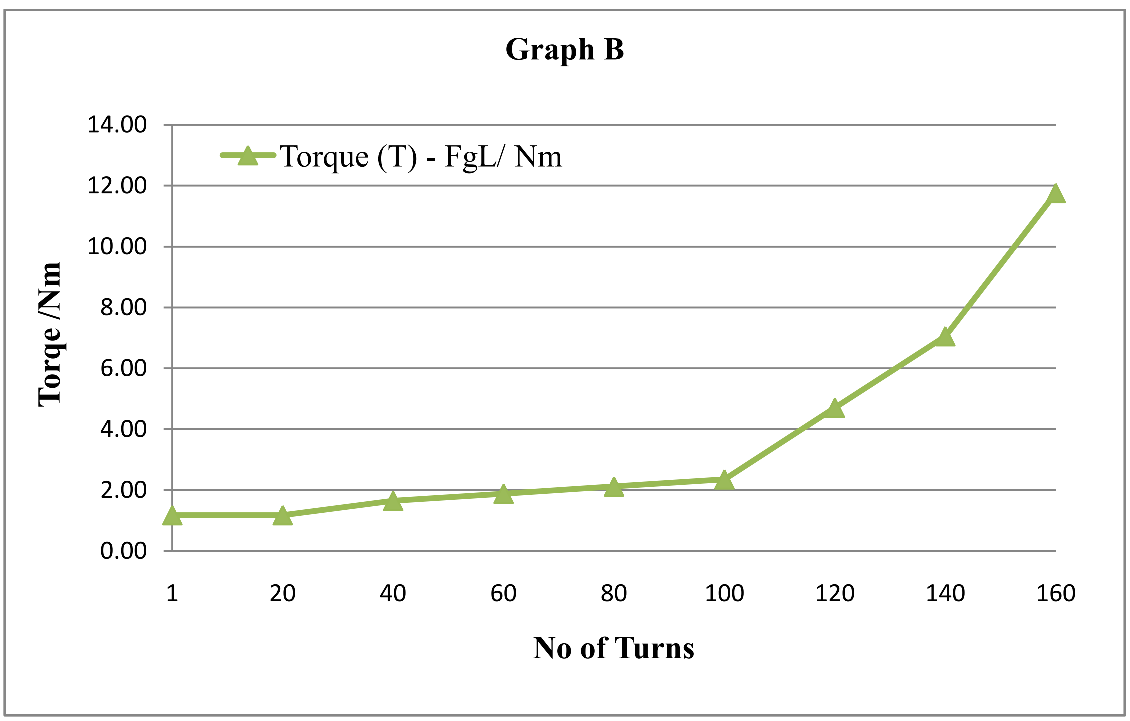


Figure 7-7 : Torque

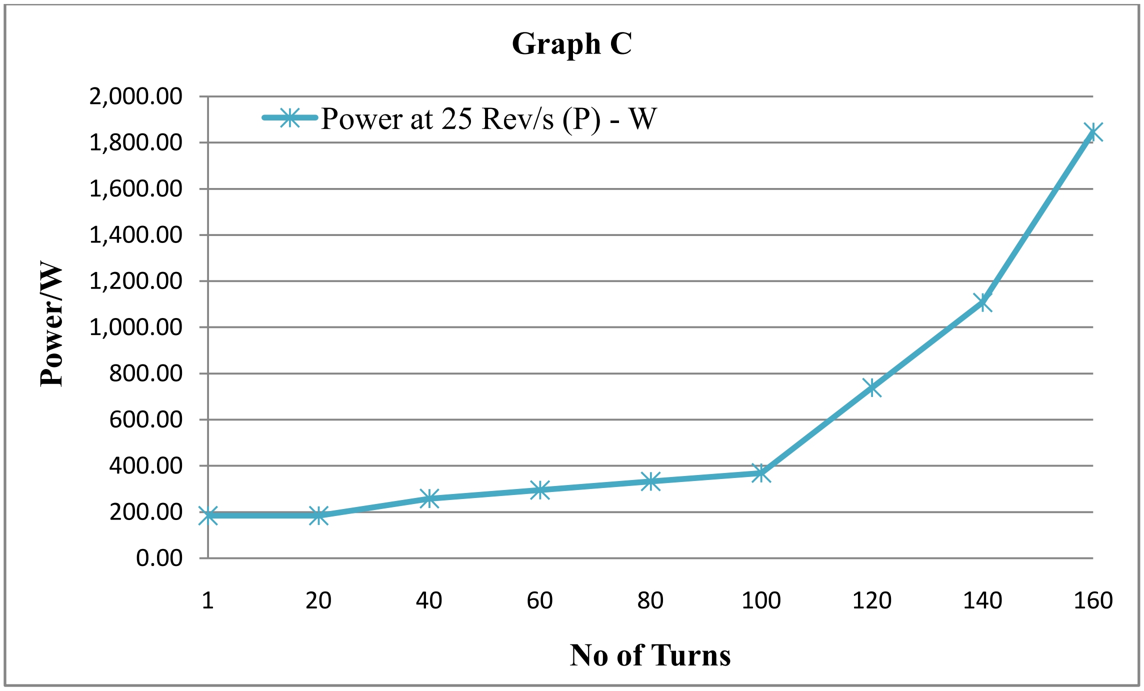


Figure 7-8: Power

7.2.4 Problems Encountered in First Attempt

Reasons identified for increasing torque are as follows

- Friction force developed due to increasing number of turns wrapped and rotating around square bar through die nut and moving along the square bar
- Length of the die nut was too high of around 75mm
- Feeding through square bar needed high torque

7.2.5 Second Attempt and Problems Encountered

By using result obtained from first attempt, whole machine configuration reduced and simplified to nut and square shaft configuration as shown in Figure 7-9 by taking following actions

- Reduced length of the Die Nut from 75mm to 10mm and reduced exerting force

- Triangular shaped thread replaced by square shape thread to stop deformation of the square corners of the stapler pins
- Increased the holding end length of the square shaft for hand driven without using tools for testing
- Separate the forming operation from other operations of bending and cutting
- Applied thin lubrication oil film to the wire to reduce friction force

Figure 7-9: Machine Configuration and Semi Processed Product

In this attempt, all the operations tested were very much successful and torque applied by free hand was very low hence the torque has not been measured. Performance of second attempt is as follows

- Feeding of wire to the bending die nut tested and completed successfully
- Bending of wire by square shaft tested and completed successfully
- Moving of bent wire through rotating square shaft tested and completed successfully
- Having used a square shape thread for die nut eliminated the edge deformation (at the two bending corners of the stapler pin) caused by the triangular thread

7.2.6 Third Attempt on Developing Mechanical Components

This attempt planned to verify and confirm the continuous feeding of wire and wire cutting operation without any kind of failure from the beginning to end of the production process. Cutting mechanism as proposed in conceptual operation design has been accommodated to the hand machine. Accordingly, components fabricated and used for this purpose are shown in following Figure 7-10 and Figure 7-11.

