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DEVELOPMENT OF PNEUMATIC CLAMPING AND SHEARING MACHINE

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ABSTRACT

To obtain a high degree of flexibility and excellent surface finish in a manufacturing process, a lot of work is done on sheet metal by cutting it into a variety of shapes and sizes. The pneumatic Sheet Metal Clamping and Shearing Machine is one of the modern machines used to efficiently cut Sheet Metal to specification. This project on the Development of Sheet Metal Clamping and Shearing Machine discusses the maximum force that the cylinder actuator can exert on the workpiece, the shearing force required to cut sheet metals of 1.0mm, 1.2mm and 1.5mm for a length of 25mm. Also, a comparison of the time taken to cut sheet metals of 0.45mm, 0.6mm, and 0.8mm for a length of 50mm with a Manual Shearing Machine and Pneumatic Sheet Metal Clamping and Shearing Machine. The time by the Pneumatic Shearing Machine is less than that of the Manual Shearing Machine as shown in the presented table. Moreover, the cutting accuracy of the developed pneumatic Sheet Metal Clamping and Shearing Machine was compared with the Manual Metal Shearing Machine, and observations made, showed that the Pneumatic Clamping and Shearing Machine has greater accuracy than the Manual Shearing Machine as a result of the clamping device on the machine which gives it greater clamping rigidity on the workpiece for the cutting operation to be carried out. The project had been able to address the following: Production time reduction, increase in cutting accuracy, and elimination of manually applied effort.

Keywords: pneumatic, sheet metal, shearing force, shearing machine, actuator.

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INTRODUCTION

Pneumatics denotes the use of pressurized gases to do work. Pneumatic devices are used in many Industrial applications. They are generally appropriate for applications requiring less force than hydraulic applications. They are less expensive than electric applications. Pneumatic devices are designed to use clean dry air as a source of energy. The energy (compressed air) generated from the Compressor is converted into Mechanical energy by an actuator (Linear Cylinder or Air motor). The type of motion produced is dependent on the design of the actuator. For linear motion, air cylinders are used while air motors are used for rotary motions.

In steel processing Industries, metal cutting is an important aspect of the daily activities of the organization. The metal-cutting process can be achieved through one of the following operations:

- Manual metal cutting (use of hacksaw)
- Manual pipe-cutting machine
- Circular cutting machine
- Manual snipping tool
- Power sawing machine
- Band sawing Machine
- Manual Guillotine cutting machine
- Electrically powered guillotine machine
- Manual Shearing machine
- Motorized Shearing machine
- Rack and Pinion operated shearing machine
- Pneumatically operated shearing machine
- Hydraulically operated shearing machine

In this research work, attention is given to the Development of Pneumatic Clamping and Shearing Machines for the following reasons:

- Reduced manual effort
- Reduced Cutting Time (as the cutting speed can be adjusted)
- Reduced Cost
- Ease of operation as the clamping device holds the workpiece in place for the cutting operation

Quite several authors have previously worked on pneumatically powered workshop equipment with different objectives. Suryawanshi *et al.* (2019) for example developed a pneumatic machine to reduce punch costs on the metallic sheet while Pandita *et al*. (2015) developed a pneumatic sheet metal cutting machine with a significant comparative advantage over manual driven sheet cutters. The efficiency of the cutter can be increased by further enhancement of the cutting blade. Polapragada and Varsha (2012) on the other hand developed a pneumatic and punching machine. The project helped to reduce manufacturing costs for small-scale industries. Barman *et. al*. (2017) developed a pneumatic sheet metal cutting machine that runs using pre-compressed air. It is an efficient way of increasing production for small-scale industries. Also, Karan Dutt *et. al.* (2013) studied various types of pneumatic machines and components along with their advantages and disadvantages. He concluded that pneumatic machines can provide poinr in a cheaper, safer, and more reliable way than electric motors and actuators.

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1.1 Pneumatic Shearing Working Principles

The working medium (Compressed air) is generated from a positive displacement compressor at a working pressure of 10 bar (150psi).

The generated air is stored in an air receiver (Storage tank) and is regulated to 7 bar by an air regulator installed on the compressor air receiver. This regulated air is passed through an air dryer to remove moisture contents of the regulated air as it is harmful to the pneumatic cylinders and other pneumatic components of the machine. The moisture-free air is then passed through the air lubricator which lubricates the tools to enhance the efficiency of the moving parts of the pneumatic systems. This processed air is then channeled to the speed-reducing valve through the air hose from where it then flows to the control valve which energizes the actuator to operate the shearing machine.

