Design and Development of an Automated Pneumatic Sheet Metal Bending Machine for Enhanced Productivity and Precision in Industrial Applications

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Abstract

The work deals with the design, development, and evaluation that were carried out on the automated pneumatic sheet metal bending machine. This new machine is developed in order to increase the productivity and accuracy of the bending process related to industrial applications. A double-acting pneumatic cylinder drives the punch and die mechanism, while control through a 5/2 solenoid operated DCV is proposed. Equipped with advanced sensor technology, this machine allows for real-time monitoring and control of the bending process to very high accuracy levels and reproducibility. Automation of the bending process is one of the machine's USPs, which gives it various benefits compared to traditional systems. In lower cycle time and at lower operational costs, the machine improves regarding productivity. The results indicate that integrating electro-pneumatic systems into manufacturing processes has very great potential for process improvement by delivering a reliable and efficient solution for sheet metal bending within an industrial setting.

Keywords: Pneumatic, automation, bending machine

2. Introduction

One of the most prominent manufacturing processes is the process of sheet metal bending that creates a large number of different shapes and forms easily into different products. The simplicity and versatility of the method make an edge to the production of new components by tailoring them according to need for an application. The process includes the application of some external forces on the sheet metal in order to have its shape altered while caging the length and thickness of the same parameter. That is inherently possible as a result of the malleability of a sheet metal, which can be subjected to any kind of shaping processes at will so as to be able to meet design requirements. This is the most common method where a punch and V-die are used to bend sheet metals to desired angles. The bending angle will depend on the pressure point of the punch; thus, this tool is very effective in bending steel plates without changing their position.

Pneumatic systems include compressors, intercoolers, controllers, and actuators, among others, which convert energy stored in compressed air into kinetic energy. A pneumatic system is used in industries to bring about automation in various operations, to raise heavy loads with precision, and so on. Common applications include air brakes, pneumatic arms, cable jetting systems, and shock absorbers. They transmit energy, usually in the form of oil, to power all sorts of machinery from the smallest hand tools to giant pieces of construction equipment. Hydraulics deal with liquids and it is governed by Pascal's Law where the control of pressure will always remain equal at any point within a confined liquid. This principle therefore enables effective functioning in a number of uses, such as: construction, manufacturing, and automotive braking systems. Pneumatic cylinders, less technically referred to as pneumatic actuators, function by converting compressed air into mechanical motion. They provide an effective, yet readily affordable means to produce linear or rotary motion in most manufacturing processes. Of wide use in automating activities where products being produced are boxed and rejected, the actuating is very durable and requires minimal maintenance under tough environmental conditions. Directional control valves regulate hydraulic and pneumatic fluid flow, controlling the movement of actuators. Consisting of a valve body and spool, these valves direct pressurized fluid to different cylinder ends while providing a return path for fluid displacement. The spool's position within the valve body determines piston movement direction and speed, operated by manual levers, electrical actuators, or hydraulic/pneumatic systems. Ultrasonic sensors operate on frequencies beyond human hearing, detecting objects based on the time taken for transmitted signals to return. These versatile sensors find extensive use in industrial applications for detecting solids, liquids, granules, and powder materials. Employed with microcontrollers like ARM, PIC, and Arduino, ultrasonic sensors provide precise proximity and distance measurement capabilities essential for automation and robotics.

Aryan Pratihar et al (2020) [1]studied the pneumatic cutting and punching machine that utilizes compressed air to power a shearing blade and punch for operations on metallic sheets. This machine is optimized to cut 1 mm thick aluminium sheets and 0.5 mm thick copper sheets with ease. Its core components include a compressor, pipelines, double-acting cylinder, actuator, and flow control valves. This integrated design aims to deliver cost-effectiveness and substantial time savings in the manufacturing process by consolidating two operations onto a single platform.Madhu Kumar et al 2016[2] The pneumatic cutting and bending machine offers a cost-effective alternative to hydraulic counterparts. By utilizing a high-pressure compressor and integrating hardened blades, it can expand its range of cutting and bending thickness. This makes it particularly beneficial for small sheet metal cutting and bending industries that face budget constraints against investing in expensive hydraulic machinery.

