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Optimization and Implementation of Tarpaulin Welding Machine Pressure Control System for Increase in Efficiency

Enya J.A , Uju I.U. , James A.O. , Ezirim U.I.
[1]Delta State Polytechnic Ogwashi-uku,Delta State,
[,2,3]*Chukwuemeka Odumegwu Ojukwu University, Anambra State,*
[4]*National Engineering Design Development Institute Nnewi, Anambra State, Nigeria*

ABSTRACT
A refrigerator compressor was implemented with a PID controller and temperature settings to control tarpaulin sealing machine capabilities. The sealing process was optimized for various tarpaulin materials through pressure and temperature combinations. For HDPE, optimal welding was achieved at 100 Psi and 140°C, yielding 6.22 N/m² weld strength with 3.2 Amps consumption. LDPE required 70 Psi and 115°C for 0.81 N/m² strength using 2.7 Amps, while PVC needed 80 Psi and 125°C for 1.80 N/m² strength consuming 2.9 Amps. The system was designed as a cost-effective alternative to conventional machines for sealing tents, canopies, billboards, and shop covers.

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I. Introduction

Tarpaulin welding machines are being recognized as crucial industrial equipment. Conventional machines are being hindered by inefficiencies in power usage and operational complexities. Pressure control inadequacies are being identified as the primary concern, leading to uneven welds and material waste.These challenges are being addressed through advanced pressure control systems. Pressurized air systems are being implemented across various sectors, from medical equipment to manufacturing facilities. Air pressure control is being utilized in multiple applications, including pneumatic tools and welding operations, where specific pressure requirements are being maintained.

II. Literature Review

A solenoid design optimization study was conducted by researchers at Anhui Polytechnic University (2023), where non-uniformity defects in internal magnetic fields were identified as limiting factors.
Linear Drive with Solenoid Coupling was examined by researchers (2018), where pneumatic installations were analyzed.
High-pressure solenoid valve dynamics were investigated (2005), noting compression requirements for hydrogen and methane transportation.
Research was conducted on compressed-air powered vehicles (2015), electronic valve timing control units (2021), pneumatic processes sequence programming, and pressure control in pneumatic gravity compensation systems (2018), which was noted to be crucial for zero-gravity simulations.
Energy efficiency in pneumatic control systems was examined through remotely-controlled pressure regulators (2022). Operating pressure reduction was studied at the University of Novi Sad.
Valve control pressure in electro-pneumatic clutch systems was investigated (2022), followed by research on non-linear pneumatic actuation systems (2018).
Pressure control utilizing generalized predictive controllers was studied (2008), and pneumatic control valve performance was examined (2013), where valves were noted as crucial regulatory components.

III. Research Methodology

The research output was focused on comparing the tarpaulin sealing machines at Ndu and Sons print venture, No 84 Nkpor Old Road Onitsha, and locally produced versions, specifically regarding pressure control utilizing an air valve coupled with a solenoid coil for airflow control to the actuator chamber. The system's effectiveness and stability were expected to be observed through this approach. The system's operation is regulated and energized by the control panel.