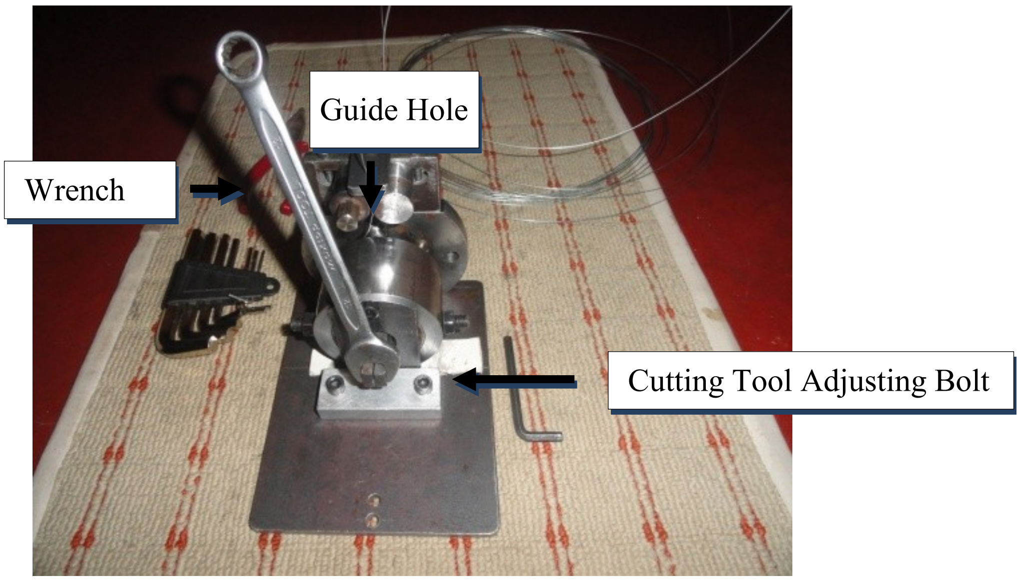


Figure 7-10 : Machine Configuration – Side View

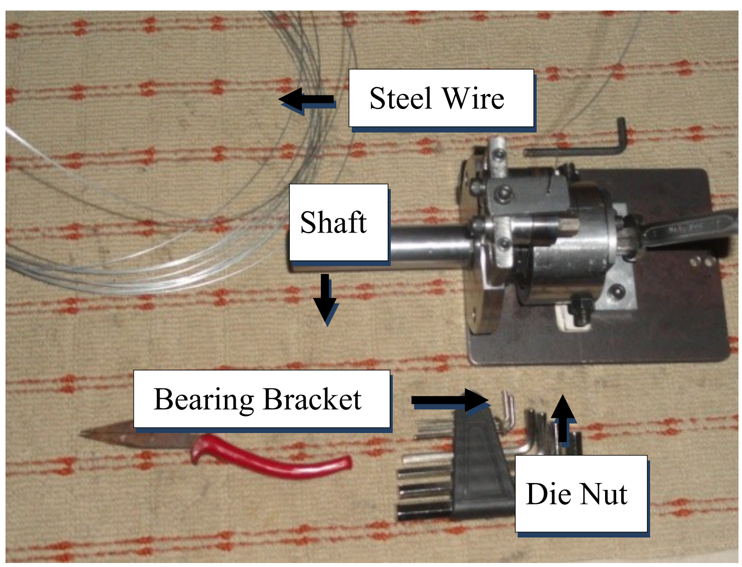


Figure 7-11 : Machine Configuration – Front View

Figure 7-10 and 7-11depicts the hand operated machine utilized in the experimental testing process completed successfully. Wire is fed through tiny guide hole through adjustable roller set which used to form its flat shape as earlier attempt. Square threaded die nut securely fixed to the bearing bracket with the shaft too fixed on deep grove ball bearing at one end. Other end passes through square shape cutting tool post and gap is provided to pass wrapped steel wire along the square bar hence cutter tools are too driven by the square bar. Provision is kept for rotating square bar by using wrench.

Hand operation is done with lubricating oil and observed a drastic reduction of torque hence this operation could be done with a minimum power requirement.

7.2.7 Test Results in Third Attempt

Testing of process by hand operation made by using wrench of size 19mm rotating with approximately 0.2kg force at rotational speed of 1 turn per second for a period of 2 minutes. During the rotating of square bar force exerted to the wrench increased gradually and reached to 0.6 kg force approximately.

Result of the secondary testing of prototype model was successful and also continuously operated as all the material went inside came out and simultaneously cutting operation took place.

For above testing, gauge 24 wire was used initially without flattening it, in order to ensure the successfulness of the hand driven operation, and secondly it was tested including wire flattening operation using the rollers.

After confirming the total process was successful, hand machine was dismantled in order to observe and inspect the hidden operation and results of basic operations are shown in following Figure 7-12.

The testing continued for wires of gauge 20,22,23,25, and 26 but all were unsuccessful.

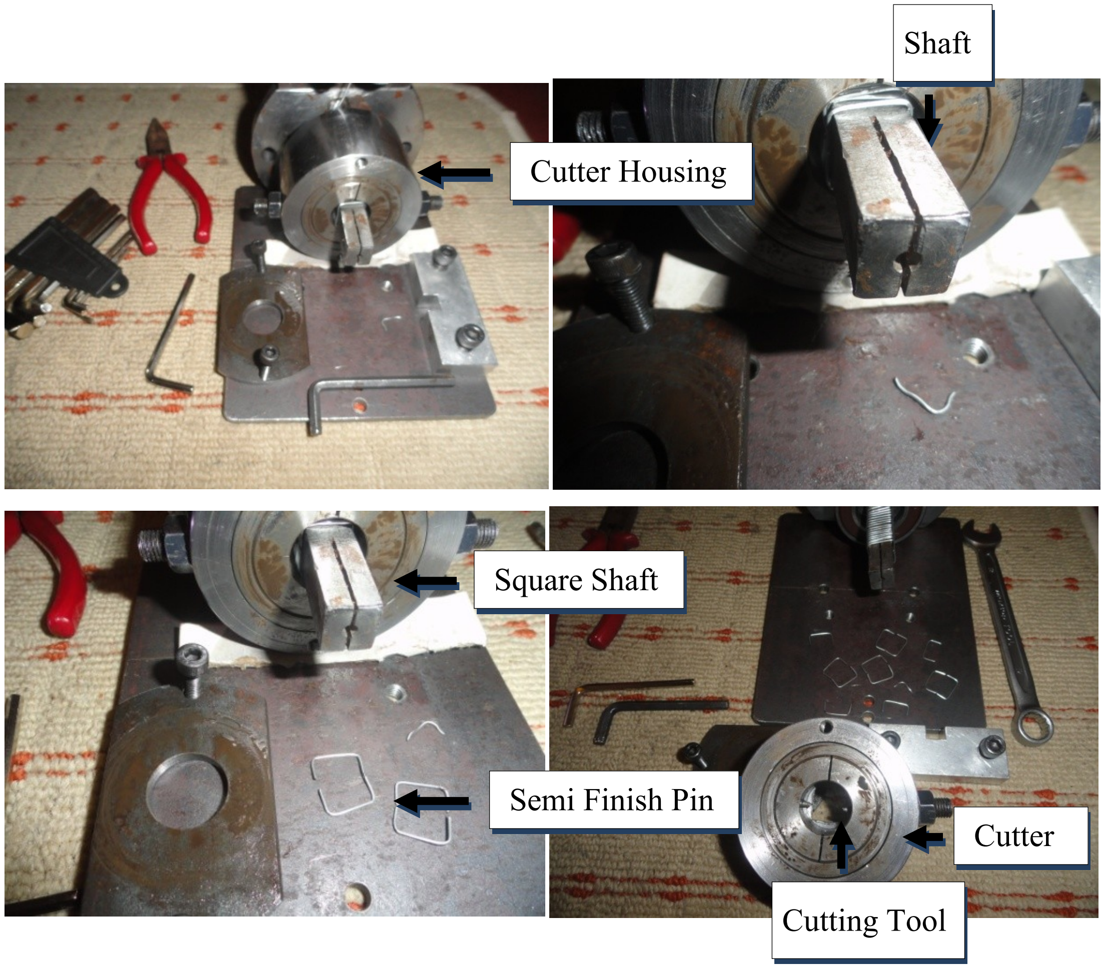


Figure 7-12 : Dismantled Components and Semi Finished product

Performance of third attempt is as follows

- Feeding of wire to the rollers tested and completed successfully
- Forming of wire by rollers tested and completed successfully
- Feeding of wire to the bending die nut tested and completed successfully
- Bending of wire by square shaft tested and completed successfully
- Moving of bent wire through rotating square shaft tested and it was unsuccessful
- Rotation of cutting tool tested and completed successfully
- Cutting operation tested and completed successfully

7.2.8 Calculation of Experimental Power

$T = FgL$……………………………………………………………………Equation 7-3

$P = T\omega$ ……………………………………………………………………..Equation 7-4

Force exerted through wrench in above testing and power and torque calculated and tabulated in following table no 7-1 using above equations same as the previous occasion.

Table 7-2: Power Consumption for Third Attempt – Gauge 24 Wire

No of turn	L m	F Kg	$T = FgL$ Nm	Power at 1 Rev/S (P) - W	Power at 25 Rev/s (P) - W
1	0.24	0.2	0.47	2.95	73.85
20	0.24	0.25	0.59	3.69	92.32
40	0.24	0.3	0.71	4.43	110.78
60	0.24	0.4	0.94	5.91	147.71
80	0.24	0.5	1.18	7.39	184.63
100	0.24	0.6	1.41	8.86	221.56
120	0.24	0.6	1.41	8.86	221.56
140	0.24	0.6	1.41	8.86	221.56
160	0.24	0.6	1.41	8.86	221.56

This power is utilized for forming, bending and pushing against friction force and cutting operation of the manual testing of manufacturing process.

Accordingly following graphs in Figures 7- 13 to 7-15are drawn in order to analyze performance of the prototype machine with practical measurements.