Position "A"

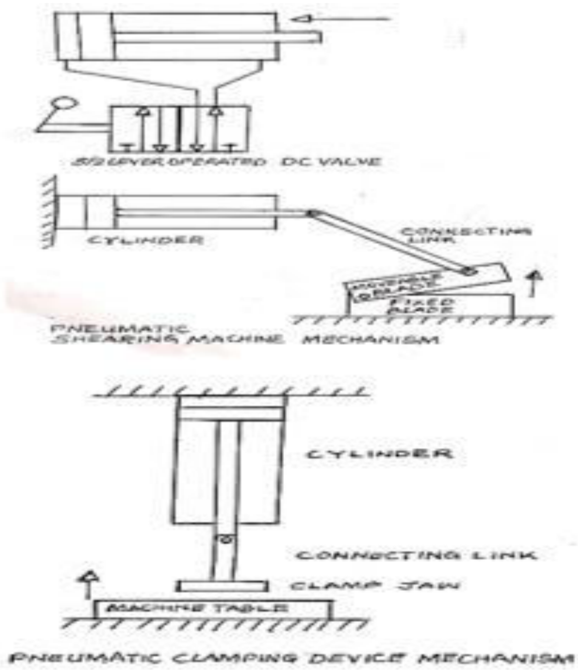

Figure-1. Pneumatic cylinder retraction for cutting blade and clamping jaw opening.

The pneumatic hose first conveys the compressed air to the flow control valve of the machine and, the air from the flow control valve is further distributed to the directional control valves of the clamping cylinder and the shearing blade cylinder.

At position "A" the clamping and shearing blade cylinders are in the retracted position of the circuit diagram. At this position, the cylinder is in return the position of the directional control valve.

At position "B", the DC valve is at the left-hand position as shown in Figure-1. The cap end port of the piston and pressure port get connected and the rod end port gets connected to the exhaust port. The compressed air then flows into the piston cap end of the cylinder and pushes the piston rod outward. The air present in the rod end side of the cylinder is then pushed out of the cylinder to the tank (Atmosphere).

As the piston moves outwards, the force is transmitted through the connecting link and the moveable shearing blade moves downwards to carry out the shearing operation. In like manner, the clamping device piston rod moves outward to clamp down the workpiece (Sheet metal) for the shearing operation to be performed.

Before actuating the DC valve, the workpiece (Sheet metal) is inserted in between the fixed and moveable blades. The clamping device DC valve is first operated to clamp down the workpiece (Sheet metal) to position before the operation of the shearing blade FC valve. As the moveable blade moves downwards, stress is generated in the sheet metal, this generated stress goes beyond the ultimate shear stress of the sheet metal, and thus the shearing action takes place.

Position "B"

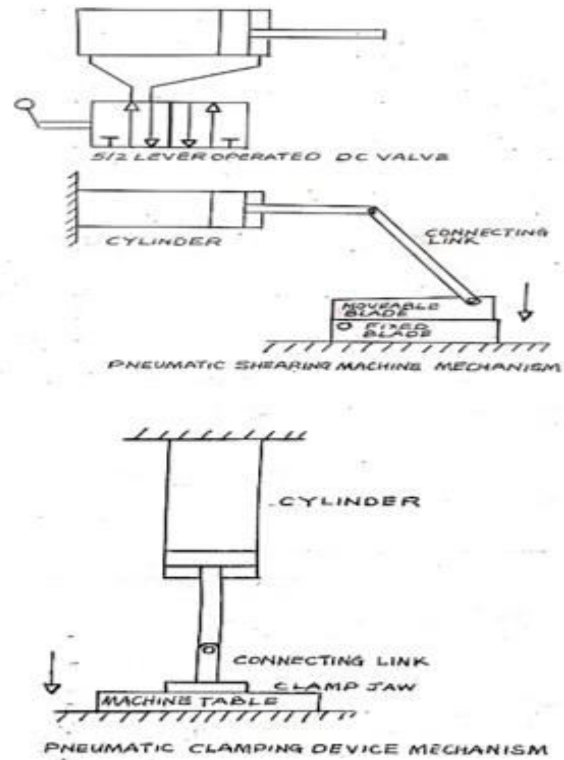

Figure-2. Pneumatic cylinder extension for clamping and cutting operations.