Vijaylaxmi G.Biradar,et al (2012)[3] emphasis on changeover of manually operated machines to Automatic Systems having Pneumatic, Electrical and Electronic Components. The Course insists that a close study of these devices is rather essential. If such know-how is utilized, it will immediately upgrade many of the older existing machines to automatic operation thus saving a great deal of the new investment needed for automated equipment. There is, therefore, immense potential in this field of automation. In case of troubleshooting, fault identification might become a problem. To address this problem, interfacing with PLCs minimizes wiring, hence providing for quick fault detection; this enhances efficiency and reduces downtime.

Viraj et al 2019 [4] Compared with a hydraulic punching machine, a pneumatic punching machine is usually the better choice for producing as long as it can satisfy the application requirements since it does not use expensive hydraulic fluids but rather compressed air. During the operation, compressed air creates high pressure that in turn drives the piston. Air directional flow to and from the cylinder is managed by a solenoid valve. These polyurethane tubes transmit the pressure from the pneumatic cylinder to the punch assembly. While the high-pressure air forces the punch against the material, the punch deforms plastically in the sheet during its descend.Mariyappan et al 202[5]Modern manufacturing manages punching machine operations and pipe bending. In mass production, a lot of automatic and semi-automatic bending systems are employed. These have proved to be quite expensive for small-scale production and unrealistic in countries with high electricity costs and relatively low supply. The manual pipe bending machines, on the other hand, are relatively cheaper to build and run. The working principle, design, and development of such systems are briefly explained in this article; it also explains the performance testing. Though pneumatic systems offer advantages in accuracy, cost, and maintenance, the solar-powered system works excellently in the right conditions.

Suraj et al 2018[6] reviewed the design and fabrication of Pneumatic Sheet Metal Cutting Machine. Designing and fabricating the pneumatic sheet metal cutting machine is very cost-effective. It saves a lot of human effort and increases factory efficiency. The machine is useful for optimizing costs and bettering workplace layout and equipment design. With the use of a high pressure compressor and harder blades, a more substantial range and thickness capacity for cutting can be achieved. This machine is hence more useful to small industries that cut sheet metals and cannot afford expensive hydraulic cutting machines.Khagendra Barman et al 2017 [7] Sheet metal of iron and other materials with high magnetic permeability, is known as laminated steel cores and is used in transformers and electric machines. Thicknesses can vary significantly, but extremely thin thicknesses are considered foil or leaf and pieces thicker than 6 mm (0.25 in) are called plate there are three basic methods of layout. they are Parallel, Radial, Triangulation. This will, to a great extent, further involve the study of Pneumatic Control Systems, double-acting cylinders, advantages of pneumatic hand-operated valves, and high-speed blades.

[8]Karan Dutt 2013, This paper describes how pneumatic systems work and gives a detailed description of the operations of different components in the systems. Pneumatic technology deals with generation of mechanical motion from the energy stored in compressed gas. The devices have extensive application in industry in assembly lines, which make use of compressed air or inert gas. The systems are all interlinked and powered from a compressor powered electrically, located at the center; this works the cylinders and other devices that are pneumatic through a solenoid valve. It provides a low-cost, better, flexible, and reliable replacement for the operation of many electric motors and actuators. Also discussed herein are the electropneumatic systems with their components and related symbols in order to provide a small brief about them. Designs and constructions for pneumatic sheet metal benders shall consider at least the capacity to bend, precision in relation to setting an angle, and safety features hitch-free. Deep design methodology coupled with intricate testing, along with proper maintenance, shall enable

these machines to deliver their best in any industrial setting. Their capabilities relate to a wide array of bending requirements for sheet metal fabrications done with efficiency and reliability.