Horizontal pattern at final stage represents in the graph as a result of the torque remain same.

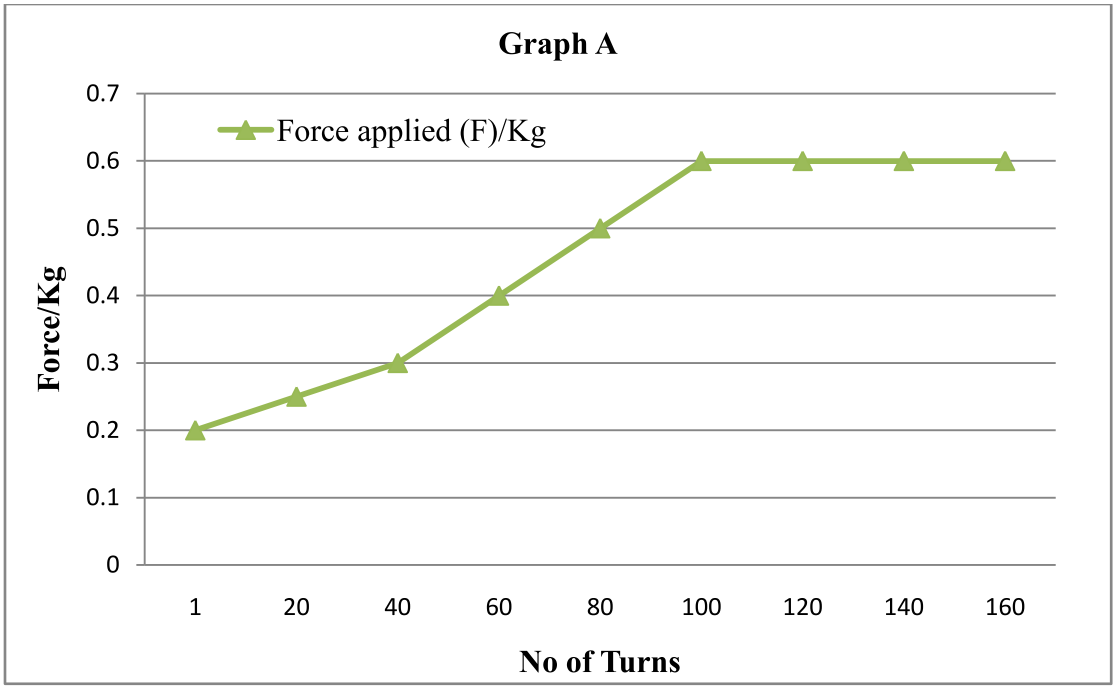


Figure 7-13 : Force

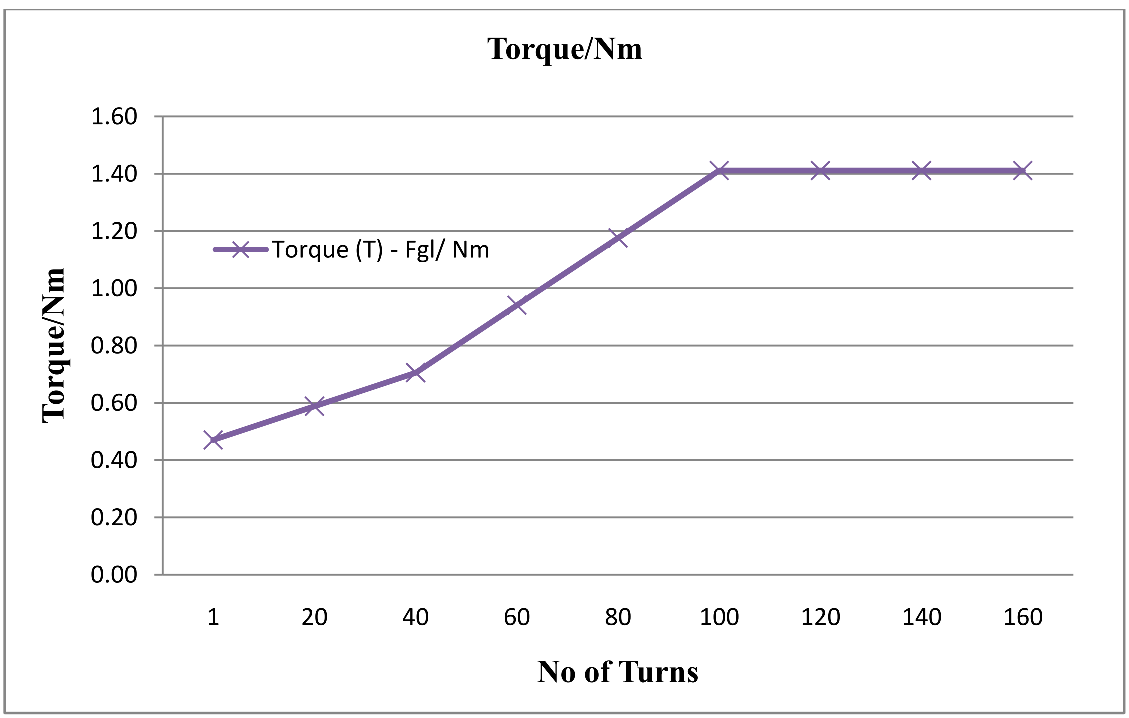


Figure 7-14 : Torque

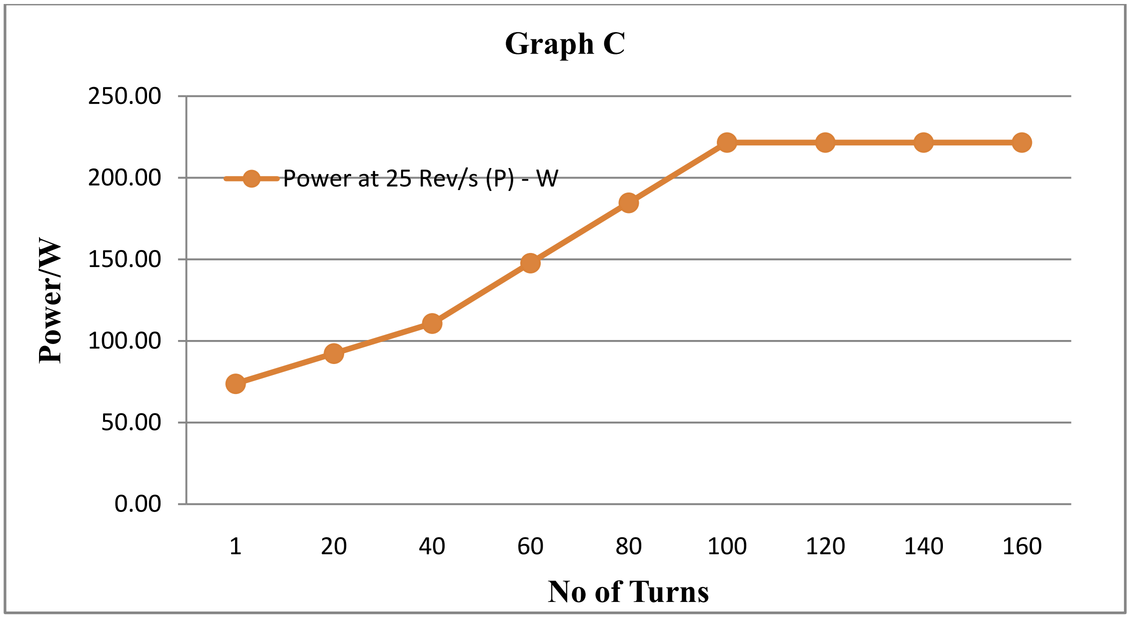


Figure 7-15:Power

7.2.9 Third Attempt and Successful Hand Operation

Third attempt is successful only for wire gauge 24, from initial step to final step without failure and other wires of gauge 20,22,23,25, and 26 could not be fed continuously due to breaking of wire at several occasions due to reasons mentioned below in tabulated form.

Table 7-3: Mode of Failure of Wire of Continuous Feeding

Gauge	Status	Appropriate Improvement
20	Failure at rollers	Increase the roller Diameter
22	Failure at rollers	Increase the roller Diameter
23	Failure at die nut	Modification of die nut feeding location
24	Successful	-
25	Jammed Inside	Modification of die nut thread
26	Jammed Inside	Modification of die nut thread

8.0 Machine Design

With respect to the experimental results of conceptual design and the trial attempts of the machine considered driving free roller with lubrication oil as a result of frequent failure of the wire while being fed to the die nut. A single phase induction motor is used to provide power for bending, moving and cutting operation simultaneously. This motor has been operated with a variable speed control system with a regulator to start operation at zero speed and changed to steady state speed of the steel wire process in order to prevent frequent failure of the wire by unexpected increasing of the tension of the wire under processing.