1.2 Components of Pneumatic Shearing Machine

Pneumatic systems are made up of various components. Some of these are:

a) Air compressor

All pneumatic systems use air compressors as this is the source of compressed air generation. The compressor may be driven by an electric motor or petrol/diesel engine for site work. The compressor is mounted on a reservoir/tank to store the compressed air.

b) Air dryers

This is used to remove the condensed water and oil that comes out of the air compressor when it is in operation.

c) Compressed air regulator

The purpose of the air regulator is to keep the operating pressure of the system (Secondary pressure) constant regardless of the fluctuations in the line pressure (Primary pressure) and the air consumption.

d) Lubricator

The Air Lubricator meters the quantity of oil mist into the air distribution system when necessary, for smooth operation of the pneumatic system.

e) Valves

The function of valves is to control the pressure of the flow rate of pressure media. For this design, two types of valves are used, and these are:

a. Directional control valve

This controls the passage of air signals by generating, canceling, or redirecting signals. For this design, we used 2-position, 5-ports (ways), lever actuated, air return Directional Control Valve.

b. Flow control valves

This valve restricts or throttles the air in a particular direction to reduce the flow rate of the air and hence controls the signal flow. It is possible to vary the restrictor from fully open to completely closed position.

a) Pneumatic actuators

Pneumatic actuators are the power components of the pneumatic system. They convert the pneumatic pressure to mechanical work. The actuators are further broken down into:

a. Linear Actuators
- Single Acting Cylinder
- Double Acting Cylinder

b. Rotary Actuators
c. Air motors
d. Rotary Actuators

b) Air-circulating devices

The compressed air is stored in an air receiver from which air is drawn out into the consumer point using a pipeline.

While laying out the pipeline for the system, care should be taken to ensure that the pressure drop from the generating point to the point of consumption remains as low as possible. For economic reasons, it is always better if the total drop of pressure is kept at a maximum value of 0.1 bar or even less.

While selecting pneumatic pipeline installations, the following factors are taken into consideration:

a) Pressure of compressed air in the lines.
b) Total flow rate per unit time through the line.
c) Permissible pressure drops in the line.
d) Types of tube material and types of line fitting.
e) Length and diameter of the tube or other pipelines.
f) Working environment.
g) Considering the above factors, we have selected the flexible hose tubes of 8mm diameter.

a. Frame base

It forms the robust support to stand the machine vertically. It holds the weight of the vertical post and supports the direction control valve. It is made of mild steel channels of a rectangular base with a vertical post and a horizontal channel. On the frame are installed the two pneumatic cylinders that operate the shearing machine and the clamping device mechanism. Moreover, the frame also houses the shearing machine.

b. Shearing blade

Shearing, also known as die cutting, is a process that cuts stock without the formation of chips. Strictly speaking, if the cutting blades are curved then they are shearing-type operations. The shearing blades are made from hardened medium carbon steel; the fixed blade is rectangular with the cutting edge at an angle 15^{o} while the moveable blade is given a curvature in such a way that the cutting operation is initiated at one end and terminates at the other end, the cutting operation is progressive. Also, the cutting edge is chamfered at an angle 15^{o}.

2. METHODOLOGY

2.1 Design Parameters

The following Design Parameters were considered

a. Shearing Blade
b. Shearing Machine Frame (Table)
c. Cylinder Mounting Plated
d. Fork End
e. Angle Section
f. Connecting Link
g. Shearing Machine Link
h. Clamping Device Link
- Clamping Jaw
- Supporting Link for Clamping Device

2.2 Standard Materials Specifications

Some of the standard units used in this work are as specified below

a. Pneumatic Cylinder
b. Directional Control Valve
c. Flow Control Valve
d. Pneumatic Hose
e. Pneumatic Quick Connect Fittings
f. Tee Connect
g. Straight Connect
h. Fork End Nut
i. Cylinder Hold Down Bolts
j. Blade Fixing Bolts
k. Clamping Jaw Bolts

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2.3 Design Calculations

Extracts of some of the relevant design calculations are stated below.

