Design and Development of Pneumatic Sheet Metal Cutting Machine


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ABSTRACT

It is important to note that in today’s industrial era, sheet metal is cut and bent into a variety of shapes to obtain better surface finish and flexibility in manufacturing processes. The use of modern techniques, such as pneumatic sheet cutting machines, has greatly improved the efficiency of sheet metal cutting and bending processes. This review focuses on the reliability, performance, and design simplification of pneumatic sheet cutting machines. Additionally, it examines the energy lost in the pneumatic cylinder while it imparts force on the cutting blade. The energy efficiency of pneumatic and compressed air systems is a critical aspect in the development of sustainable production. The objective of this cross-discipline review is to provide production and life cycle engineering researchers with an update on the state of the art in energy efficiency for pneumatic production and associated compressed air infrastructure.

Keywords : Pneumatic Cylinder, Life Cycle Engineering, Air Infrastructure, Modern Manufacturing, Mechanical Motion

I. INTRODUCTION

The pneumatic sheet metal cutting machine is a key player in the world of modern manufacturing, characterized by the pursuit of precision, efficiency, and technological innovation. This machine has revolutionized the way sheet metal is shaped and transformed, offering a fast and accurate solution to a once-labour-intensive process [1-5]. The machine operates on the principles of pneumatics, utilizing compressed air as the driving force for mechanical motion. The components of the machine include a compressor, pneumatic cylinders, control valves, and cutting tools, all carefully engineered to execute precise and controlled actions on sheet metals [6-10]. One of the defining features of the pneumatic sheet metal cutting machine is its versatility, capable of handling an array of sheet metal types and applications across various industries [11-16]. The advantages of employing pneumatic systems in sheet
metal cutting are multifaceted, providing rapid response times, high operational speeds, and consistent performance, making them suitable for continuous manufacturing processes. Safety considerations are paramount, with these machines equipped with emergency stops, guards, and designed to operate within stringent safety standards. As technology continues to advance, the pneumatic sheet metal cutting machine is poised to be at the forefront of innovation, with anticipated developments in materials, cutting tools, and control systems expected to elevate precision and efficiency to unprecedented levels [17-20]. The importance of generating new ideas for a business project, product, or means of reducing manufacturing costs is also discussed, emphasizing the need for established creative techniques such as brainstorming. In summary, the pneumatic sheet metal cutting machine is a crucial component of modern manufacturing, offering a fast, accurate, and versatile solution to sheet metal processing [21-24].

II. CONFIGURATION OVERVIEW

This section provides information on the mechanics and limitations of the pneumatic sheet metal cutting machine.

A. Working Principles of Pneumatic sheet metal cutting machine and its Limitations

The following figure shows general layout for the machine.

The air-compressor is turned on and fills the receiver tank with air pressure up to 8 bar. The supply air is filtered, regulated, and lubricated (FRL) and then passed to the machine through a separate line, which is connected to an ON/OFF switch. The compressed air then goes to the machine's Direction Control Valve. In the non-actuated circuit diagrams, at position 'A', the piston is stationary and locked, and all ports are closed.

![Fig 1.1: General Layout](image1)

![Fig 1.2: Working model](image2)

![Fig 1.3: Position ‘A’](image3)

![Fig 1.4: Position ‘B’](image4)
At position ‘B’ in the diagram, the DC valve is on the left-hand side. This connects the cap end and pressure port while connecting the rod end port to the exhaust port. Compressed air enters the cap end of the cylinder and pushes the pistons outwards, causing the air in the rod end side to be expelled from the cylinder. The force is then transmitted through the connecting link, causing the upper blade to move downwards. At this point, a sheet is inserted between the upper and lower blades before the actuating DC valve. As the upper blade moves downwards, stress is generated in the sheet metal, exceeding the ultimate shear stress of the sheet metal, and the shearing action takes place. Once the shearing action is complete, the DC valve is moved to position ‘C’ as shown in the diagram. The rod end port and pressure port now get connected, while the cap end port is connected to the exhaust port. Compressed air now comes from the rod end of the cylinder and pushes the pistons inward, expelling the air in the cap end side of the cylinder. The process can now be repeated for further cutting, with the small cut pieces removed and the next sheet inserted for cutting in case of larger pieces.

III. LITERATURE SURVEY

The developed a pneumatic and punching machine. The project helped reduce manufacturing cost for small scale industries and manually controlled press into an automatic machine using which they saved maximum operating time. Using this maximum output increase and human intervention decreased.

The developed a manually operated conventional sheet bending machine to an automatic machine and eliminated the problem of signal overlapping by using stepper module. The employed a stepper module, a component of advanced pneumatics for automation of conventional sheet metal bending machine operations thus converting a manually operated bending machine to an automatic machine.

The developed a pneumatic sheet metal cutting machine which runs by means of recompressed air. It is an efficient way of increasing production for small scale industries. The developed a pneumatic accelerator for high-speed punching which can be easily employed in conventional presses thus eliminating the use of high energy rate forming (HERF) machines to store energy. The accelerator when employed on mechanical presses converts low speed operation of hammer to high-speed operation.