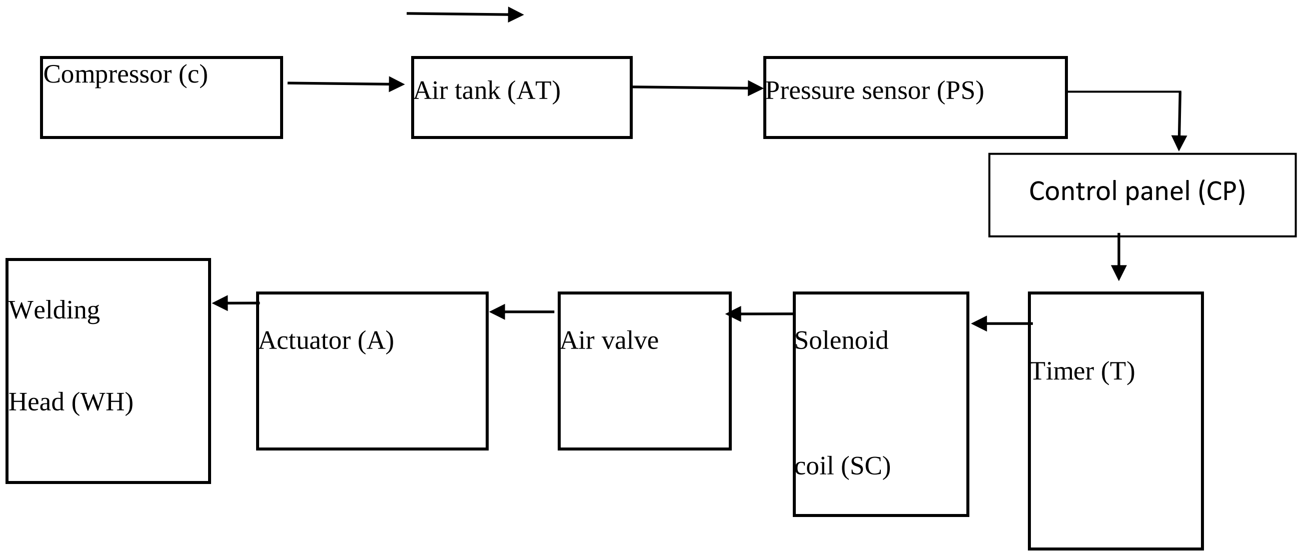


Fig 3.1 Block diagram of the pressure control system

System Operation

1. Compressed air is delivered to the air tank by the compressor (c).
2. Air tank (At): Compressed air is stored in the air tank, where a buffer against pressure fluctuation in the system is provided, and the impact of sudden changes in demand or supply is reduced.
3. The pressure being applied to the welding head is monitored by the pressure sensor (Ps).
4. The entire system is regulated by the control panel (cp).
5. The duration of the welding process is controlled by the timer (t).
6. Solenoid (SC): Electrical energy is converted into mechanical energy by this electromagnetic controller, through which the flow of air in the system is regulated.
7. The air flow to the actuator is controlled by the air valve through the solenoid coil; pressure is then applied to the welding head by the actuator.
8. Actuator (A): Pressure is applied to the welding head by the actuator.
9. The welding head (wh): Tarpaulin materials are welded by the welding head. The sealing operations are carried out by the welding head, which is coupled with a heating element and a temperature sensor.

System Control

Input from the compressor's timer and pressure sensor (Ps) is received by the control panel (CP). A signal is sent to the control panel when the pressure reaches its set point, and through the pressure switch, the compressor is activated or deactivated, and the timer for operation is activated.

The desired pressure needed for perfect tarpaulin sealing is maintained by the air valve controlling the air flow to the actuator.

The welding duration is controlled by the timer based on the material type. The operation is stopped when the timer, which is embedded in the control panel, deactivates the air valve through the magnetic solenoid coil.

As previously described, compressed air is drawn from the atmosphere by the compressor. It is stored in the storage tank at high pressure. The required pressures are ensured by regulation using the pressure gauge at the unit, and lubrication is provided for free air flow to the cylinder. The clean compressed air is directed, and the flow pressure is maintained to the actuators, by which the levers for switching and actuation are engaged.

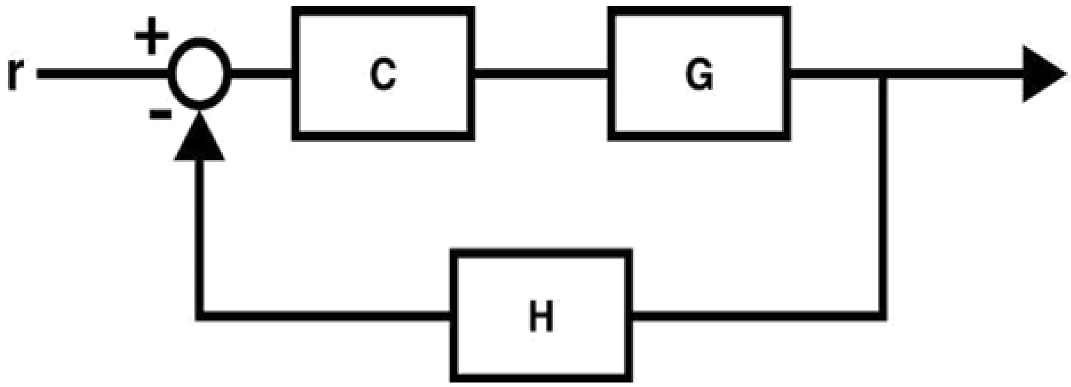


Figure 3.2: Canonical form of the block diagram.