2.3.1 Maximum force that the actuator can exert

Since we are working with a standard linear cylinder of 40mm bore and 25mm piston rod diameter. The bore diameter of the cylinder determines the maximum force that the actuator can exert in both the outstroke and instroke.
Considering both sides of the piston

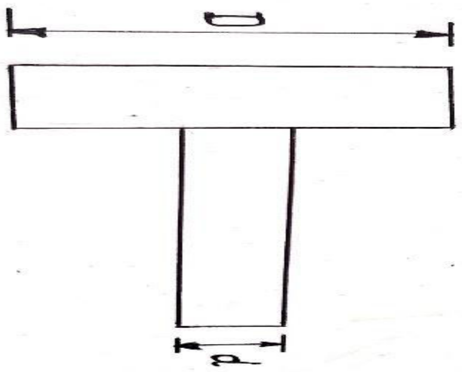

Figure-3. Pneumatic Cylinder Piston Rod.

Let the piston outstroke diameter = D,
Piston rod instroke diameter = d
Theoretical Thrust outstroke (Force) = F_T,
Theoretical Thrust instroke (Force) = F_P
The forces acting on both sides of the piston can be calculated
From Pressure (P) = Force (F) / Area (A)
The theoretical force on the cylinder is given by:
For outstroke,
$F_T = (\pi D^2/4) * P$
Instroke
$F_P = [\pi(D^2-d^2)/4] * P$
Since we are working with standard cylinders,
D = 40mm
d =25mm
Let the working pressure P = 7bar (For safety purposes)
For outstroke,
$F_T = (\pi * 0.04^2/4) * 7$
$= 8.80KN$ or $880N$
For instroke,
$F_P = [\pi\ (0.04^2-0.025^2)/4] * 7$
$=5.36KN$ or $536N$

2.3.2 Force required to cut the sheet metal

The force required to cut the Sheet = $L*t*\tau max$, where τmax = maximum shear stress. For sheet metal of 0.3 mm thickness (t), and cutting length (L) of 25mm and τmax (mild steel) = $300N/mm^2$
Force required = 25×0.3×300= 2250N

Determining machine efficiency

(MA/VR) ×100 …………………………………. (4)

Where; MA is mechanical advantage, VR is velocity ratio
MA = Load/Effort $=L_1/b_1$ ………………………. (6)

Where; L_1 = weight of the material part to be cut (Wp_1)
$W_m = LM_mg$
g = acceleration due to be gravity = $9.8m/s^2$
$M_m = V_m\boldsymbol{\rho}$
V_m = Volume of the material part to be cut
$V_m = Ls_2 \times t_m \times b_m$
Where:
Ls_2 = Maximum shearing length = 255mm
T_m = Maximum metal sheet thickness = 0.5mm
Let the breadth (b_m) = unity = $1x10^{-3}m$
$V_m = 255 \times 10^{-3} \times 0.5\times10^{-3} \times 1 \times 10^{-3}$
$V_m = 1.275\times10^{-7}m^3$
$\boldsymbol{\rho}$ = density of material to be cut = $7.83\times10^3\ kg/m^3$

$M_m = V_m\boldsymbol{\rho} = 1.275\times10^{-7}\times 7.83\times10^3$
$M_m = 9.98x10^{-4}kg$
$W = M_mg = 9.98x10^{-4}\times9.8 = 9.78x10^{-3}N$
:. $L = W = 9.78x10^{-3}N$
MA = L/E; Where,
E = expected axial load or force to cut the metal
$MA = L/E = 9.78x10^{-3}/0.2 = 0.0489$
For $VR = D_E/D_L$ ....(7)

Recall that from the design, D_E = 14mm; Where,
D_E = Distance moved by effort
D_L = Distance moved by load = Ls_2 = 255mm
VR = 14/255 = **0.0549**
Hence, Efficiency = (MA/VR) × 100% = (0.0489)/(0.0549) × 100%
:. Efficiency = 89%

MODEL DRAWING

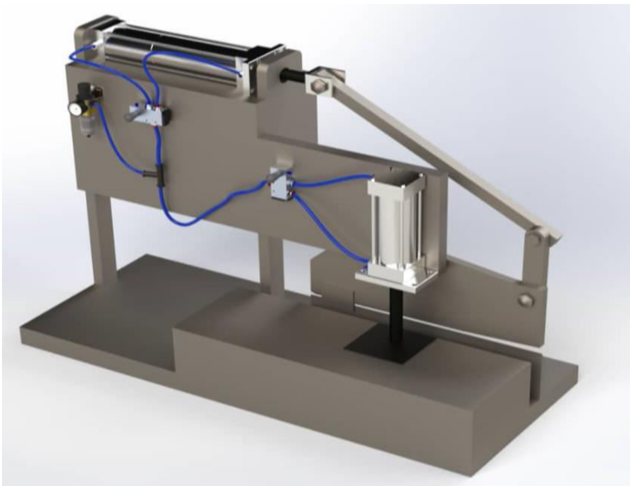

Figure-4. Pneumatic sheet metal clamping and shearing machine model drawing.