To produce a successful motorized machine, modifications of mechanical components and operation sequence have been done in several times.

8.1 Selection of Motor and Machine Speed

Experimental power requirement for producing 24/6 staple pin is calculated as 221.56W from table no 7-2 and the theoretical power requirement is calculated214.27 W from table no 6-14 for same size. Both experimental and theoretical values are almost same. Therefore to run all size of wire gauges with same motor it is required to select maximum power requirement. According to the table no 6-14 maximum power requirements is 1,495.57 W.

If consider 50% efficiency of the machine, required power is 2,991.14W

Electric current required to run the Machine = 2,991.14 W/(230VX 0.9) = 14.4 A

In order to run the machine in domestic environment it is required to run motor by using single phase 230V supply below 5A current for maintaining safety to the appliances instead of using 15 A plug base.

By backward calculation, to run the machine by 0.5 HP , (372.85 W) motor using single phase 230V motor current can be calculated.

Electric current required to run the machine= 372.85 W/(230VX 0.9) = 1.8 A

Therefore reduction of speed by using gear a box and chain drives have been introduced to the machine and overall speed reduction is calculated as follows.

Overall speed reduction = Actual Power of motor/ Selected Power of Motor

Overall speed reduction = 2,991.14 W / 372.85 W = 8.02

Therefore output speed of the square bar = 1500 RPM / 8 = 187.5 RPM

Single phase 230V, 1500RPM, 0.5HP induction motor of Model YL7124, Make JULANTE, China selected to run the machine. It can be operated in safely in domestic environment and easy to find in the market.

8.2 Variable Speed Controller of the Induction Motor

Importance of motor speed controller is to eliminate tensile failure of wire at the start due to sudden impact act on wire between the rollers and the die nut feeding point. It is capable of increasing the production capacity of various wire gauges used in the operation in order to comply with torque and power.

Dimmer switch Model DS 1500 and Make *KHiND,* Malaysia of 1500W is used for this purpose. Circuit of the dimmer is shown in following Figure8-1

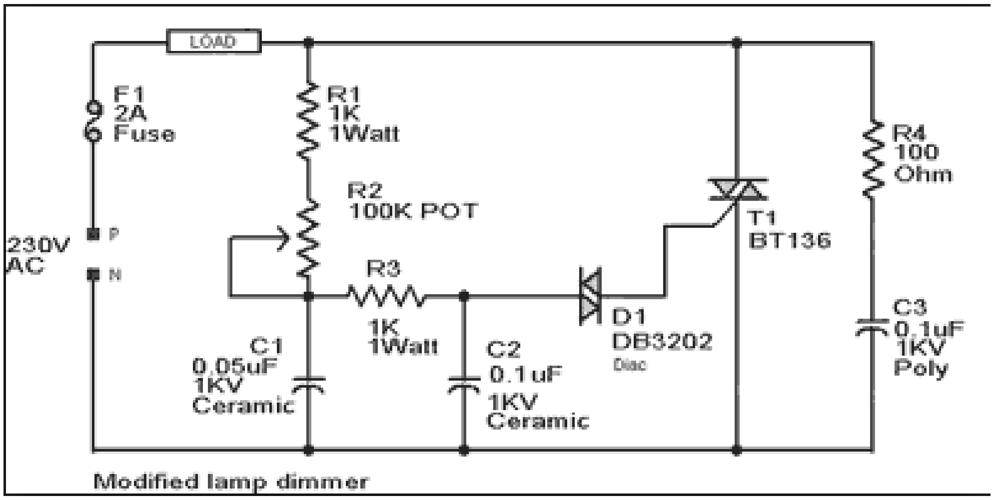


Figure 8-1: Dimmer Circuit Used for Induction Motor Speed Control

8.3 Machine Design and Testing of Performance – Stage 1

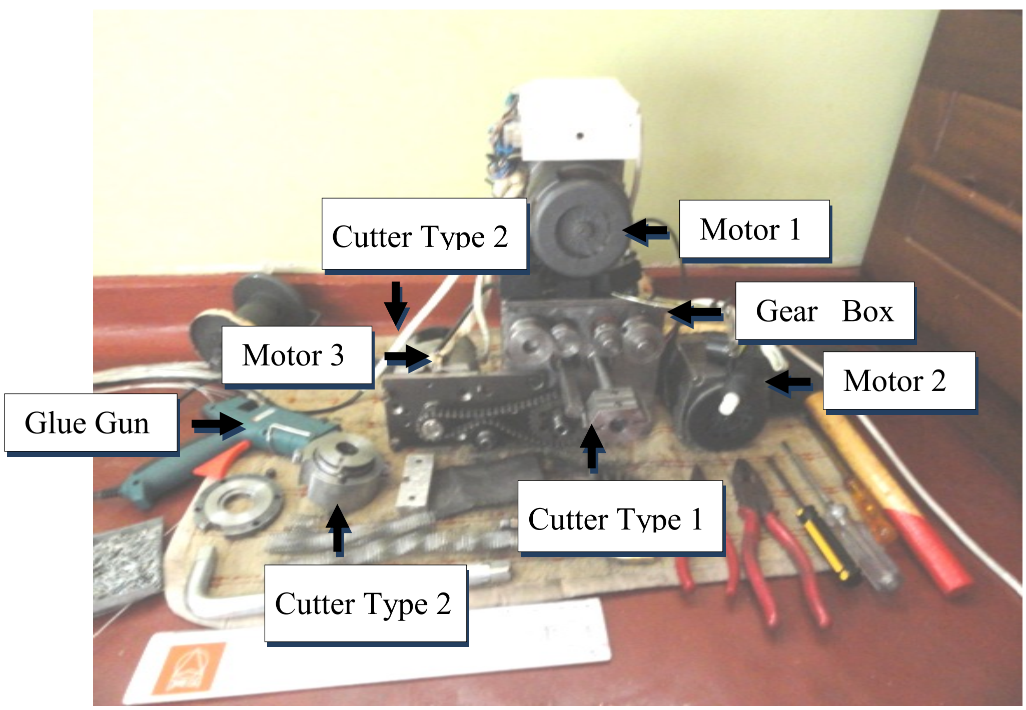


Figure 8-2: Machine Configuration – Stage 1

In this stage three, single phase induction motors of 80W each are used, step by step when increasing the power by manually switching on the respective motor when slowing the process due to increase of torque for various wire gauges for this experiment. Reduction gear box incorporated to the machine around 1:4 reduction ratio and variable speed controller has not been used.

Using wire cutter is same as proposed in the conceptual process, type 1. Function of cutter worked perfectly but failed to operate continuously as a result of deterioration of the shape of the stapler pin due to deformation while rotating. Therefore type 2 cutter in conceptual design required to be adapted to the next development.

Gluing of pins has been tested by using glue gun which generally used for soldering of Printed Circuit Boards. Process of gluing by this method has been successfully completed but further development required. 100w glue gun is used for testing the gluing operation. Nozzle of glue is modified by providing hole in order to accommodate wire passes through heated glue in the heating chamber of the glue gun.

In this process, forming to flat shape is tested separately using rollers shown in Figure8-1 from other operations, bending, moving, gluing and cutting operation. Hence power requirement is less compared to total operation; hence gear reduction ratio is selected as 1:4.

All the size of wire gauges, Gauge 20, 22,23, 24, 25 and 26 are tested successfully for a few seconds but continuous operation failed due to sudden increase of power by switching on next motor due to increase the wire tension and occurring tensile failure.

In this instant identified further insufficient facilities for smooth feeding. Therefore further developments have been introduced to second stage of machine design.

