NIPES

Advances in Engineering Design Technology

Journal homepage: www.nipesjournals.org.ng

Design and Development of a Cost-Effective Automated Metal Sheet Bending Machine

Eke Lawrence Azundah & Ashiedu Festus Ifeanyi

Mechanical Engineering Department Federal University of Petroleum Resources Effurun Warri, (+234) Nigeria.

ARTICLE INFORMATION

Article history:
Received 17 March 2023
Revised 22 April 2023
Accepted 02 May 2023
Available online 12 June 2023

Keywords:
Fabrication, bending machine, micro-controller, transistor, power supply.

https://doi.org/10.5281/zenodo.8029569

ABSTRACT

In the metal production industry, metal sheet fabrication is crucial. This involves the manufacturing of products like hinges, tools, vehicles, and machine plates. A single flat sheet of metal can be folded into different shapes without being stretched or chopped. Numerous research studies have been carried out to design metal sheet bending machines using techniques ranging from manual, semi-scale metal, and metal product makes is a crucial job driven by the worldwide movement towards intermediate technology and sustainable development. Manual metal bending which is done with the aid of a vice and hammer requires the use of human effort which could result in accidents, man- hour loss, and a reduction in revenue. Hence, this research focuses on the development of a cost-effective automated metal sheet bending machine. This design comprises a microcontroller, display, power supply, roller bending components, rigid metallic frame, relays, transistors, actuators, and other discrete electronic components. The device is aimed at effortlessly bending aluminum sheet that is 0.5 to 0.7mm thick with the elimination of extensive human effort, and time wastage, and also ensuring safety. The results of the performance evaluation carried out on the developed bending machine show a reduced cycle time, an increase in productivity, manpower reduction, and an increase in the safety of the operator which has the potential of increasing the revenue of metal sheet bending operators.

1. Introduction

Any nation's economy depends heavily on the production of iron and steel. This is so because the iron and steel industry, which serves as the foundation for all other industries, directly impacts the creation of a sustainable society. This is achieved by exerting stress on a metal sheet, which causes it to bend into the required shape, the bending process—also known as metalworking—produces a V-shaped (channel or U-shape) shape along the axis of a material, conducted using ductile materials. Such materials are employed in machine processes such as brake presses, pan brakes, and specialist machinery [1]. When utilizing a pressure pad to hold the sheet against the die, wipe bending causes the sheet to bend against the radius of the edge.

As a result, the trend in steel production and consumption is seen as a sign of the health of the national economy. For this reason, steel is sometimes referred to as the "backbone" of an economy [2]. Thus, by increasing steel production, a significant contribution to the expansion of the economy of a nation can be achieved.

The sheet metal sector relies heavily on cutting and punching equipment, and since large-scale enterprises are well-established, they can afford to outfit themselves with hydraulically controlled cutting and punching machines that produce a lot of force and are simple to automate. Consequently, the vast production output of large-scale industries. The same is not true for medium-sized to small-scale industries. Most of these sectors are limited to solely utilizing hand-operated cutting or punching machines because hydraulic machinery is too expensive. The adaptability of the sheet metal process has led to its widespread use as a metal-forming technique worldwide [4]. Because sheet metal forming is one of the most crucial semi-finished and finished products utilized in the steel industry, sheet metal forming technology is a crucial technical discipline within the field of mechanical engineering. As a result, sheet metal forming products are today used in a wide range of industries, including infrastructure, domestic appliances, buildings, airplanes, and the manufacturing industry [2]. The sheet metal process is extremely productive and its use grows yearly, [3].

The aim of this project is to design and construct an automated metal sheet bending machine which uses actuators to drive the bending mechanism. This involves: implementing a Computer Aided Diagram (CAD), selecting a hydraulic system capable of delivering a sufficient load for 1 mm sheet metal bending, selecting and assembling the appropriate electronic components for the automation, and evaluating the performance of the developed system using the sheet metal dimension. The metal sheet is automated and calibrated to minimize manpower. This calls for the use of Programmable logic circuit as an interface for controlling mechanical movements through electronic systems. Several metal sheets bending machine designs have been implemented including designing and developing of a bicycle-integrated pipe bending system [5]. However, the previous designs require extensive manpower.

2. Methodology

In order to develop an efficient metal sheet bending machine, certain procedures such as reviews of research articles, books, periodicals, manuals, and electronic sources that describe the design, manufacture, and mechanics of the sheet metal production process served as the basis for the study's literature evaluation. In addition, the design was subdivided into two namely: hardware and software sections.

