Design & Development of a Semi-Automated Pneumatic System for Production of Washers

J.Om Prasaad, Chetan Aade, Pranav Ghanvat, Biradar Mustaffa, Praseed Kumar, Shamim Pathan*

Department of Mechanical Engineering
Fr. C. Rodrigues Institute of Technology, Vashi
Navi Mumbai, India 400 703
*Email: omprasaadj@gmail.com

Abstract

Sheet metal forming is a field in product manufacturing in which many sheet metal forming operations are coordinated to enhance the formability of three-dimensional forming involving good quality and accuracy. Punching is a common sheet metal forming process carried out in small and medium-scale industries. To perform this operation, such industries incorporate machinery which is operated manually which in turn does not promise accuracy and precision. Thus, such industries require an economical option for performing punching operation which provides better accuracy than the current systems used. The main objective of this project is to design, develop and fabricate a pneumatic sheet metal punching system which can punch sheets successively to produce washers. Pneumatic cylinders, actuated by an air compressor, would be employed to punch the metal sheets successively. The sheets would be fed using a system of automated rollers, to avoid manual input. After the washers get manufactured, primary packaging is performed, by collecting a specific number of washers within boxes, over an automated conveyor belt. This project, fabricated in association with S-Tech Engineering, Navi Mumbai, aids small and medium-scale industries to produce washers, by decreasing costs incurred while providing accurate products, which ultimately results in profits for the company.

Keywords: Automation, forming, pneumatics, punching, solenoid valve

Introduction

Punching is a common sheet metal forming operation incorporated to produce and manufacture washers of variable sizes. The most common method implemented for this purpose is punching through mechanical systems, with a standard die and punch unit. Small and medium-scale industries find such mechanical systems to be expensive to purchase and implement. Thus, they are on the lookout for economical and easy alternatives which would promise the same results as their mechanical counterparts, with minimal human interference.

The proposed system is a possible alternative to current mechanical systems, to produce washers. The system tends to manufacture washers using a pneumatic system, which consists of two pneumatic cylinders, along with their respective punch and die units, to carry out the punching operation. The sheet supply unit is automated so that the sheets are fed automatically for sequential punching. The system is complemented by a conveyor unit, which collects the washers produced in containers placed over the conveyor, and conveys them forward, in accordance with the batch production protocol. The washers produced are counted using an IR sensor, which enables batch production. During the entire operation, human involvement is minimal and is limited to include only the replenishment of a fresh sheet, regularly.

Literature Review

Arunkumar et al. (2021) focus on the requirements of various varieties of mechanical presses used for riveting or punching in industries. The author used pneumatic presses to increase efficiency and reduce workload. The machine, powered pneumatically, consists of a five-way directional control solenoid valve with a single port for input, two ports for outputs, and two exhausts. Ghatge et al. (2017) display the importance of the shearing operation. Typically, the clearance between the two is 5 to 10% of the material's thickness. The machine developed can cut bars of mild steel material by the shearing operation. Shearing between punch and die can deform the metal plastically in the die.

Air is used as a working fluid which is available free of charge. Raman et al. (2019) focus on alternative applications for working on an automated sheet metal cutting unit powered pneumatically, to create a low-cost machine for laboratory use. The machine proposed was successfully assembled after designing in solid works and optimizing blade design. The unit uses a metal cutter, with a double-acting cylinder and a two-way system. After fabrication, the machine is activated through solar energy, which can be used in small-scale industries, as an unconventional source. Prajapati et al. (2018) developed a machine for the sheet metal industry, and they can be customized. The pressure exerted during the punching operation results in the plastic deformation of the metal. Low clearance between the die and the punch ensures guaranteed deformation. The sheet metal cutting machine is actuated using a double-acting cylinder. The machine is compact, making it easy for transport. The pneumatic cylinder actuates the machine, to perform cutting and punching. The piston is linked to the cutting tool in motion. The timer control unit circuit alters the speed of the cutting and releasing strokes. Utkarsh Sharma (2015) fabricated an Automatic Pneumatic Hole Punching Machine. Upon opening the exhaust valve, the compressed air exerts pressure over the cylinder’s piston forcing it downward, ultimately pushing the punch downward. Thus, the punch applies an impact load over the sheet placed on the die, effectively punching it in the process. The die is attached to the machine's base. The power supply for the whole machine is provided using solar energy. This technology could be used in small-scale industries, eliminating the need for electricity, and saving money on energy bills.