3.DESIGN OF PNUMATIC SHEET METALBENDING MACHINE

The pneumatic sheet metal bending machine is designed to meet specific bending capacity and angles and safety requirements, followed by a second design, which is detailed for fabrication, installation, and commissioning to ensure adherence to maintenance schedules and operator training for long-term reliability and functionality.Fig 1 shows the 3D modeling view and Fig 2 shows the Frame fabrication

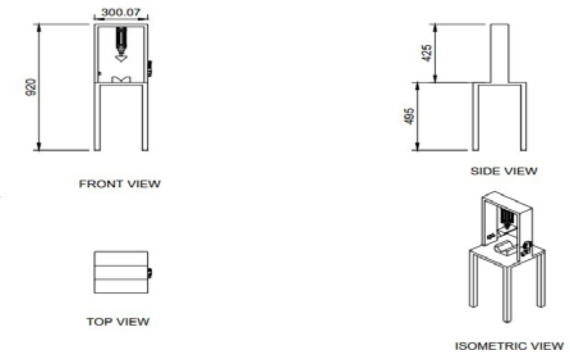


Fig 1. 3D MODELLING USING FUSION 360.

Design Calculation For Pneumatic Bending

Bending Force, F = Kbf TS Wt^2F - Bending Force
Kbf - 1.33 (For Bending)
W - part width,t - thickness of the sheet metalD - Die opening
Ts - Tensile strength of sheet metal
Material - C45
Tensile strength - 65kg/mm²
→650 N/mm²,W - part width 100 mm
T - Thickness of sheet metal = 2mmD - Die opening = 50mm
F = (1.33 x 650 x 100x (2)^2)/50
Bending Force, F = 6916 N

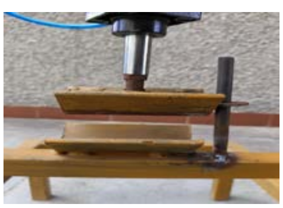
Bend Allowance for sheet metal:
BA = A*π/180* (R+kT)BA - Bend Allowance A - Bend Angle in deg
R - Inside Bend radius in mmK – constant -material thickness in mm
Cylinder Selection:
Compressor pressure (P) = 10 Bar
=10/10 = 1 N/mm²
Cross-sectional Area of piston (A):
Internal Diameter of cylinder **(d)**
F = 6916 N
d = (4F/p π)^0.5
d = (4x6916 /1* π)^0.5
d = 93.83~mm (design diameter)d = 94mm
Thrust developed in double acting cylinder
(P) Compressor Pressure = 10 bar
Cylinder diameter (D) = 400mm Piston rod (d) = 14 mm

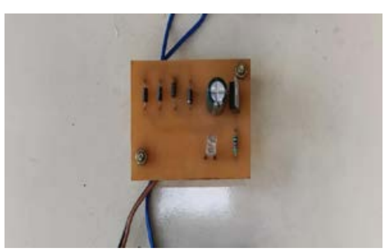
Thrust in forward stroke, A = $4 * \pi D^2$A = 452.38 mm^2

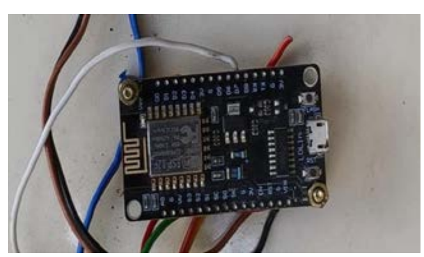
FABRICATION DETAILS

It begins at the well-detailed CAD modeling, from which the real recording of measurements and calculations is taken, to give the best of dimensions and material specifications to use in making a frame. The frame in view should have been made of sturdy materials like steels or aluminum alloys that, by their very characteristics, it can show a significant amount of response to render freedom at the same time. The CAD designs for the hollow structures are there after applied for fabrication techniques that include welding or precision machining in developing the frame components. Fig. 2 shows the frame preparation.

Fig 2 FRAME PREPARATION







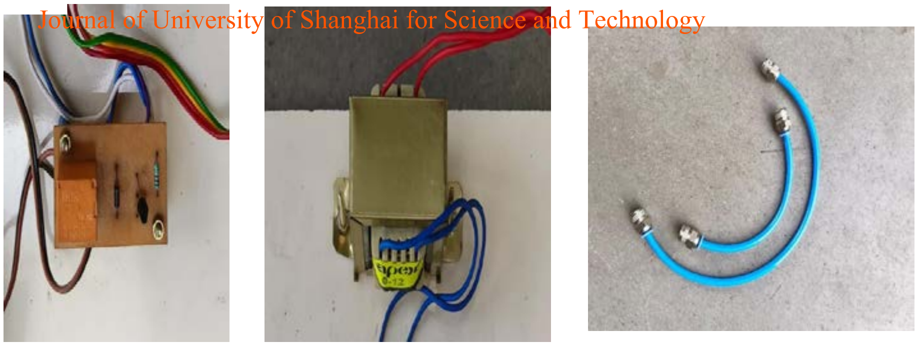


Fig 3 major components of a pneumatic sheet metal bending machine:
DCV, 4.3 Die & Punch Preparation, Double Acting Cylinder,Ultra Sonic Sensor, Compressed Air Supply Sheet, Metal, Rectifier, Nodemcu:Relay, Transformer, Polyurethane Tubes