There are diverse metal bending techniques, but this research is focused solely on developing a cost-effective metal sheet bending machine using a V-shaped technique. To achieve the objectives of this research, the design implementation is subdivided into control circuit and mechanical sections. Figure 1 shows the basic block diagram of the developed automated metal sheet bending machine. The block diagram highlights the basic control and mechanical components required for the design of the set objectives. The integration of the actuator in the developed design has replace manpower required for shape bending of metals in previous machines, while the controller; a programmable electronic device will be used to coordinate the operations of the developed metal bending machine.

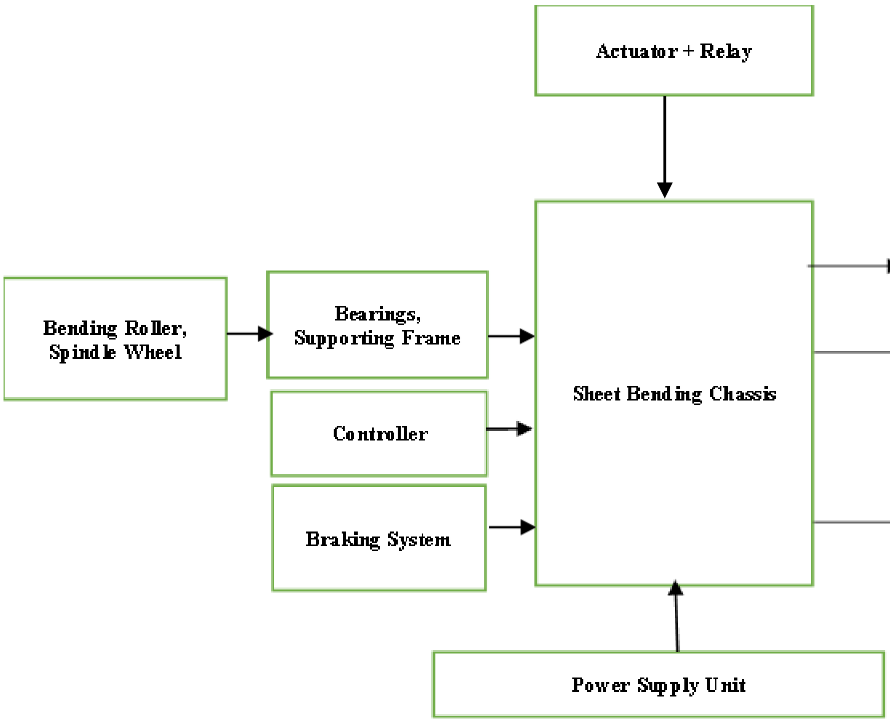

Figure 1: Block diagram of the developed automated metal sheet bending machine

2.2 Control Circuit

Automation and control of machines play a crucial role in eliminating manpower, and safety, and also increasing productivity. The electronic circuit consists of discrete components such as resistors, capacitors, a solid-state relay, an actuator, a potentiometer, and an integrated circuit. This section is designed, assembled, analyzed, and critically tested to ensure the optimum performance of the metal sheet-bending machine. The software used is Arduino Integrated Development Environment (IDE) for programming the machine and Proteus as a circuit simulator, while the hardware interface comprises a sensing unit, a filtering section, and the microcontroller unit. Table 1 below shows the list of the electronic components for the design.

There are two classes of power supply required for the design; a direct current (dc) power source and an alternating current (ac) power source. The ac power source is 220 V/50 Hz obtainable from mains, generator, and inverter, while the dc power supply is obtained via rectification and voltage reduction of the ac mains. The dc supply is subdivided into two namely; 5 V AND 12 V supplies. This is a result of the voltage requirements by the actuator and the programmable microcontroller circuitry required for the machine's operation.

Table 1: Components List for the Automated Metal Sheet Bending Machine

Electronic Components	Specifications
Controller	Arduino Mega
Limit Switch	5V
Relay	5V, 30 A
Power supply unit	220V/50 Hz
Liquid Crystal Display	5V
Actuator	12V

Potentiometer (Emergency)	5V
1.5 mm and 2.5 mm electrical cable	220V
Cat-6 cable	5V

2.3 Solid-State Relay

It is an electro-mechanical relay (EMR) that uses coils, magnetic fields, springs, and mechanical contacts to operate and switch a supply, the solid-state relay, or SSR, has no moving parts but instead uses the electrical and optical properties of solid-state semiconductors to perform its input to output isolation and switching functions. Just like a normal electromechanical relay, SSRs provide complete electrical isolation between their input and output contacts with its output acting like a conventional electrical switch in that it has very high, almost infinite resistance when non-conducting (open), and very low resistance when conducting (closed). SSR is utilized to run the activation of the actuator to implement the mechanical process for bending the metal plates.