Scope Of Research

The machine is designed to manufacture circular washers of Aluminium material. The following specifications signify the dimensions of the sheet that can be fed into the system per pass for optimum punching (which means after each pass in the punching cycle the same sheet can be adjusted, so as to utilize the available material, for punching in subsequent cycles, until the sheet is completely exhausted and scrap is minimized) and the specifications of the final washer produced,

Dimensions of sheet supplied per pass

Length	60-100 cm
Breadth	10-15 cm
Thickness	1mm

Dimensions of washer produced

Inner Diameter	5mm
Outer Diameter	10mm
Thickness	1mm

Theoretical Analysis

A theoretical analysis is performed to calculate and analyze the sufficient pressure, required to effectively punch an aluminium sheet followed by the selection of suitable pneumatic cylinders based on the results obtained.

Pressure Calculations

For the successful completion of the theoretical analysis, certain assumptions must be considered to obtain the subsequent values. The respective assumptions are as follows-

- The outer diameter and inner diameter of the desired washer are 10mm and 5mm respectively.
- The shear strength of an aluminium sheet (T_{max}) is found to be 103.86 N/mm^2.
- The machine can punch a sheet thick up to 1mm.
- The operating pressure of each pneumatic cylinder is 6 bars.

The bore diameter of the pneumatic cylinder for punching the 10mm hole, is calculated as follows,

Punching Force

$F_C = L \times t_3 \times T_{max}$ …………………………….(1)

The Eq^n. (1) is used to evaluate the force necessary to punch the aluminium sheet.

F_C – force required to punch metal sheet

L – perimeter to be punched = Π x d = 31.41mm

t_3 – sheet thickness = 1 mm

T_{max} – shear strength of aluminium sheet = 103.86 N/mm^2

$F_C = 31.41 \times 1 \times 103.86$

$F_C = 3262.24$ N

Stripping Force

$F_S = 0.15 \times F_C$ …………………………….(2)

The Eq^n. (2) is used to evaluate the force necessary to strip the aluminium sheet.

F_S – stripping force

F_C – force required to punch metal sheet = 3262.24 N

$F_S = 0.15 \times 3262.24$

$F_S = 489.336$ N

Total Force

$F_T = F_C + F_S$ …………………………….(3)

The Eq^n. (3) is used to evaluate the total force necessary to shear the aluminium sheet.

F_T – total shear force

F_C – punching force = 3262.85 N

F_S – stripping force = 489.336 N

F_T = 3262.85 + 489.336

F_T = 3752.18 N

Reduced Force

F_R = 0.37 x F_T……………………………(4)

The Eq^n. (4) is used to evaluate the total force necessary to shear the aluminium sheet, after considering reduction.

F_R – reduced force

F_T – total shear force = 3752.18 N

F_R = 0.37 x 3752.18

F_R = 1388.306 N

Bore of Pneumatic cylinder

P_C = (F/A) ……………………………(5)

The Eq^n. (5) is implemented to calculate the bore of the cylinder.

P_C – punching pressure = 6 bar = 0.6 N/mm^2

F – actual shear force = 1388.306 N

A – bore area = $A = \frac{\pi}{4} d^2$

d – bore of rod

d = 54.27 mm

Thus, a suitable bore w.r.t a standard pneumatic cylinder is

d = 70 mm

Thus, a double-acting cylinder of a bore diameter of 70mm is suitable to punch a 10mm hole in the Aluminium sheet.