C = control, G = the entire system, H = the thermocouple/actuator.
The diagram shown above is being utilized as a model for developing a transfer function to determine system stability. From what can be observed, C is represented by the control, which in this case is indicated by the PID. The G is being depicted as the plant in the canonical diagram, while in this implementation it is defined by the output relay that is connected to the solenoid and pneumatic system for upward or downward pressure. H is being designated as the feedback element, represented by the actuator. It should be understood that the error signal (e_t) is being transmitted to the control block from the summing point, while y represents the output, which is identified as air.

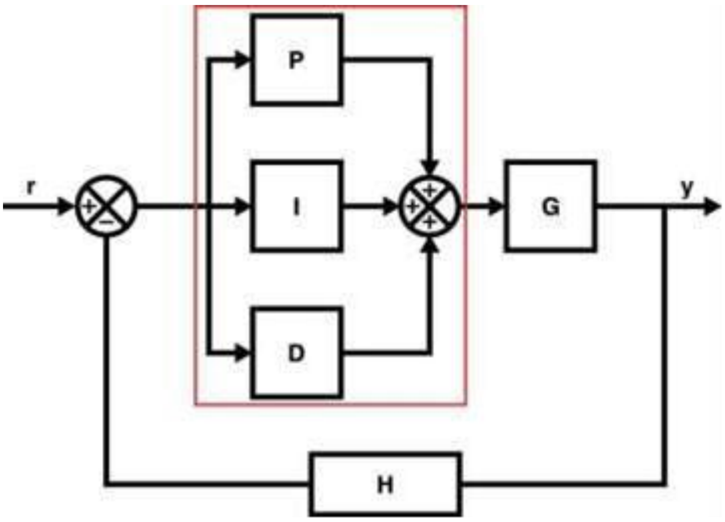


Figure 3.3: The system block diagram

The diagram above is an expansion of fig. 3.1 where the PID is well represented.

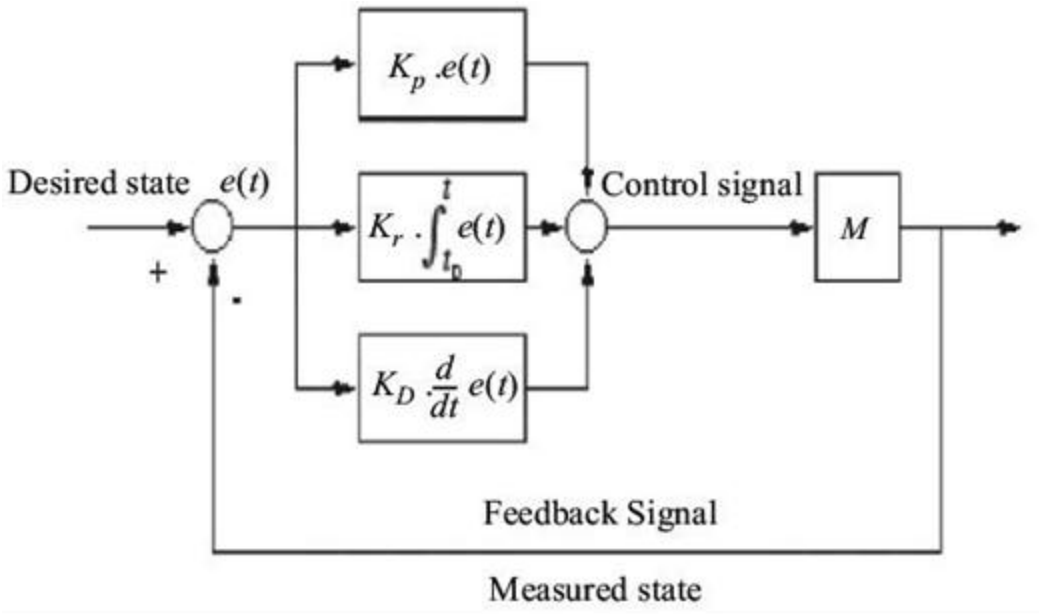
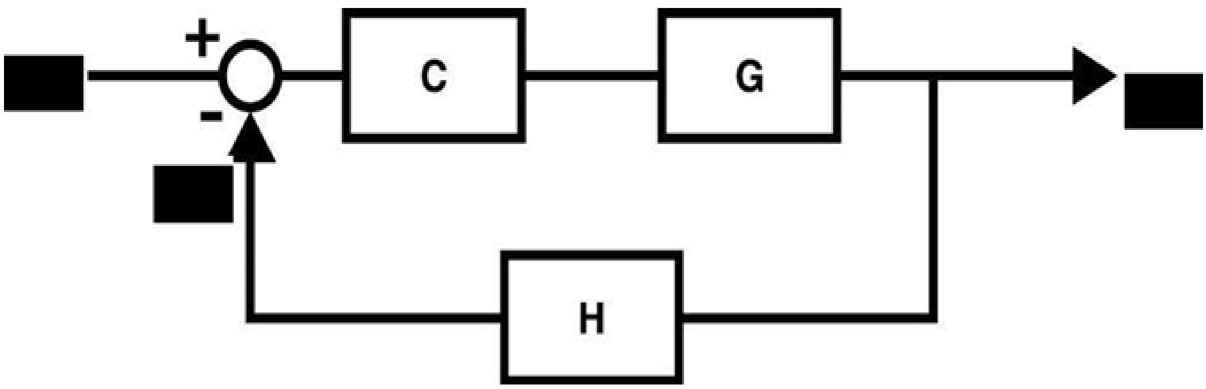