The actuator is connected to the solid state relay in an H-bridge configuration in order for the machine to be automatically operated. Now just apply a voltage to the free coil pins of the relay you wish to energize, one clockwise, and the other counterclockwise.

Figure 2: Solenoid Valve

2.4 H-Bridge Configuration

An H-bridge is an electronic circuit that switches the polarity of a voltage applied to a load. The H-bridge arrangement is generally used to reverse the polarity/direction of the motor, but can also be used to 'brake' the motor, where the motor comes to a sudden stop when the motor's terminals are connected together. By connecting its terminals, the motor's kinetic energy is consumed rapidly in form of electrical current and causes the motor to slow down. Another case allows the motor to coast to a stop, as the motor is effectively disconnected from the circuit. Figure 3 below shows the designed H-bridge configuration for the operation of the actuator attached to the metal bending machine.
In order to achieve the H-bridge configuration for the actuator, the following procedures were ensured.

- A wire was connected between the motor and the common pin of the SSR, this was repeated with other wire and SSR.
- The two Normally Open (NO) pins of the relays were soldered together. The same was repeated with the Normally Closed (NC) pins.
- The NC pins were connected and the jumped-together coil pins were to the Ground (or negative).
- The NO pins were connected to the VCC (or positive).

Actuator

A linear actuator is an actuator that creates motion in a straight line, in contrast to the circular motion of a conventional electric motor. Mechanical linear actuators typically operate by conversion of rotary motion into linear motion. Attached to the notch of the actuator is the V-shaped die required for the bending of metal. The actuator is interfaced with the SSR via the microcontroller for the control signal to be initiated. As shown in Table 2 below, the actuator has the following specifications:

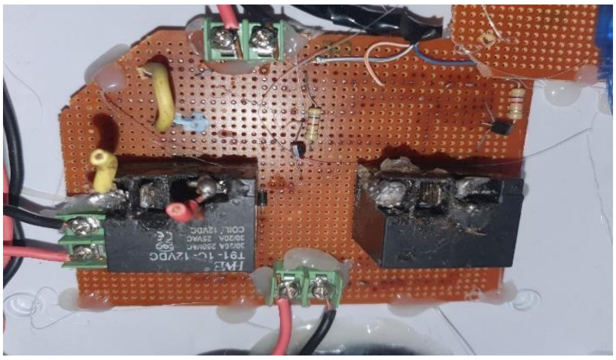

Figure 3: H-bridge Configuration

Figure 4: Linear Actuator with an Attached Die to the Notch

2.5 Mechanical Unit

Any machine part preparation requires careful material selection while taking design and safety into account. Table 2 shows the mechanical materials required for the design of the metal bending machine, while Table 3 shows the specifications of the metal sheet to be used on the machine. Equations (i) and (ii) highlight metal sheet cutting force calculation and metal sheet bending force calculation. The following considerations determine the choice of material for engineering applications:

Table 2: Mechanical Components for the Design of an Automated Metal Sheet Bending Machine

Components	Engineering Standard	Specifications
Bending Rollers	alloy steel	Length = 155 mm, Diameter= 70 Ø
Joints	AISI 4037	Diameter = 40 Ø, width = 10 Mm
Screw	AISI 4037	Length = 135mm , Height =22mm
Bearings	52100 chrome steel	Diameter = 30 Ø, Thickness= 9 mm
Spindle Wheel	410 stainless	Length = 173.20 mm , width = 25 mm, Diameter = 10 Ø
Moving Roller	alloy steel	Length = 155 mm, Diameter

		= 70 Ø
Supporting Frame		
Actuator		150 mm
Die, Pneumatic valve, Pneumatic pipe, screws, and bolts.		