The bore diameter of the pneumatic cylinder for punching the 5mm hole, is calculated as follows,

Punching Force

$F_C = L \times t_3 \times T_{max}$ ……………………………(6)

The Eq^n. (6) is used to evaluate the force necessary to punch the aluminium sheet.

F_C – force required to punch metal sheet

L – perimeter to be punched = Π x d = 15.707mm

t_3 – sheet thickness = 1 mm

T_{max} – shear strength of aluminium sheet = 103.86 N/mm^2

$F_C = 15.707 \times 1 \times 103.86$

F_C = 1631.33 N

Stripping Force

$F_S = 0.15 \times F_C$ …………………………….(7)

The Eq^n. (7) is used to evaluate the force necessary to strip the aluminium sheet.

F_S – stripping force

F_C – force required to punch metal sheet = 1631.33 N

$F_S = 0.15 \times 1631.33$

F_S = 244.69 N

Total Force

$F_T = F_C + F_S$…………………………….(8)

The Eq^n. (8) is used to evaluate the total force necessary to shear the aluminium sheet.

F_T – total shear force

F_C – punching force = 1631.33 N

F_S – stripping force = 244.69 N

$F_T = 1631.33 + 244.69$

F_T = 1876.02 N

Reduced Force

$F_R = 0.37 \text{ x } F_T$ …………………………….(9)

The Eq^n. (9) is used to evaluate the total force necessary to shear the aluminium sheet, after considering reduction.

F_R – reduced force

F_T – total shear force = 1876.02 N

$F_R = 0.37 \text{ x } 1876.02$

F_R = 694.12 N

Bore of Pneumatic cylinder

$P_C = (F/A)$ …………………………….(10)

The Eq^n. (10) is implemented to calculate the bore of the cylinder.

P_C – punching pressure = 6 bar = 0.6 N/mm^2

F – actual shear force = 694.12 N

A – bore area = $A = \frac{\pi}{4} d^2$

d – bore of rod

d = 38.37 mm

Thus, a suitable bore w.r.t a standard pneumatic cylinder is

d = 40 mm

Thus, a double-acting cylinder of a bore diameter of 40mm is suitable to punch a 5mm hole in the Aluminium sheet.

Proposed Design of The Machine

The proposed system is designed to manufacture washers through a semi-automated pneumatic system. Two pneumatic cylinders, with their punches, are positioned vertically over their respective die units, held over a frame. A roller unit feeds the sheet inside, upon the activation of the system, after subsequent punching is performed. An automated conveyor unit is positioned below the punching unit. Once a washer is produced, it gets collected in a box placed over the conveyor unit. After a certain quantity of washers is produced, the conveyor unit conveys the next box forward, for the collection of the next set of washers. The design is illustrated in Figure 1.