Figure 3.4: The system block diagram with PID well described

In this system, the feedback (H) is maintained at unity, and the actuator's actions are represented by it. The relay's operations combined with the heat element are denoted by (M). The mathematical formulation is utilized to represent the PID controller. As observed in Fig. 3.3, the controller receives error and error changing rate as input variables, while the output variables are determined by PID control parameters, specifically ΔK□, ΔK_i, and ΔK^d. The changing rate is indicated by e.
The output generated by the PID controller is formed by combining the outputs from proportional, integral, and derivative controllers. Equations are derived from the block diagram shown above and are utilized in developing the system model.
U(t) = K□ e(t) + ∫ e(t) dt + K^d (3.2)
The proportionality constant is represented as:
U(t) = K□ e(t) + ∫ e(t) dt + K^d (3.3)
These equations are expressed in the time domain, but since the PID transfer function is prioritized, the system is converted to the s domain.
Therefore, U(S) = K□ E(S) + K^d S E(S) (3.4)
U(S) = [K□ + K^d S] (3.5)
= K□ + K^d S (3.6)
From Fig. 3.2, C is expressed as shown below.



C here is ―――――――

Therefore,

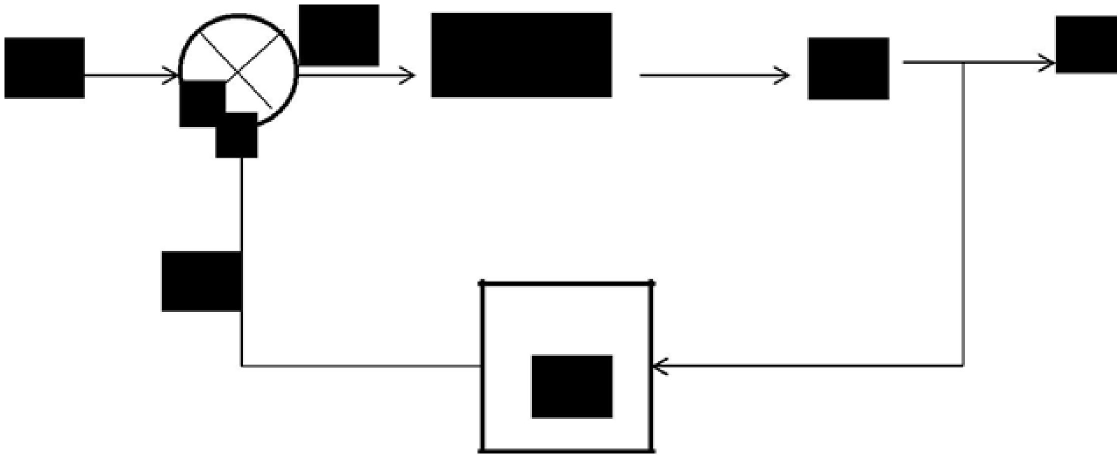


Figure.3.5: Modeled block diagram

Transfer function Vo/Vref = (3.7)

G represents the resistive and inductive properties of the output relay, whose s domain is RI(S) + SI(S).