The experimented on the high-speed perforation of mild steel plates for impact velocities up to 300 m/s analyzed the bulge height at perforation. The studied various types of pneumatic machines and components along with their advantages and disadvantages. He concluded that pneumatic machines can provide power at a cheaper, safer and more reliable way than electric motors and actuators. The designed and fabricated mechanically operated paper shearing machine with the capacity to cut 25mm thick and 300mm wide paper. The machine could produce a variable force using screw press which made it useful to perform other operations like bending, punching and embossing. The developed methods to measure the formation of edge cracks on shearing blades. It has been found that the forming strength of high strength steels is curtailed due to edge fractures and can be improved by varying process parameters like die clearance, geometry and cutting line. The designed and fabricated an automatic pneumatic hole punching machine powered by solar energy. The machine has
been designed on Solid Works software. Since the machine uses solar energy as a source of energy it will eliminate/reduce the usage of electricity in running the machines in small scale industries. The developed a pneumatic machine that would perform cutting as well as bending operation to reduce the cost of operations performed on sheet metal. Further modifications in their design can also increase the cutting force. Also studied the influence of punch–die clearance in blanking process. Their investigation showed that by decreasing clearance the required blanking force increased. They found that 10% is the optimum clearance is required for minimizing blanking force. The fabricated a pneumatic punching machine to reduce punching cost on metallic sheet. The investigated the reasons behind the failure of mould dies in a punching machine. They found out that die failure happened because of improper heat treatment thus reducing the toughness and fatigue resistance of die material. The developed a pneumatic sheet metal cutting machine which is better in comparison to manual driven sheet cutters. The efficiency of the cutter can be increased by further enhancement in cutting blade. The designed a PLC controlled pneumatic punching machine. The machine reduced the production time and increased productivity from 60 units per hour to 420 units per hour. The studied the influence of parameters like blanking force, clearance, blanking layout on sheet deformation. They found that the tolerance in the dimension of the punch hole can be minimized by increasing the compressor pressure. They found that variation in the dimension was more in case of a galvanized iron sheet as compared to the aluminum sheet. The found out that by changing the pressure of compressed air variable cutting forces could be obtained and by adding more accessories this equipment can cut a higher range of sheet thickness.

IV. Theoretical Analysis

The theoretical analysis performed asserts on the pressure necessary to cut the sheet and the best blade position for the same.

4.1. Pressure Calculations

The design calculations, to obtain the optimum pressure for cutting is performed considering the parameters from literature reviews and practical application of the project-

- The maximum width (L) of the sheet, which the machine can cut in one cycle is taken as 120 mm, based on practicality and length of the blade used.
- The strength of sheet metal (Tmax) is found to be 180 N/mm².
- The maximum thickness of the sheet, which the machine can cut is taken as 2.5 mm, based on scope defined.
- The factor of safety for the calculations is assumed to be 1.2.
- The mass of the cutting machine is taken to be 3 Kg, based on individual weights of the components used.
- The area of the bore was calculated to be 1963.4954 mm², based on the blade designed on Inventor.

4.1.1. Cutting Force

\[ FC = L \times t3 \times T_{max} \ldots \]  

The Eqn.1 is implemented to calculate the force required to cut the metal sheet. FC – force to cut the sheet
L – width of sheet = 120 mm
\( t3 \) – thickness of the sheet = 2.5 mm
\( T_{max} \) - strength of sheet metal = 180 N/mm²

\[ FC = 120 \times 2.5 \times 180 \]

\[ FC = 54000 \text{N} \]
4.1.2. Stripping Force

\[ FS = 0.2 \times FC \]  

The Eqn. 2 is implemented to calculate the force required to strip the metal sheet. \( FS \) – force to strip the sheet
\( FC \) – force to cut the sheet = 54000 N
\( FS = 0.2 \times 54000 \)
\( FS = 10800 \) N

4.1.3. Static Force of the cutting mechanism

\[ F_{ST} = M \times g \]  

The Eqn. 3 is implemented to calculate the static force of the cutting mechanism. \( F_{ST} \) – static force
\( M \) – total mass of the cutting system = 3 Kg.
\( g \) - Gravitational moment of acceleration= 9.81 m/sec2
\( FST = 3 \times 9.81 \)
\( FST = 29.43 \) N

4.1.4. Total Force

\[ FT = FC + FS + FST \]  

The Eqn. 4 is implemented to calculate the total force required to shear the sheet. \( FT \) – total force to shear the sheet
\( FC \) – force to cut the sheet = 54000 N
\( FS \) – force to strip the sheet = 10800 N
\( FST \) – static force = 29.43 N
\( FT = 54000 + 10800 + 29.43 \)
\( FT = 64829.43 \) N

<table>
<thead>
<tr>
<th>Position</th>
<th>Angle of Force Component (°)</th>
<th>Cutting Force exerted (N)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>56.88</td>
<td>35419.75</td>
</tr>
<tr>
<td>2</td>
<td>43.83</td>
<td>46764.26</td>
</tr>
<tr>
<td>3</td>
<td>32.68</td>
<td>54562.75</td>
</tr>
<tr>
<td>4</td>
<td>29.54</td>
<td>56398.09</td>
</tr>
</tbody>
</table>
4.1.5. Pressure

\[ PC = \frac{F}{A} \]  

The Eqn. 5 is implemented to calculate the pressure that is supplied by the pneumatic cylinder.