8.4 Machine Design and Testing of Performance – Stage 2

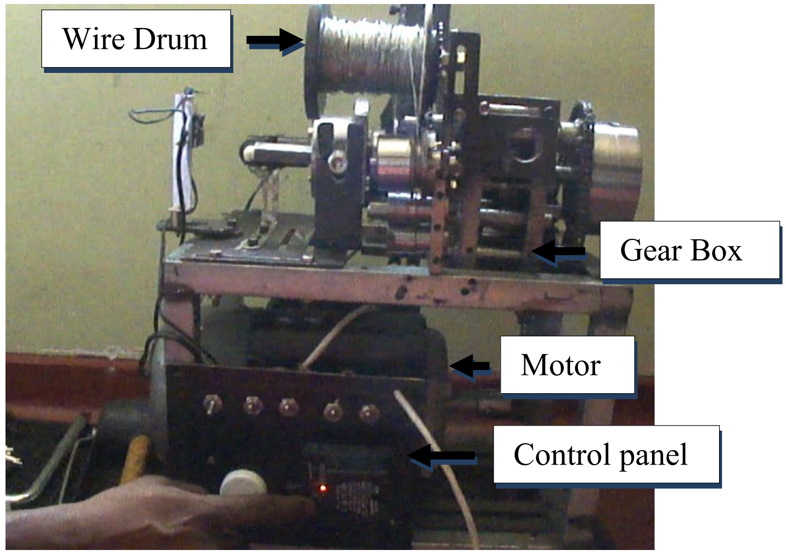


Figure 8-3 : Machine configuration Stage 2

This stage used single phase induction motor of 372.85 W (0.5HP) and a speed controller to increasing the speed when slowing the process due to increasing of torque for various wire gauges for this experiment in order to maintain continuous feeding of wire simultaneously by manually operated speed regulator. Reduction gear box has been incorporated to the machine around 1:8 reduction ratio by intergrading additional chain drives and sprockets.

Cutter is changed, as proposed in the conceptual process, type 2 with further modification by reducing number of tool for two nos. Function of cutter works perfectly but failed to operate continuously as a result of broken tool bit inside the cutter when using gauge 20 wire while rotating. Therefore type 2 cutter in conceptual design requires adapting to next development by increasing the size of cutting tool bits.

Gluing of pin is tested by using same glue gun but mechanically feeding to the hole by using a mechanical actuator coupled to the rotational shaft. Process of gluing by this method is successfully completed but further development required.100w glue gun is used for testing gluing operation. Due to mechanical actuator glue stick consuming drastically hence mechanical feeding of glue is not viable. Therefore free gluing by gravity feeding system is proposed to incorporate in next development stage.

All the sizes of wire gauges, Gauge 20, 22, 23, 24, 25 and 26 tested successfully for a few seconds but continuous operation failed due to sudden failure of cutting tool.

Parting off mechanism for the separating 50 no of stapler pins, installed in this development by using a limit switch and a linear motor of which the supply voltage is 12V DC. To provide DC 12V, 1A power pack is used.

The mechanism is, keep the limit switch aligned with square shaft, maintaining the gap of limit switch and the square shaft end position at the distance of 50 no of stapler pin.

When the glued set of pins touches to the limit switch in on position while rotating, linear motor get switch on and it is actuated and moved its spring loaded arm until hit the set of pins and collapse it. Then it discontinues the power supply to the linear motor and return to the original position with the help of return spring attached to the arm.

There are few number of appliances, therefore control panel has been introduced in this step. Main switch, individual switches for motor, glue gun, heater and switch for DC power pack have been installed in the control panel. Motor speed is controlled by variable speed regulator accommodated in to it.

Having identified further lapses more developments have been introduced to the third stage of machine design in order to overcome those difficulties.

Main machine components used for wire feeding, bending, gluing and cutting operation have been designed by using Solid Works Design Software and are shown in the following figures 8-4 to 8-6.