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3. RESULTS AND DISCUSSIONS

The performance evaluation data taken and analyzed at the end of the project development to ascertain its effectiveness and efficiency are contained in Tables 1-5.

Table-1. Shearing time comparison with manual shearing machine.

S. No	Sheet Metal Thickness (mm)	Shearing Time in (Secs)	
	Mild Steel	Manual Shearing Machine	Pneumatic Shearing Machine
1	0.45	0.97	0.66
2	0.6	1.0	0.82
3	0.8	1.02	0.87
	Aluminum		
1	0.35	0.78	0.52
2	0.45	0.82	0.68
3	0.55	0.95	0.72
	Copper		
1	0.2	0.80	0.62
2	0.3	0.93	0.86
3	0.4	0.99	0.92

Table-2. Reduced shearing time compared with electric guillotine machine.

S. No	Sheet Metal Thickness (mm)	Shearing Time in (Secs)	
	Mild Steel	Electric Guillotine Machine	Pneumatic Shearing Machine
1	0.45	0.80	0.66
2	0.6	0.88	0.82
3	0.8	0.93	0.87
	Aluminum		
1	0.35	0.55	0.52
2	0.45	0.81	0.68
3	0.55	0.85	0.72
	Copper		
1	0.2	0.65	0.62
2	0.3	0.88	0.86
3	0.4	0.95	0.92

The results from Tables 1 and 2 showed that the shearing time for the Pneumatic Clamping and Shearing Machine is less than that of the Manual Shearing Machine and Electric Guillotine Machine, hence a decrease in production time.

Table-3. Shearing pressure reading for different materials.

S. No	Material Used	Thickness (mm)	Applied Pressure Nf/m^2
1	Mild Steel	0.45	30
2		0.6	48
3		0.8	56
1	Aluminum	0.35	23
2		0.45	37
3		0.55	45
1	Copper	0.2	27
2		0.3	43
3		0.4	49

From Table-3, the result showed that the applied pressure for shearing of Mild Steel plate is higher than that of Copper and Aluminum, which shows that the machine is more effective in Aluminum material shearing than the other materials in comparison.

3.1 Shearing Force Calculation

Maximum pressure applied in the cylinder (P): 8 bar

Diameter of the cylinder bore (D): 40 mm

Area of the cylinder (A) = (3.14 D^2)/4

= (3.14 x 0.04^2)/4 = 1.25637m^2

3.1.1 For mild steel

Force acting on the sheet of 0.45 mm (F)

= Pressure x Area = 30 x 1.256 = 37.68Nf

= 37.68 x 9.81 N = 369.64 N

Force acting on the sheet of 0.6 mm (F)

= Pressure x Area = 48 x 1.256 = 60.29Nf

= 591.45 N

Force acting on the sheet of 0.8mm (F)

= Pressure x Area = 56 x 1.256= 70.34Nf= 690N

3.1.2 For aluminium

Force acting on the sheet of 0.35mm (F)

= Pressure x Area = 23 x 1.256 = 28.89Nf

= 283.4 N

Force acting on the sheet of 0.45mm (F)

= Pressure x Area = 37 x 1.256 = 46.47Nf

= 455.89N

Force acting on the sheet of 0.55mm (F)

= Pressure x Area = 45x1.256 = 56.52Nf

= 554.46N

3.1.3 Copper sheet metal

`Force acting on the sheet of 0.2mm (F)
= Pressure x Area = 27x1.256 = 33.91Nf
= 332.68N
Force acting on the sheet of 0.3mm (F)
= Pressure x Area = 43x1.256 = 54Nf = 529.82N
Force acting on the sheet of 0.4mm (F)
= Pressure x Area = 49x1.256 = 61.54Nf
= 603.75N

3.2 Force and Temperature Readings for Different Metals

Table-4. Force readings for different materials.