Table 3: Metal Sheet Specifications

Metal Sheet Material	Aluminum Sheet
Max Shear stress of the Aluminum sheet (τmax)	25 N/ mm^2
Length (L)	20 mm
Thickness (t)	0.7 mm
Tensile Strength for Aluminum	400N/mm^2

2.6.1 Metal Sheet Cutting Force Calculation

Force = L X t X τmax
Metal sheet thickness = 1 mm
Force, F = 20 X 1 X 25
F = 500 N (This is the force needed to cut the sheet metal)

2.6.2 Metal Sheet Bending Force Calculation

The force required to bend the sheet metal = (L× K ×ut × t) / (w)
Where, ut = Tensile Strength of Aluminum (400N/mm^2)
K = Die opening Factor (1.33 for V-Bending)
w = Width of Die Opening,
For the value of K=1.33,
w=16t
Force required = (25 × 1.33 × 400 × 0.7) / (16 × 1) = 9310/16
F = 582N
Therefore, the Maximum force required to bend 0.5 -0.7mm thickness of the metal sheet is 582N

2.7 V-shaped Die

The V-shaped bending technique implemented in this research is considered the most crucial die-bending procedure, where the deformed shape is produced as a result of the sheet being driven into the die by the punch until it is in as much contact as possible with the sides of the die. The sheet first experiences the air-bending stage. As the bending continues, it reaches a point where the bent metal sheet edges are tangent to the die's sides close to both support points. The coining stage officially starts at this moment.
The following factors are considered for the V-shaped metal bending machine.

2.7.1 Factors Considered for the V-shaped Bending Procedure

i. BA = bend allowance
ii. BD = bend deduction
iii. R = inside bend radius

iv. K = K-Factor, which is t / T
v. T = material thickness
vi. t = distance from the inside face to the neutral line
vii. A = bend angle in degrees (the angle through which the material is bent)

The absence of any internal forces is symbolized by the neutral line, which is an illustrative line that can be drawn through the cross-section of the workpiece and is also known as the neutral axis. The material between the neutral line
and the inside radius is compressed during the bend at the bend-zone. During the bend, tension is applied to the material between the neutral line and the outside radius. The material's needed length before bending is shown by the neutral line or flat pattern, which is the difference between the created bend and the bend allowance.

2.8 Automated Metal Sheet Bending Machine Procedure

The design procedure for the development of an automated metal bending machine follows the following:

- Figure 5 shows the technical template with the dimensions of the proposed automated metal sheet bending machine
- Figure 6 shows the construction of the metallic frame of the automated metal bending machine
- Figure 7 shows the assembling of the actuator on the automated metal bending machine
- Figure 8 shows the construction of the protective enclosure for the constructed automated metal bending machine

2.9 Design Implementation of the Developed Automated Metal Bending Machine

The core unit of the developed automated metal bending machine is the programmable microcontroller. Its primary purpose in this design is to receive feedback, process it, and initiate the appropriate execution algorithm to carry out the V-shaped bending of the metal sheet. The actuator receives coordinated vertical movement instructions from the microcontroller to exert sufficient force for bending flat metal sheets to V-shaped designs. The flat metal plate must be placed on the V-shaped die, while the potentiometer is turned clockwise to initiate the start algorithm of bending. After the start sequence for bending is initiated, the operator needs to push the metal plate inward or forward in a form of a feeding sequence for the machine punch to bend the metal.

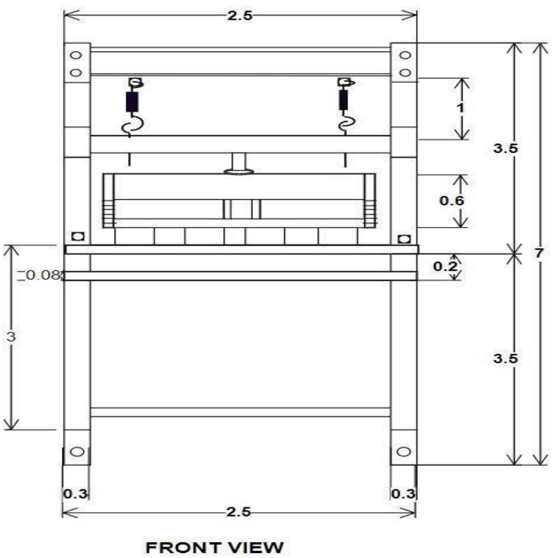

Figure 5: Engineering Drawing of the Automated Metal Sheet Bending Machine

Figure 6: Metallic Frame of the Automated Metal Bending Machine

Figure 7: Actuator Assembling on the Automated Metal Sheet Bending Machine

Figure 8: Assembling of the Automated Metal Sheet Bending Machine

Figure 9: Fully Assembled Automated Metal Bending Machine

3. Results and Discussion

The assembling and testing of the control and mechanical components, the machine was subjected to metal sheets of 0.5 mm, and 0.7mm to validate the performance of the system. The result clearly shows that the developed metal bender performed favorably when compared against a standard. Also, the bending time and angle reproduced by the developed metal bender is of higher degree than the manual bender as shown in Figure 10.