The process is initiated with a start block, wherein the compared voltage (Vref) is directed into the summing block. At this point, the compared voltage and feedback voltage are combined, whereby an error signal is generated. This error signal is subsequently transmitted to the control panel (PID). Following its analysis, the PID transmits an amplified signal to the plant, which is represented by the output timer relay that is utilized for engaging the solenoid valve in the pneumatic system's operation.

When the pressure range is deemed unsatisfactory, signals to the output devices are not transmitted. However, when satisfactory, the output devices are energized.

The sealing process is executed when the relay and solenoid valve are engaged. The pressure sensor is employed as a feedback loop between the compressor and PID through the summing point, whereby current from the compressor is terminated upon reaching optimal pressure.

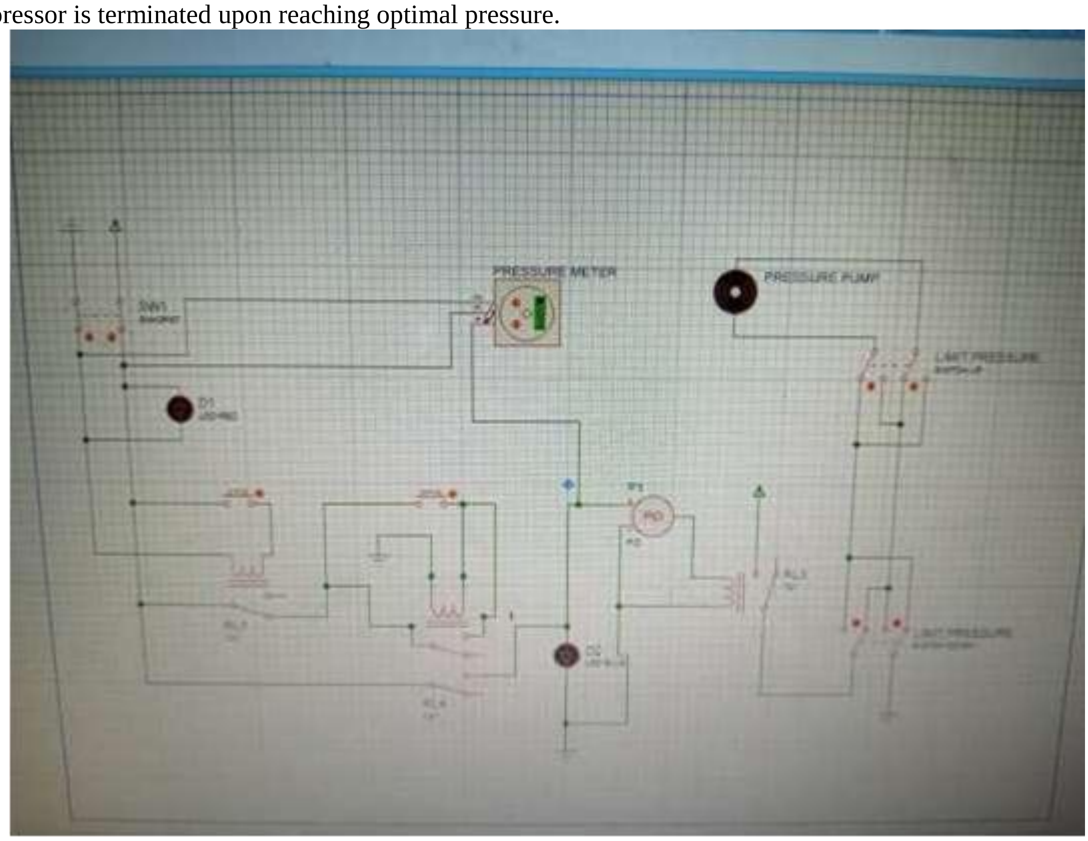


Figure 3.7: Pressure Control Circuit Diagram

SYSTEM OF OPERATIONS

The system is designed for sealing various tarpaulin types based on configuration and pressure specifications. The operational sequence is initiated from an input power section, which is comprised of a power switch, LED indicator lamp, stop/emergency and start buttons connected to relay actuators, and a running lamp.

The system control block containing the PID controller is positioned next, serving as the central processing unit governing all operations.

In the pressure generator block, an electric motor is housed to generate sealing pressure, with airflow valves engaged with pressure switches.

The output block is where pressure is produced and evaluated, with measurements being transmitted to the PID for operational decisions.

The feedback loop block contains a barometer that converts analogue to electrical signals for controller comparison.