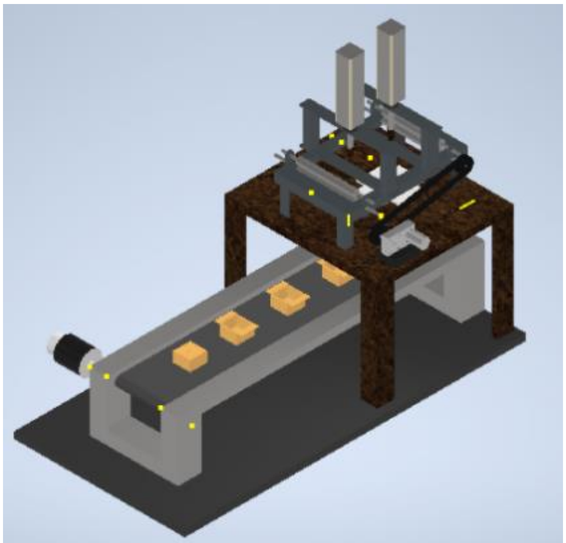

Figure 1: CAD Model of Design

Punching Unit

The punching unit consists of a pneumatic unit, with 2 cylinders of specifications 40mm bore 100mm stroke and 70mm bore 125mm stroke, for punching holes of 5mm and 10mm respectively. The punches with punching diameters of 5mm and 10mm, are attached through a threaded joint, to their respective cylinders. The cylinders are held over a base frame of dimensions, 350mm x 200mm x 100mm, of MS material. A pair of rolling units, consisting of 2 rollers in each unit, is positioned on either end across the width of the base frame, which facilitates easy feeding of the sheet. The driver roll is actuated using a belt drive unit, which consists of a driver and a driven pulley, and is driven using a DC motor. The entire unit is held over a table, which houses a hopper below the 10mm die, to guide the washer produced. 5/2 Solenoid valves are equipped to actuate the cylinders individually, by regulating the air they receive from the air compressor.

DC Geared Motor (12V, 60 RPM)

This DC Motor has an RPM of 60, which operates at 12V. It has a shaft of 8mm diameter. It provides a torque of 20 kg-cm, which is achieved using a gearbox unit, attached to the motor, as shown in Figure 2.

Figure 2: 60 RPM DC Motor

Pneumatic Cylinders

The cylinders used are of the double-acting type, with 70mm bore 125mm stroke and 40mm bore 100m stroke respectively. The pistons are provided threading at their ends, to attach the punches to the cylinder. The operable pressure range is 1-10 Bars, as shown in Figure 3.

Figure 3: Pneumatic Cylinders

Punches

The two punches have outer diameters 5mm and 10mm individually, and are held by an encasement. They are composed of Hard Steel material, optimum for performing punching operations. The encasement has a threading along its inner diameter, for hassle free attachment to the piston of the pneumatic cylinder, as shown in Figure 4.

Figure 4: Punches

Dies

The dies used are of dimensions 200mm x 70mm x 10mm. A clearance of 0.06mm i.e. 6% of the thickness of the sheet that would be punched, is provided to both the die holes, for optimum punching, as shown in Figure 5.

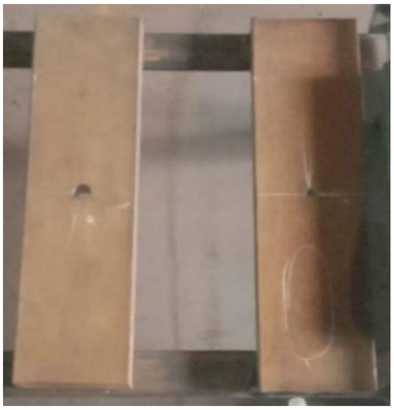

Figure 5: Dies

Pulleys

The driver pulley has an outer diameter of 50mm and an inner diameter of 8mm to accommodate the motor shaft. The driven pulley has an outer diameter of 50mm and an inner diameter of 10mm to accommodate the roll shaft, as shown in Figure 6.

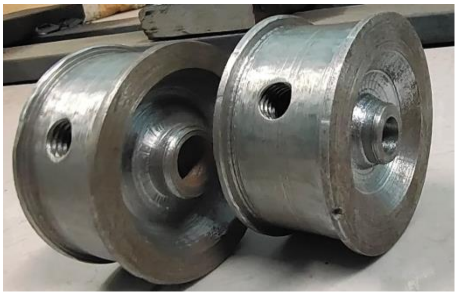

Figure 6: Pulleys

5/2 Solenoid Valve

Two solenoid valves are used to operate upon two pneumatic cylinders individually. Both the solenoid valves are single- type valves, which work under a pressure range of 6-8 Bars. They are powered using a 220V AC supply. Air hoses are connected to its ports, to receive and regulate air as per requirements, as shown in Figure 7.

Figure 7: 5/2 Solenoid Valve

Belt
The belt used in the belt drive is of Nylon material and has a centre to centre distance of 350mm and a thickness of 2mm, as shown in Figure 8.