\( PC \) – pressure required to cut the metal sheet  
\( F \) – Maximum force to shear the metal sheet  
\( A \) – Area of the bore

\[ PC = \frac{56398.09}{1963.4954} \]  
\( PC = 28.7233 \) N/mm\(^2\)  
\( PC = 2.87233 \) bar

4.1.6. Total Pressure

Considering Factor of safety (FOS) to be 1.2.  
\[ P = PC \times FOS \]  

The Eqn. 6 is implemented to calculate the total pressure required to shear the metal sheet.  
\( P \) – Total pressure supplied by the pneumatic cylinder  
\( PC \) – pressure supplied by the pneumatic cylinder

\[ P = 2.87233 \times 1.2 \]  
\( P = 3.4467 \) bar

V. METHODOLOGY

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It is interesting to note that the sheet metal cutting machine can be easily converted from a manually operated machine to a pneumatically operated one with the help of proper design procedures. The machine is equipped with a pneumatic double-acting cylinder, solenoid valves, flow control valves, and a timing unit to automate the process. This makes the machine more efficient and economical as it requires less manual labour. The compressed air from a compressor is used as the force medium for the operation. It is worth mentioning that the design and building of a pneumatic sheet metal cutting machine involves several key steps. Although this is a general guide, specific details may vary based on project requirements and available resources. Nonetheless, the machine is portable, easy to transport, and provides a safe and effective way to cut sheet metal with minimal maintenance cost.

VI. CONCEPT GENERATION

![3D Model of Concept Front view](image1)

Fig.5.1 : 3D Model of Concept Front view

![3D Model of Concept Top view](image2)

Fig.5.2 : 3D Model of Concept Top view

Concept generation is a crucial phase in the product design process, where ideas are generated based on target specifications and requirements. The goal is to develop a final design for the product that meets the customer's needs. This phase involves analyzing the customer requirements from different angles, including the product's functionality, aesthetics, and ergonomics. The ideas generated during this process should describe the design and working principles of
the product, and how it can meet the customer's requirements. The proposed design may be illustrated as a 3D model, blueprint, or rough drawing. The concept generation process requires creativity and problem-solving skills to come up with innovative ideas that meet the target specifications and requirements. The ideas generated during this phase are evaluated based on several factors, including feasibility, cost, and the impact on the product's performance. It is essential to generate a sufficient number of ideas to ensure that the final product design meets the customer's needs and stands out in the market. In conclusion, the concept generation phase is a critical step in the product design process, where creativity and problem-solving skills are essential to generate innovative ideas that meet the target specifications and requirements.

VII. CONCEPT SELECTION

![Fig.6.1: Basic assembly of Pneumatic Sheet Metal Cutting Machine](image)

The necessary components were bought based on the design calculations to assemble and check the functionality of the proposed machine. After the assembly, a preliminary check was conducted to verify if the chosen pneumatic cylinder could actuate the blade down with the necessary force to cut it. The initial setup was done by attaching the pneumatic cylinder to the solenoid valve through the valves, while the air compressor was attached to the other side of the solenoid valve. The piston of the pneumatic cylinder and the frame held the cutting mechanism in place, which consists of the upper and lower blade. The switching circuit, powered by an AC supply, was used to control the pneumatic cylinder, which was attached to the solenoid valve. It consisted of 2 LED bulbs. When the circuit was powered, the first LED glowed, indicating that the circuit was active. When the switch was initiated, a signal was sent to the solenoid valve, which allowed the air from the air compressor to flow into the pneumatic cylinder to complete its forward stroke, which was the cutting stroke. After the cutting operation was performed, the switch was pressed again to retract the piston back.

It was ensured that the piston was in its retracted position before testing to keep the sheet at its cutting position over the blade. The air compressor was activated, and the pressure was set to 7 bars. The test was conducted with a controller controlling the cutting operation of the blades using the switch. It was observed that the machine could efficiently and quickly cut the sheet with thickness of around 2.5 mm.

VIII. CONCLUSION

This paper presents an efficient and cost-effective method for shearing sheet metal using a pneumatic actuation system that can be applied in small and medium-scale industries. The machine is accurate in its operation and is considered safer than manual cutting. Pneumatic systems are less expensive than hydraulic systems as they use air, which is abundant, inexpensive, and easy to contain and regulate. Additionally, pneumatic systems have a longer operating life and require less maintenance since
gases are compressible, making them less susceptible to damage from shock. On the other hand, hydraulic systems require regular maintenance as their fluids need to be replaced over time, which increases the cost. Therefore, a pneumatic system is a more reliable option than a hydraulic system with lower maintenance costs. This project provides a safe and effective way to cut sheet metal with minimal maintenance costs. The cutting thickness range can be increased by arranging a high-pressure compressor and installing more hardened blades. This machine is ideal for small sheet metal cutting industries that cannot afford expensive hydraulic shearing machines.

IX. REFERENCES


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