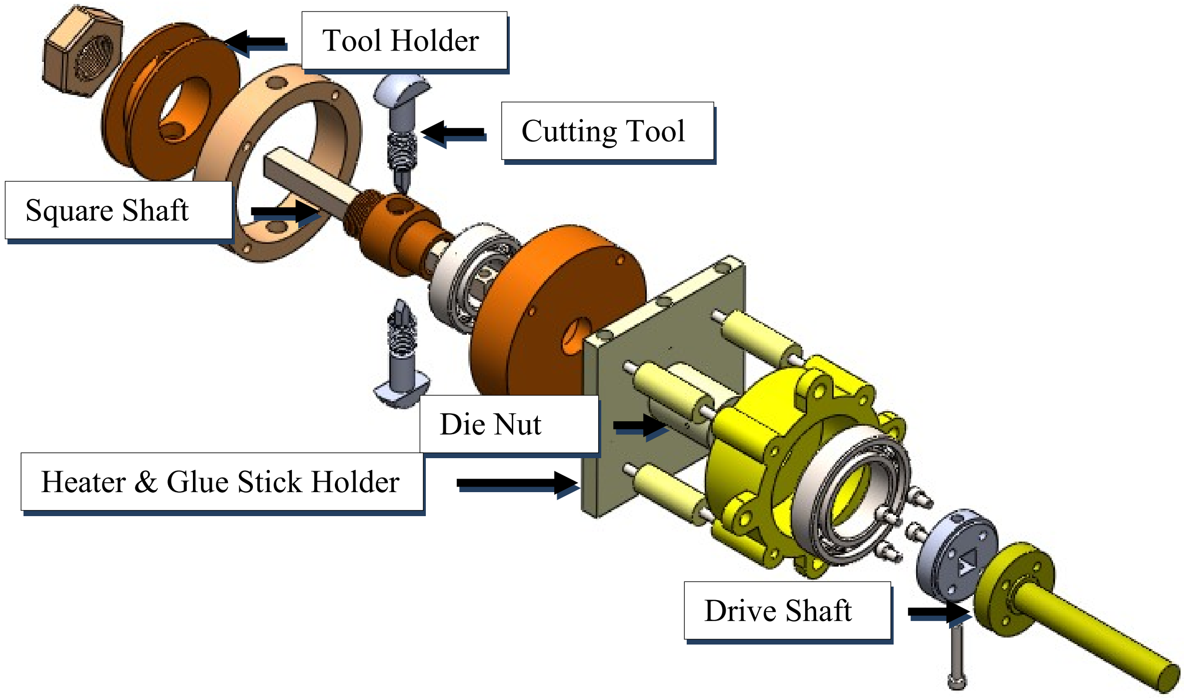


Figure 8-4 : Exploded 3D View

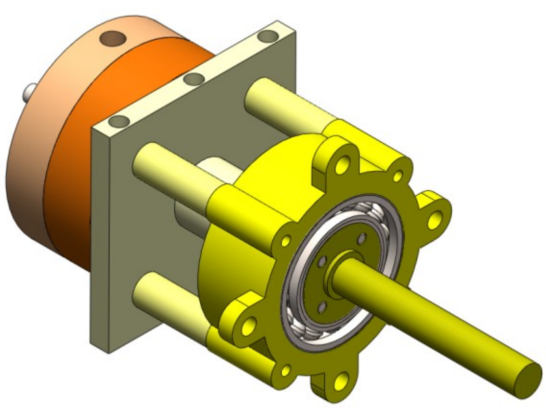


Figure 8-5 : 3D View

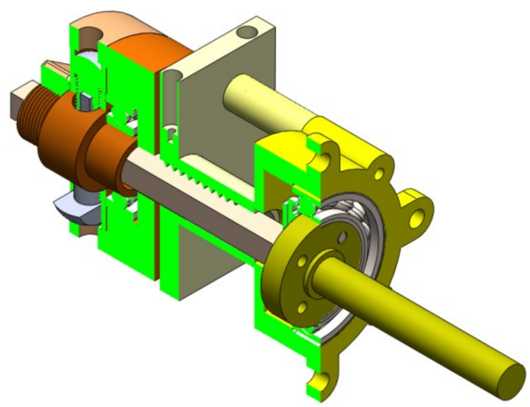


Figure 8-6: 3D Sectional View

8.5 Machine Design and Testing of Performance – Stage 3

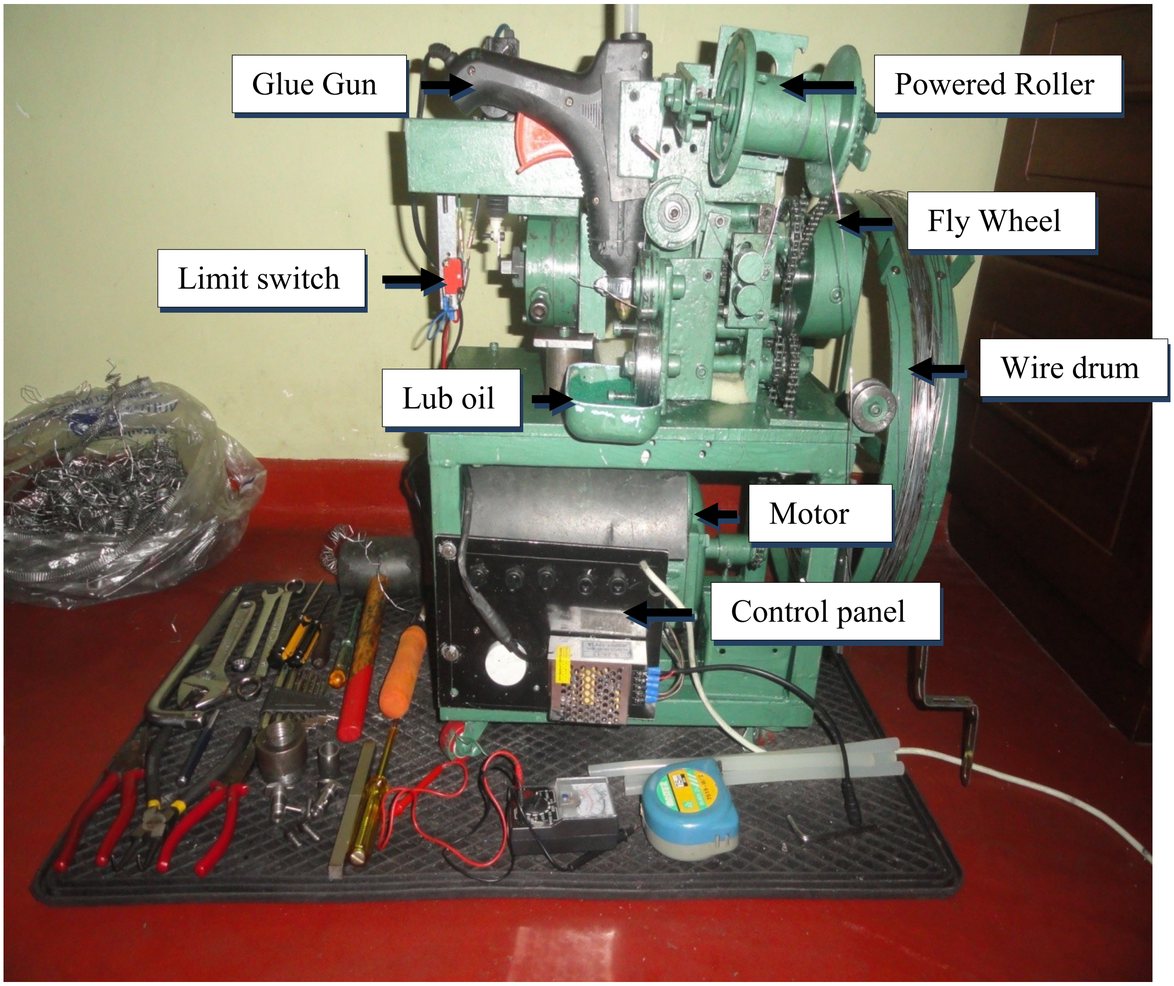


Figure 8-7 : Machine Configuration Stage 3

Complete machine configuration is shown in aboveFigure8-7. It develops to produce stapler pin shape shown in Figure 7-1. Dimensions of the machine components are designed accordingly. Auto CAD and Solid Work, software's are used to design the mechanical components. In this stage single phase induction motor of 372.85 W (0.5HP) as same as previous, same appliances and the control panel with further modifications have been used. Another heater has been installed closer to the cutter feeding point to make sure applying of glue properly.

Bigger sizes of wire drum which is free to rotate and the wire guiding mechanisms with mechanical accessories have been installed to ensure to feeding the wire at correct place.

Lubrication oil container and applying mechanism is installed at wire forming station and integrated to the wire forming rollers.

Rotor type cutter used in previous occasion has been changed, by increasing its size of the mechanical component in compatible with the same mechanism to withstand the frequent failure of cutting tool. Replaceable cutting tool is accommodated to the cutter.

Mechanism of gluing by mechanical system has been changed and allows to freely flowing heated glue therefore glue gun heating chamber is installed vertically and feeding is due to gravitational force. If the gum stuck in the feeding chamber a hand trigger is available for apply external force to accelerate gluing operation. Extra heater has been provided after the bending operation. This is to pre heat the mechanical components and reheated the cooled glue at the initial stage of the operation after starting the production until getting into the steady state temperature of the mechanical components.

Same parting off mechanism and control panel is used as previous with changing the accessories of the control panel.

All the sizes of wire gauges, Gauge 20, 22,23,24,25 and 26 are tested successfully

8.6 Power, Speed, Torque and Production Capacity Characteristics

In this manufacturing process two numbers of stapler pin are produced at one turn of the shaft and required torque for rotating the system is varying according to the gauge of wire under process.

All the results obtained from the theoretical and experimental approach, power, speed, and torque, production capacity characteristics calculated and tabulated in following table no 8-1 for the all types of wire gauges used.

In order to obtain production capacity characteristics assumed that rotor speed can enhance using variable speed gear drive integrating to the regulator. Accordingly required torque for the small gauge wire can be run at higher speed while higher size wire gauge can run at slow speed by using same motor.

Table 8-1 : Performance Characteristics for Gauge 20, 22 and 23

Description	Units	Gauge 20	Gauge 22	Gauge 23
Rotor				
Theoretical power (at 1500RPM)	W	1,495.57	550.81	300.59
Measured power	W	-	-	-
Power Required (at 1500RPM)	W	1,495.57	550.81	300.59
Overall Efficiency		0.50	0.50	0.50
Total Power Required (at 1500RPM)	W	2,991.14	1,101.62	601.18
Actual Torque at 1500rpm	Nm	19.05	7.02	3.83
Motor				
Power of Motor Selected	W	372.85	372.85	372.85
Torque at 1500rpm	Nm	2.37	2.37	2.37
Require reduction ratio		8.02	2.95	1.61
Selected reduction ratio		8.00	3.00	2.00
Required Torque at 1500rpm	Nm	2.38	2.34	1.91
Speed of Motor	Rad/s	156.56	156.10	156.10
Speed of Motor	RPM	1,495.82	1,491.40	1,491.40
Production Capacity				
Speed of Rotor	RPM	186.98	497.13	745.70
No of pins produce	No/min	373.95	994.27	1,491.40
No of Packet of 1000 pins	Packet/min	0.37	0.99	1.49
No of Packet of 1000 pins	Packet/Hour	22.44	59.66	89.48
Rated Capacity (Theoretical)	Packet/Hour	22.00	60.00	90.00

Table 8-2 : Performance Characteristics for Gauge 24, 25 and 26

Description	Units	Gauge 24	Gauge 25	Gauge 26
Rotor				
Theoretical power (at 1500RPM)	W	214.27	148.42	101.36
Measured power	W	221.72	-	-
Power Required (at 1500RPM)	W	214.27	148.42	101.36
Overall Efficiency		0.50	0.50	0.50
Total Power Required (at 1500RPM)	W	428.54	296.84	202.73
Actual Torque at 1500rpm	Nm	2.73	1.89	1.29
Motor				
Power of Motor Selected	W	372.85	372.85	372.85
Torque at 1500rpm	Nm	2.37	2.37	2.37
Require reduction ratio		1.15	0.80	0.54
Selected reduction ratio		1.50	1.00	0.50
Required Torque at 1500rpm	Nm	1.82	1.89	2.58
Speed of Motor	Rad/s	156.10	156.10	156.10
Speed of Motor	RPM	1,491.40	1,491.40	1,491.40
Production Capacity				
Speed of Rotor	RPM	994.27	1,491.40	2,982.80
No of pins produce	No/min	1,988.53	2,982.80	5,965.60
No of Packet of 1000 pins	Packet/min	1.99	2.98	5.97
No of Packet of 1000 pins	Packet/Hour	119.31	178.97	357.94
Rated Capacity (Theoretical)	Packet/Hour	120.00	179.00	358.00