Fig 3 shows the There are major components of a pneumatic sheet metal bending machine. The DCV or directional control valve is what flows air to different pneumatic cylinders; this is quite important to control the operation of bending. The die and punch preparations are tools meant to shape out the metal sheet in the process of bending, The double-acting cylinders, with the ability to effect the bending movement along with the return movement, use compressed air to retract the extended pistons. The ultrasonic sensor correctly reads the position or thickness of the sheet metal. The pneumatic installation, used for driving cylinders, is fed by the compressed air supply. The rectifiers convert AC into DC to feed any electronics that are applied to the NodeMCU, which may drive or get information about devices. The relays deal with the high-power circuit concerning, most of the time, driving pneumatic valves. Transformers adjust voltage levels for different parts of the system, ensuring the smooth operation of everything. These polyurethane tubes are responsible for carrying the pressure between the pneumatic components without letting the air that is carrying this pressure out of the system. They ensure joint efficiency, accuracy, and safety in the industry while dealing with metal bending.

3.2 WORKING PRINCIPLE OF PNEUMATIC SHEETMETAL BENDING MACHINE

Fig 4. Shows the working model of pneumatic bending machine. A good quality pneumatic sheet metal bending machine is constructed from a frame consisting of good quality steel components, cut and welded to a rigid structure, with further reinforcement of the critical joints. The frame dimensions shall be 600mm x 300mm x 500mm. It is made of hard steel, which gives stability and strength to the structure. Critical Components used in project Overview: The 5/2 DCV (5 Ports, 2 Positions) is used for controlling compressed air. This makes up the pneumatic actuators comprising cylinders and rotary actuators. Adjustment of bending dies and punch tools to bright work surfaces and specified working size; for instance, the opening of a die is 50 mm. Use a double-acting cylinder with a 400 mm bore and 75 mm stroke, that's all, then select a proper piston rod diameter to hit a force result that would stand to assure the required force for the bending process. Mount an ultrasonic sensor for measuring the tool-to-sheet distance in real time for appropriate setting of the bending force and angle. A good compressor and reservoir can provide compressed air at 10-bar pressure. Provide electrical elements to power the rectifier, NodeMCU, relay, and transformer for operations and control of machine functionality. Provide polyurethane tubes as per specs of 4mm x 6mm size. It provides equal pressure while bending in such a manner as not to damage the sheet metal. This process is then followed by the assembling of all these parts into one core, and the accurate alignment of these in one unit, followed by thorough testing for the efficient performance in bending various thicknesses of sheet metals.
These pneumatic sheet metal bending machines avail the aid of compressed air to produce force in bending metal sheets. Basically, they are made up of a pneumatic cylinder, bending die, a clamping-type workpiece holder, along with the controls. All there is to it is that the part of metal sheet layover is against the holder beneath the bending die; once it gets powered with compressed air, the piston within the cylinder will get pressed down. The compressed air is then further transmitted as a force through a lever mechanism to a bending die. The latter will compress a metal sheet and thus allow for it to bend into an angle along a preset line. Force applied is either manifoldly or automatically regulated to have an accurate bend. The cylinder will then retract after bending for the ejection of the bent sheet. These machines have features that handle the application speed of the force, putting in mind the different thicknesses of the sheets, ease, and low cost, but taking into account the force involved, proper care has to be exercised for safety.