S. No	Material Used	Thickness (mm)	Applied Pressure Nf/m^2	Force (N)
1	Mild Steel	0.45	30	369.6
2		0.6	48	591.45
3		0.8	56	690
1	Aluminum	0.35	23	283.4
2		0.45	37	455.89
3		0.55	45	554.46
1	Copper	0.2	27	332.68
2		0.3	43	529.82
3		0.4	49	603.75

From Table-4, it is observed from the result that the shearing force increases as the thickness of the metal plate increases. The shearing force for Aluminum is least in comparison to that of copper and mild Steel plates.

Table-5. Temperature readings for different materials.

S. No	Material Used	Thickness (mm)	Shearing Temperature (^oC)
1	Mild Steel	0.45	46
2		0.6	49
3		0.8	52
1	Aluminum	0.35	40
2		0.45	42
3		0.55	45
1	Copper	0.2	46
2		0.3	48
3		0.4	54

The result from Table 5 shows that the shearing temperature increases as the sheet metal thickness increases, moreover, the shearing temperature for copper is higher than that of Aluminum and Mild Steel of the same thickness; this is a result of the high conductivity nature of copper.

From the experimental observation, as the clearance between the moveable blade and the fixed blade is decreased, the cutting force increased, this is in tandem with the investigation of Quasi *et al*. (2012).

3.3 Other Performance Indicators

3.3.1 Chip formation

The edge of the sheet metal cut by the Pneumatic Shearing Machine was observed for Chip formation, the observed edge showed that there was no chip formed during the shearing operation.

3.3.2 Cutting edge cracks

The edge of the sheet metal cut by the Pneumatic Shearing Machine was observed for cracks formation, the observed edge showed that there were no cracks formed during the shearing operation.

3.3.3 Edge roughness

The edge of the sheet metal cut by the Pneumatic Shearing Machine was observed for roughness, the observed edge showed a smooth sheared edge during the operation.

3.3.4 Vibration

The Pneumatic Shearing Machine operates with minimum vibration. The metal sheet Clamping Table provides the base for the metal sheet to be placed during cutting. The impacted load on the sheet is directly absorbed and clamped by the Table and it guards its edges. For this purpose, the Machine Table was designed to have a considerable thickness to overcome the vibration.

3.3.5 Noise

The result showed that the machine operates with minimal noise.

3.3.6 Wear resistance

The shearing blade (fixed blade and movable blade) was designed to minimize wear. The spring possesses the properties of strength, toughness, and elasticity.

3.3.7 Sheet metal shearing accuracy

The Clamping Device incorporated in the Pneumatic Clamping and Shearing Machine improved the accuracy of the Machine's cutting operation.

The Metal Sheet was rigidly clamped on the machine's worktable, hence enabling precision cutting on the marked-out portion of the workpiece. This eliminates the adjustment of the workpiece for cutting/shearing as is obtainable during manual shearing machine operation.

3.3.8 Availability of applied pressure

The Applied pressure was easily read with the pneumatic Clamping and Shearing Machine because the pressure gauge of the pneumatic system indicates the pressure while the applied pressure of the Manual Shearing Machine cannot be determined as a result of the human effort used in the operation of the machine.

3.3.9 Versatility of pneumatic shearing machine

The Shearing Machine is not limited to Mild Steel shearing but can be used for shearing of other types of metals.

To shear other metals such as Stainless-steel sheet metal, the shearing blades (Fixed and Moveable) are changed to High-Speed Steel (HSS) material or Carbide Brazed material that has higher toughness and shearing strength than the stainless-steel material being sheared. Similarly, to shear other sheet metals, the shearing blades are the only components to be altered. This is in agreement with the study carried out by Pandita *et al*. (2018).

Figure-5. Pneumatic sheet metal clamping and shearing machine setup.

4. CONCLUSIONS

The pneumatic Clamping and Shearing Machine is developed from locally available material. The machine is capable of shearing mild steel sheets of 0.45mm, 0.6mm, and 0.8mm thicknesses, aluminum steel sheets of 0.35mm, 0.45mm, and 0.55mm thicknesses, and copper steel sheets of 0.2mm, 0.3mm, 0.4mm thicknesses.

The efficiency of the machine is about 89% which makes it comparable with other sheet metal shearing machines. As an innovation, the machine is incorporated with Clamping Mechanism which enables it to operate with maximum safety and accuracy.

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