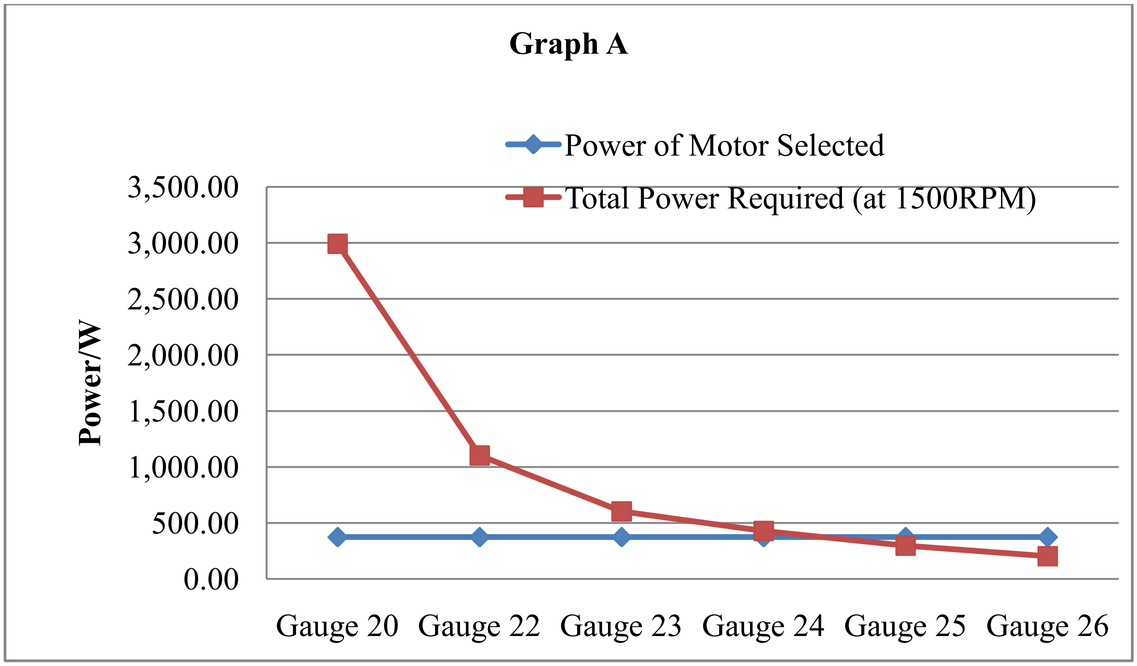


Figure 8-8 : Power

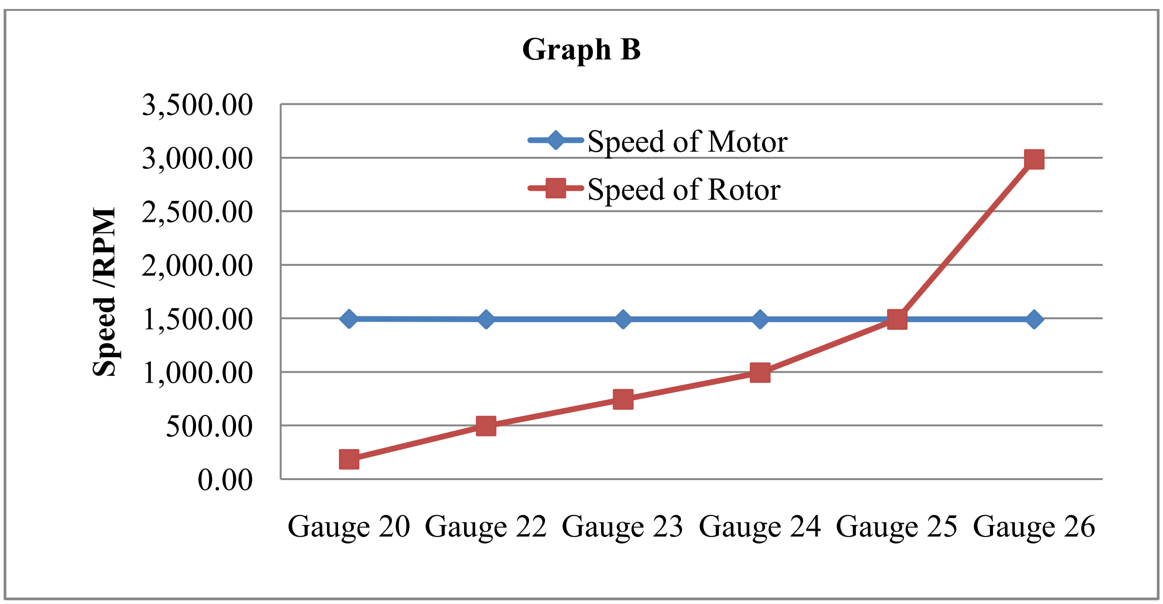


Figure 8-9 : Speed

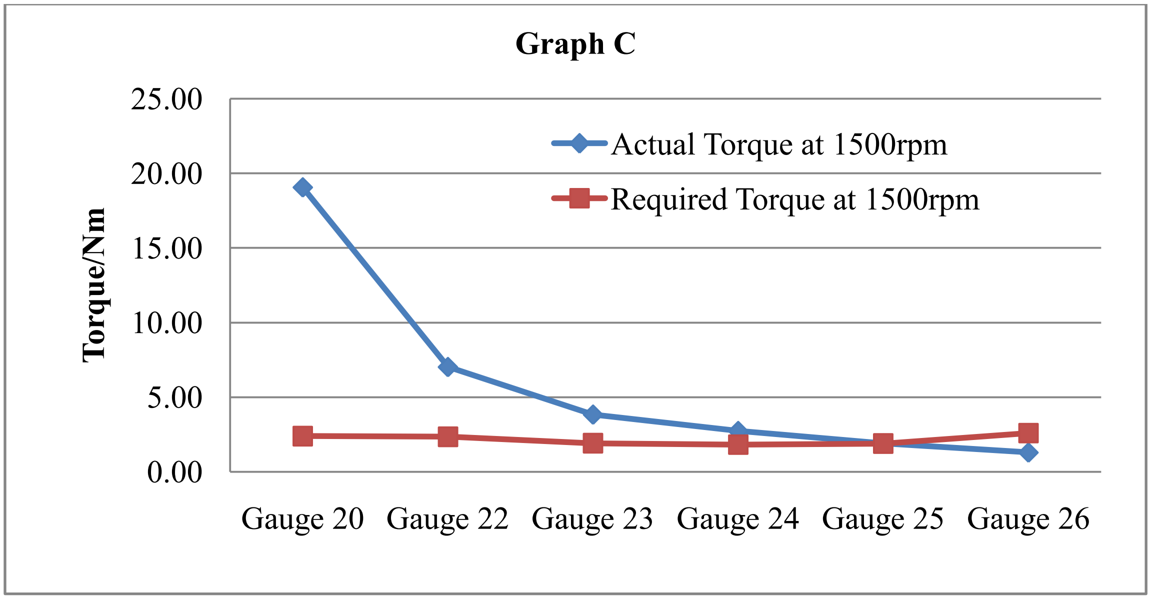


Figure 8-10 : Torque

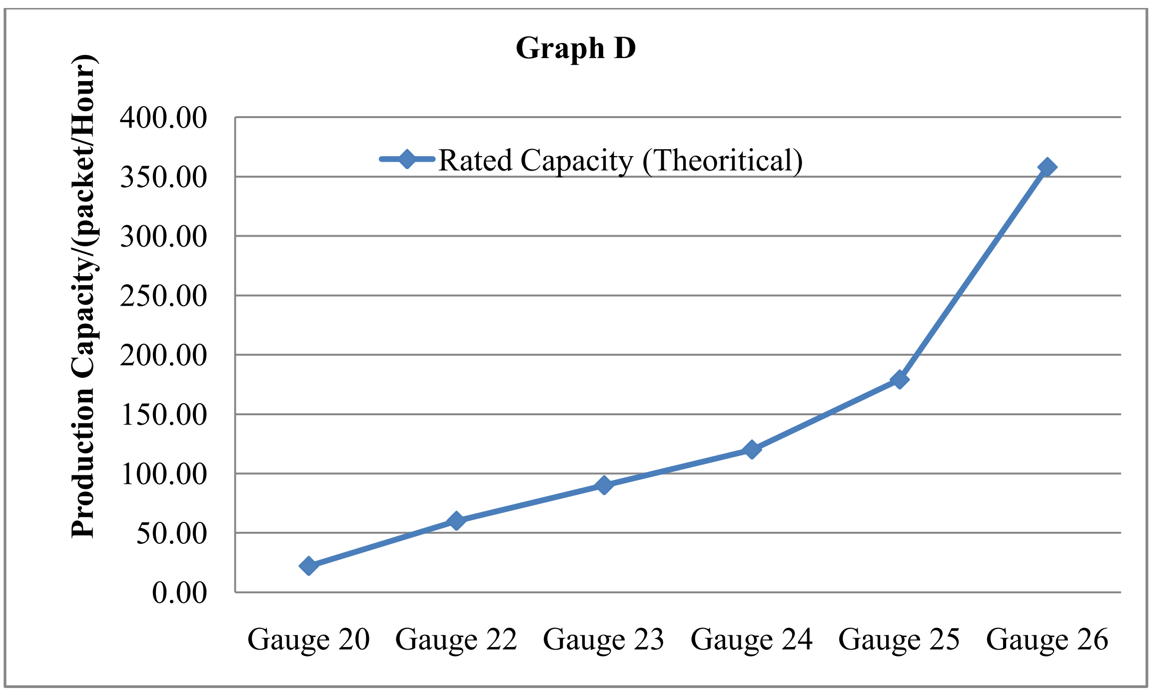


Figure 8-11 : Rated Capacity

8.7 Successful Motorized Operation

Continuous feeding of wire ensured by freely rotated wire drum passes through the slipping rotor drum powered by same motor by using chain drive. Please refer Figure8-7. If the wire drum stuck due to lack of inertia, this mechanism provides power to rotate the wire drum.