Figure 8: Belt

Belt Conveyor

The belt conveyor is positioned below the punching unit, to collect the washers produced after each consequent punching operation. The assembly consists of a base frame, which supports the legs along the sides. A pair of rolls is positioned at either end of the belt conveyor frame, along its length. Roller contact bearings are positioned over the shafts of the rolls, so that the rolls rotate smoothly, with minimal slippage. The rolls support the belt, along its ends. The conveyor is designed in such a way that the tension along the belt can be varied, based on desired capacity, using a slot mechanism. The DC motor is coupled to the driver roll using a coupling. Once the system gets activated, after the desired number of washers gets manufactured and counted (by the counting unit), the DC motor transfers its rotary motion to the roller shaft, axially attached to it, through the coupling, which leads to the rotation of the conveyor belt.

DC Geared Motor (12V, 45 RPM)

This DC Motor has an RPM of 45, which operates at 12V. It has a shaft of 10mm diameter. It provides a torque of 80 kg-cm, which is achieved using a gearbox unit, attached to the motor, as shown in Figure 9.

Figure 9: 45 RPM DC Motor

Belt

The PVC belt used has a total length of 900mm and a thickness of 1mm, as shown in Figure 10.

Figure 10: Conveyor Belt

Shaft Coupling

The shaft coupling has an outer diameter of 22mm. One end has an inner diameter of 10mm, and the other end has an inner diameter of 15mm. The material used is Mild Steel, as shown in Figure 11. Two holes are provided at either ends along an axis, perpendicular to the axis of the shaft to accommodate grub screws, which would then be used to fix the roller support from the conveyor roller and the motor shaft, along the same axis.

Figure 11: Shaft Coupling

Rolls

The rolls used are of MS material. The rolls are of outer diameter 20mm. The shaft along its sides has an outer diameter of 15mm, as shown in Figure 12.

Figure 12: Rolls

Bearings

The bearings used are of roller contact type and have an inner diameter of 15mm, as shown in Figure 13. They ensure that the rollers in the belt conveyor rotate freely, without any obstructions, which ensure the consistent delivery of the manufactured washers, without any slipping.

Figure 13: Bearing unit

Simulation Study of Pneumatic System

The punching unit mainly comprises the punching system, which performs the punching operation. It comprises two double-acting pneumatic cylinders, controlled using 5/2 solenoid valves. A study is conducted on this system, through a simulation analysis using FluidSim.

The pneumatic system is modelled schematically in the FluidSim environment. It consists of a pneumatic cylinder, controlled using a 5/2 solenoid valve, which receives air from a compressor. An FRL unit is used between the compressor and the solenoid valve, as shown in Figure 14.

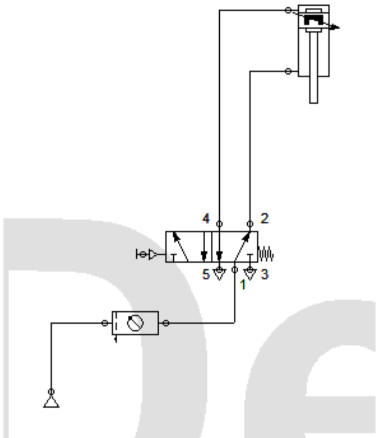

Figure 14: Schematic of the Pneumatic System

In the case of the first pneumatic cylinder, which performs the punching operation to produce the 5mm hole, the specifications added into the software are a stroke length of 100mm, piston diameter of 40mm, piston rod diameter of 16mm and an added mass (punch) of 0.75 Kg. From the simulation performed, it was inferred that the piston gets actuated forward with a mean velocity of about 0.22 m/s and an acceleration of 42 m/s^2, as per Figure 15. These results promise a quick punching action with minimal delays.