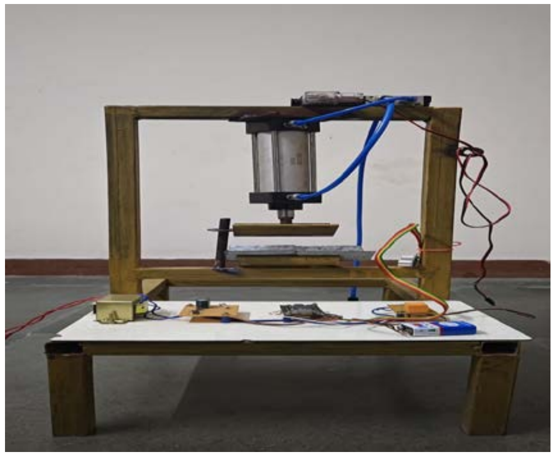


Fig 4. Working model of pneumatic bending machine

4.Conclusion

This pneumatic sheet metal bending machine is of tremendous intrinsic value in the manufacturing sector, They are the most valuable machines across a wide range of industries. These machines are affordable, and the kind of skills required is quite basic, hence there is no need to employ high-grade professionals, thus benefiting a lot of the enterprises that are small. In more expansive industries, the large volumes of work produced by one machine work to ensure minimum maintenance and low interruptions. It is likely that pneumatic technology will continue to improve in terms of precision, automation, and cost efficiency since it is developing every day. The bending machine has found favor with quite a number of industries, more so in the acquisition of custom-made metal parts, and it will continue to bring more efficacy in production processes.

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References

1.Pratihar Ayog Kumar Rastogi Adarsh Raunak Aakash Sharma, Vikas Kumar Singla, Design and Fabrication of Pneumatic Sheet Metal Cutting and Punching Machine Aryan International Journal of Engineering Research and Technology, Vol. 9 Issue 07, July-2020,pp1230-1232.

2.Madhu Kumar V, Arun Kumar N, Harsha B S,Naveen Kumar K N, Nagaraja T.K,2016 Design and Fabrication of Pneumatic Sheet Metal Cutting and Bending Machine ,,International Journal of Engineering Research And Advanced Technology (IJERAT) Special Volume. 02 Issue.01,

3.Vijaylaxmi G.Biradar, Siddharam Patil , R M Lathe, (2012) Automation of Sheet Bending Machine Using Electro Pneumatic Devices, International Journal of Scientific & Engineering Research Volume 3, Issue 9, September-2012

4.Viraj N. Suryawanshi, Nilesh V.Wakade, Prof. Prashant A. Narwade 2019 Design and Development of Pneumatic Punching Machine,International Research Journal of Engineering and Technology (IRJET) Volume: 06 Issue: 05 .

5 K Mariyappan, Santhosh V, Abinav Krishna A, MD Fyazuddin S, Fabrication of Pneumatic Punching and Bending Machine Powered by Solar Panel,International Journal of Scientific Research in Science, Engineering and Technology January-February-2023, 10 (1) : 241-245

6 Suraj V Bhosale1, Gajanan S Ghute2, Nikita H Dudhe3, Ashish G Ingle, Design and Fabrication of Pneumatic Sheet Metal Cutting Machine-A Review International Research Journal of Engineering and Technology (IRJET) Volume: 05 Issue: 01 | 2018 pp 751-753

7.Khagendra Barman, Md. Nesar Ali, Md Rayhan Hasnat , S. M. Humayun Kabir , fabrication of a pneumatic sheet metal cutting machine ,Proceedings of the International Conference on Mechanical Engineering and Renewable

Energy 2017 (ICMERE2017) 18 – 20 December, 2017, Chittagong, Bangladesh ICMERE2017-PI-108
8.Karan Dutt, Analytical description of pneumatic system, international journal of scientific & engineering research, volume 4, issue 9, september-2013 1443,
9.Adnan I. O. Zaid and Frank W. Travis, An examination of the effect of target thickness in the perforation of mild steel plate by a flat-ended projectile, International Journal of Mechanical Sciences 1974 16 pp 373-383
10.Handbook of pneumatic system, Mr. S.R. Mujumdar.
11.Handbook of component of pneumatic control system, Mr. Lev Abramovich Zalmanzon.
12.Milan Virani, Jagdish Vekariya, Saurin Sheth, Ketan Tamboli,"Design and Development of Automatic Stirrup Bending Mechanism", Gujarat, pp.598-606, 2013.