Wire then passes through freely rotating roller which needs to maintain tension of the wire while feeding. However forming of wire is not in action in this location. Guide rollers and arms accommodated in this area moves wire to the next process.

Hand operation is tested with lubricating oil and observed drastically reduction of torque; hence this operation can be done with minimum power requirement. Therefore it is applied to the motorized operation too. Engine oil is use as lubrication oil in this process which is available in any petroleum shed in Sri Lanka.

After passing through the forming rollers with lubrication, next step is applying heated glue. Therefore it passes through heated glue chamber and enters to the feeding point of the die nut. Correct angle of feeding have to be maintained by adjustable die nut otherwise frequent failure of wire takes place due to tension. Then it enters to the die nut which use for bending and moving operation. When the wire comes out from the die nut, all are closely packed together and bond with the glue. Extra heat generated in this process is significantly high and it is used for self heating of the mechanical components. Then it passes through the secondary heater and enters to the cutter through square section, it enables to distribute the non evenly applied glue on the wrapped wire to heat further and applying evenly while rotating and moving along the square bar. While rotating the cutter, cutting action takes place and produces two stapler pins at one rotation of square shaft. Then parting off action takes place using same mechanism previously being used producing 50 no of bonded stapler pins together.

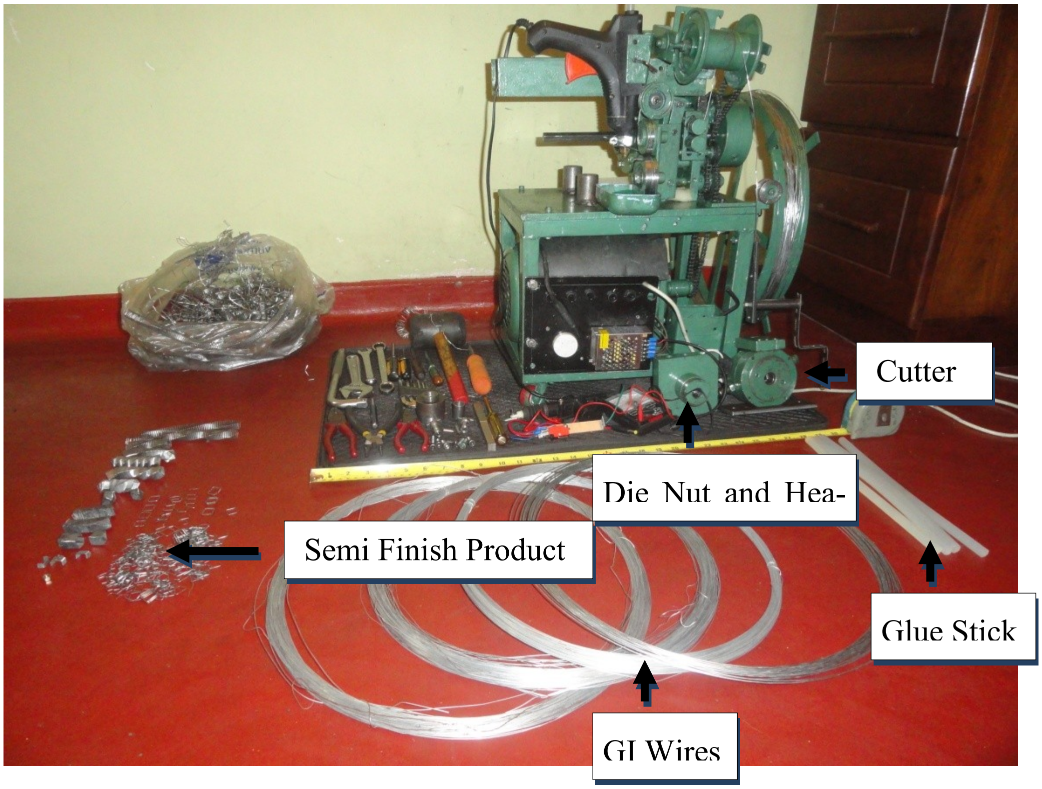


Figure 8-12 : Machine parts, Semi Finish product and Glue Stick

Figure 8-13: Lubrication Mechanism Figure 8-14 : Product Come Out from the Cutter

8.8 Startup Procedure

Startup operation is the most important part in the production process. Through the trial and error correction procedure, sequence of the startup operation is setup as follows.

Please refer Figure 8-9

1. Remove the cutter and the extra heater and die nut from the square shaft
2. Enter the wire through guides and idle rollers in the order
3. Enter the wire to first roller set and rotate the roller by hand to pass through roller gap.
4. Pull the wire and pass through the rest of idle roller and guides
5. Enter the wire to forming roller set and rotate the roller by hand to pass through roller gap.
6. Entre the wire to die nut feeding hole and push die nut to the square shaft.
7. Ensure the wire comes out from the other end of the die nut and fix the die nut to the housing properly.
8. Ensure properly center the die nut to the square shaft
9. Switch on the main switch, pre heater and glue gun subsequently, then ensure heated glue is fed to the wire properly.
10. Start the motor and ensure wrapping of wire and bending of wire take place and moves to end of the square shaft
11. Enter the cutter to square shaft and center it properly. Fix the cutter housing properly.
12. Adjust the cutting tool by measuring the gaps and ensure the cutting operation by rotating shaft by hand force.
13. Start the motor and continue the operation.
14. Ensure the parting off mechanism in order.

9.0 Final Product Quality and Limitations

Measurements of dimensions of stapler pin and standard pin available in the market have been compared and the values are almost same. However finished pin is twisted from its crown edges due to wrapped action around the square bar and increased the overall thickness of the pin by half of the wire thickness. This difference can be minimized by the reduction of thread pitch of the die nut.

Cutting shape of the conventional pin looks like symmetrical as a nail point, but in new production, the cutting edge looks like a wedge shape which gives better advantage for stapling action when used in the stapler machine.

Product quality of the novel processed pin requires to be improved further due to following reasons.

Gravity feeding mechanism for applying glue is done perfectly but it has not distributed evenly on the entire surface of the stapler pin. It was observed that amount of glue applied was too high and required to be controlled further.

Twisting action of the pin has not affected the feeding to the staple machine of size 26/6; however it is required to be eliminated by secondary process.

Sharp edges of the pin and the shape have to be improved by maintaining smooth machining of the machine parts in accurate dimensions specially for the threaded nut and the square shaft used in the bending mechanism.

Stapler pins produced using thicker wires have deformed it’s corner edges and should be improved by increasing depth and width of the square thread in the die nut hence it is required to change the die nut when using different sizes of wire gauge

10.0 Conclusion

Mechanism of the novel process has been successfully completed in this research and it can be applied for use in the industry with further development of connected functions in the overall process. Speed and the capacity of the machine directly relates to the rotor speed; therefore it is capable of competing with high capacity machines available in the market. After ensuring smooth operation of novel machine, next step is to speed up the machine by high speed motors to increase the maximum production capacity and also, the entire operation has to be monitored by using sensors and actuators.

Feeding mechanism of wire product by using nut and bolt principle can be utilized in wire processing industries sine this mechanism has the capability to increase the production capacity.

Rotational cutting operation using cam mechanism can be utilized in wire processing industries.

Use of heat generation during the process by friction between moving parts can be utilized for drying glue; hence able to reduce heating power.

Novel production process is viable to use in the stapler pin manufacturing industry with further improvement of the smooth operation in the process. Machine has to be run with high speed motor and enhance production capacity.

Mechanical automating of cutting process can be replaced by electrically operated cutting action by introducing linear motors to the cutting tool actuation. Accordingly cutting position can be offset to produce various sizes of stapler pins. Different sizes of square bars can be used for producing different sizes and shapes of the stapler pins.

11.0 References

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