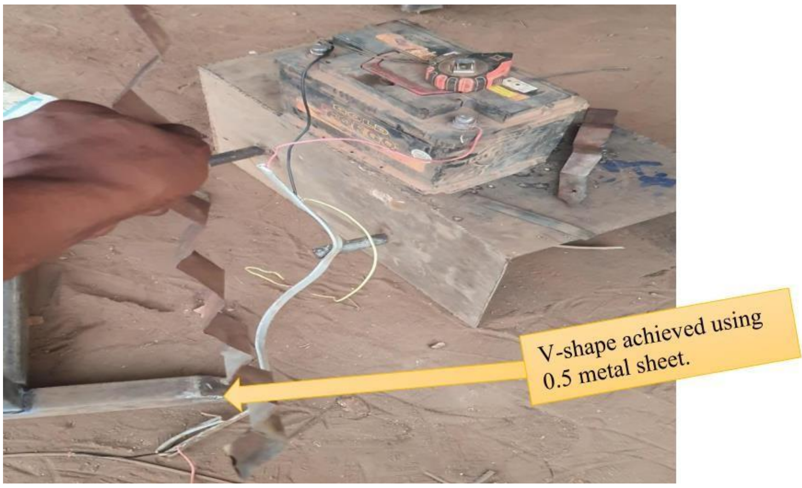

Figure 10: The V-shaped Obtained from the Automated Metal Sheet Bending Machine

4. Conclusion

This research has produced an efficient low-cost automated metal sheet bending machine capable of eliminating extensive manpower, enhancing the safety of the operators, affordable, and easy to maintain using readily available materials.

Nomenclature

L	Length (mm)
ϕ	Diameter
^{0}F	Fahrenheit
v	Voltage
lbs.	Pound
LT	Series
A	Ampere
Hz	Frequency
t	Thickness
N	Newton
BA	Bend allowance
BD	Bend deduction
R	Inside bend radius
K	K-factor which is t/T
T	Material thickness
A	Bend angle in degree

References

[1] Ahmed K., Zied A., Nader H. and Khaled E. Modeling and computation of the three-roller bending process of steel sheets, Journal of Mechanical Science and Technology 26 (1) (2012) 123-128
[2] Anas Muzamil Bin, Hamiddin, Design, and Fabrication of Multipurpose machine, Universiti Malaysia Pahang November 2009
[3] Groche P., A. Zettler, S. Berner: Development of a One-Step-Model for The Design of flexible
[4] Michael Lindgren, Experimental and Computational Investigation of the Roll Forming Process, Luleå University of Technology 2009
[5] Xiaoyun Liao, Evolutionary Path Planning for Robot-Assisted Part Handling in Sheet Metal Bending, Dept. of Mechanical & Industrial Engineering, The University of Manitoba, 2007.
[6] Wanisevic A, Milutinovi M, Strbac B, Skakum P (2013) Stress state and spring back bending operations. J Technol Plast 39(2):157–168.

Appendix

Table 1: Components and specifications

Component	Specifications
Series	LT
Capacity	27 to 225 lbs. (120 to 1000 N)
Voltages	12 Vdc or 24 Vdc
Std. Stroke	1 to 11.8 in
Length (inch)	85 mm
Max Speed at Rated Load	Up to 1.3 in/s (33 mm/s)
Limit Switches	Fixed
Feedback	Hall effect sensor
Current Drawn at Rated Load	3.5 A (12 Vdc) 2.0 A (24 Vdc)
Translating Tube Material	Polished Aluminum
Temperature Range	-13 °F to 150 °F

Metal Sheet Cutting Force Calculation

Force = L X t X τmax
Metal sheet thickness = 1 mm
Force, F = 20 X 1 X 25

F = 500 N (This is the force needed to cut the sheet metal)

Metal Sheet Bending Force Calculation

The force required to bend the sheet metal = (L× K ×ut × t) / (w)
Where, ut = Tensile Strength of Aluminum (400N/mm^2)
K = Die opening Factor (1.33 for V-Bending)
w = Width of Die Opening,
For the value of K=1.33,
w=16t
Force required = (25 × 1.33 × 400 × 0.7) / (16 × 1) = 9310/16
F = 582N
Therefore, the Maximum force required to bend 0.5 -0.7mm thickness of the metal sheet is 582N