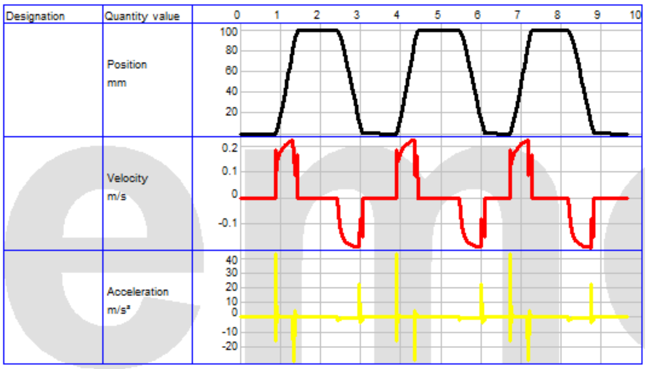

Figure 15: Simulated Velocity and Acceleration of the 1st pneumatic cylinder

From the simulation performed for determining the force exerted by this pneumatic cylinder, it was inferred that the piston is capable of exerting a force of 700N on the Aluminium sheet, through the punch, which complements the theoretical analysis performed for calculating the desired punching force, as per Figure 16. Thus, a pneumatic cylinder of the aforementioned specifications, is optimal for ensuring desired results.

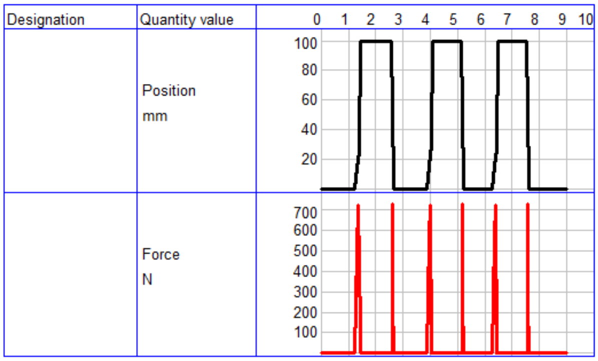

Figure 16: Simulated forces of the 1st pneumatic cylinder

In the case of the second pneumatic cylinder, which performs the punching operation to produce the 10mm hole, the specifications added into the software are a stroke length of 125mm, Piston diameter of 70mm, piston rod diameter of 20mm and an added mass (punch) of 1 Kg. From the simulation performed, it was inferred that the piston gets actuated forward with a mean velocity of about 0.17 m/s and maximum acceleration of 50 m/s^2, as per Figure 17. These results promise a quick punching action with minimal delays.

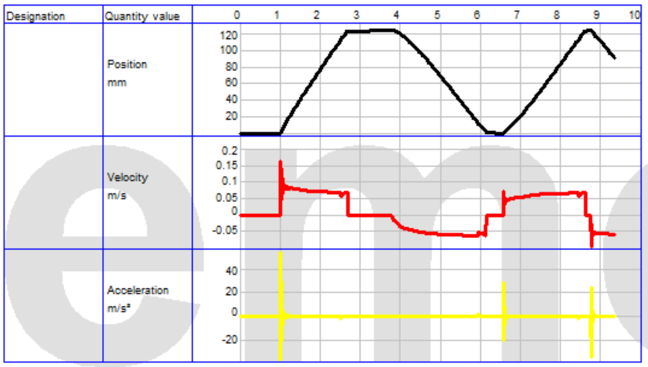

Figure 17: Simulated Velocity and Acceleration of the 2nd pneumatic cylinder

From the simulation performed for determining the force exerted by this pneumatic cylinder, it was inferred that the piston is capable of exerting a force of 1400N, on the Aluminium sheet, through the punch, which complements the theoretical analysis performed for calculating the desired punching force, as per Figure 18. Thus, a pneumatic cylinder of the aforementioned specifications, is optimal for ensuring desired results.

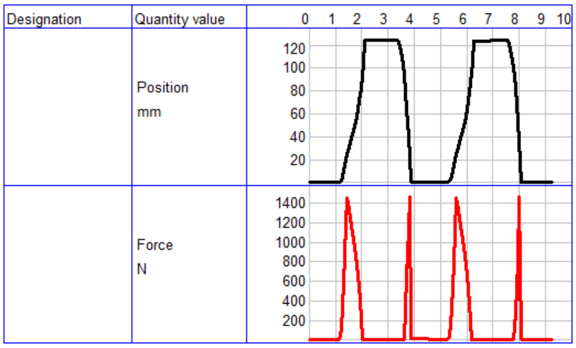

Figure 18: Simulated forces of the 2nd pneumatic cylinder

Table 1: Summary Of Theoretical And Simulated Punching Forces

Cylinder No.	Hole Diameter (mm)	Theoretical Force (N)	Simulated Force (N)
1	5	694.12	700
2	10	1388.306	1400

Thus, it can be inferred that the simulated punching forces are close to the theoretical punching forces, which would be exerted on the sheet while punching, as per Table 1.

Results & Discussion

The design proposed was successfully fabricated and tested for results. Based on the tests performed it was observed that the punches were successful in punching Aluminium sheets of 1mm thickness, upon the supply of the required pressure, i.e., 7 bars. The rolls were found to feed the sheet without any slip. Upon the production of washers, the IR sensor unit of the belt conveyor system counts the washer and updates it on an LCD screen. When the count reached a pre-defined limit, the DC motor was activated and conveyed the belt forward, so that the next box in line can start collecting the next lot of washers. The washers produced were found to be free of sharp edges, which can cause skin injuries. The final assembly of the model is shown in Figure 19.

Figure 19: Front View of the Assembly

Figure 20: Application of washers produced

Conclusion

The design proposed in this paper aims at introducing a safe and efficient way to manufacture washers while making sure that the cost incurred during purchase and maintenance is minimum. Based on the results obtained from tests, it can be inferred that the machine was successful in accomplishing the desired tasks, with assured safety, when operated at the optimum pressure and the washers produced were found to be feasible for application, as shown in Figure 20. The pneumatic system was thus found to be a feasible substitute to conventional mechanisms, as it is economical comparatively.

The design was thus fabricated as per the established scope and can be updated upon further usage, based on desired applications and possible improvements, as a part of future scope.

References

Arunkumar, G., Antonio, J. T. and Pon, V. (2021). Design and Development of Autofeed Pneumatic Punching and Riveting Machine. Journal of Physics: Conference Series (Vol. 2054, No. 1, p. 012025). IOP Publishing.

Ghatge, D. A., Birje, C. and Yadav, P. S. (2017). Use of Shearing Operation for MS Bar Cutting by Pneumatic Bar Cutting Machine. Young. 11(11.3): 10-18.

Dagar, R. R. M. G. K. and Kaushik, A. (2019). Some investigation on Design Analysis and Fabrication of Automated Metal Sheet Cutting Machine. IJSRD-International Journal for Scientific Research & Development. (pp. 1000-1003).

Prajapati, P. A., Patel, M. G., Patel, M. R., Lalit, M. and Patel, D. (2018). Design and Development of Pneumatic Metal Sheet Cutting Machine. 4(2): 340–344.

Sharma, U. (2015). Design of Automatic Pneumatic Hole Punching Machine. International Research Journal of Engineering and Technology (IRJET). 2(09).

Arun, S., Rajendra, S. and Bongale, V. (2014). Automatic Punching Machine: A low cost approach. International Journal of Advanced Mechanical Engineering. ISSN. 2250-3234.

Polapragada, A. A. and Varsha, K. S. (2012). Pneumatic Auto Feed Punching and Riveting Machine. International Journal of Engineering Research & Technology (IJERT). 1(7): 2278-0181.

Kelaginamane, S. and Sridhar, D. R. (2015). PLC based pneumatic punching machine. Journal of Mechanical Engineering and Automation. 5(3B): 76-80.

Bhandari, V.B. (2017). Design of Machine Elements. Chennai, TN: McGraw Hill.

Achchagam, K. (2016). Design Data-Data Book for Engineers. Coimbatore, TN: PSG College of Technology.