System operation is initiated through power supply activation. Current flows through the stop button until the start button is engaged. The PID is then powered, activating the pressure-generating motor. Pressure is increased until the required working pressure is achieved. Generated pressure is continuously compared against preset values. When exceeded, the barometer signals the PID to disengage the pump. This cycle is maintained throughout the sealing operation.

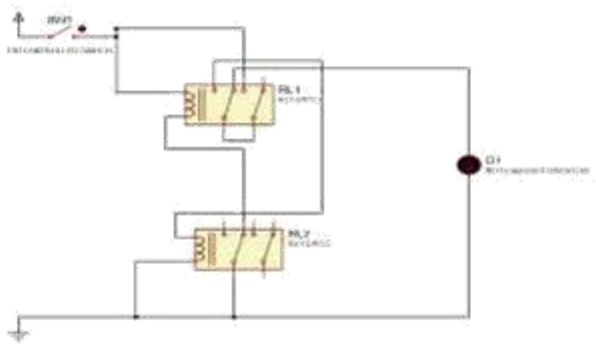


Figure 3.8: Solenoid control circuit.

Figure 3.13 Front View of the Remodeled Tarpaulin Sealing Machine

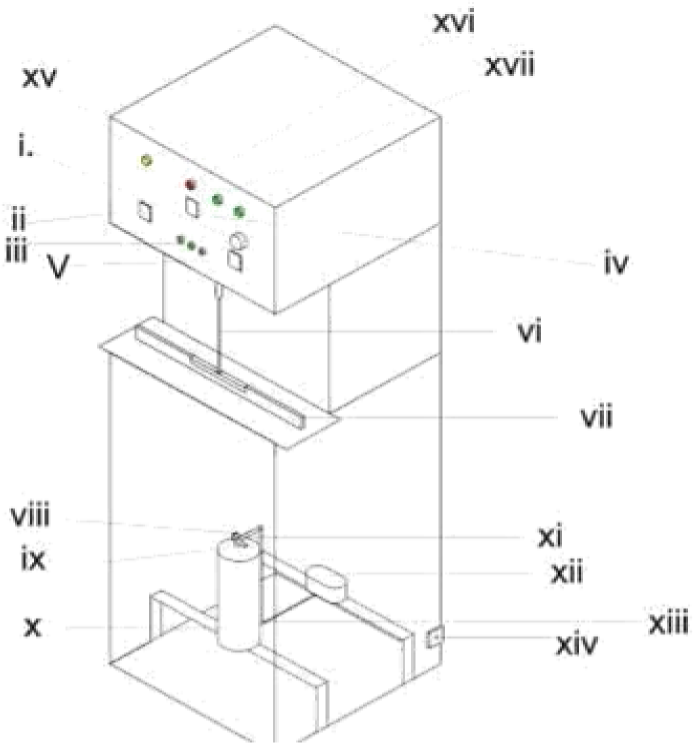


Figure 3.14: Isometric Drawing of the Tarpaulin Sealing Machine

i. Pressure guag

ii. Temperature controller (Rex 100)

iii. Power switch

iv. Volt meter

v. Pressure controller with timer

vi. Actuator (shaft)

vii. Ion bare with thermocouple

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viii. Pressure switch

ix. Outlet port

x. Reservoir tank

xi. Sensor

xii. Air compressor

xiii. Hose (connecting pip)

xiv. Manual pressure regulator

xv. Temperature indicator

xvi. Power indicator

xvii. Normal open (shaft) indicator

xviii. Normal close (shaft) indicator

IV. RESULT AND DISCUSSION

The system model using sum link revealed that temperature levels were found to impact energy consumption, while market alternatives were observed to lack temperature adjustment capabilities, resulting in higher energy usage.
Energy was noted to be conserved through customized temperature settings for different tarpaulin materials in the developed model.
A one-horsepower compressor (750 watts) was utilized, whereas imported machines were found to employ 2.5 HP compressors.
The heat element was determined to be 2 feet long with 15-ohm resistance, compared to 25-30 ohms in alternatives.

Analyzing this, let's look at the two machine

The one in the Market using the equation

W = IV

With the compressor being 2.5 HP (1875 watta), using 220 volts .the current is the calculated as

I = W/V = 1875 / 220 = 8.5 amps.

Calculating the energy emitted for 10 seconds by the heat element using

I^2Rt

Thus.

$(8.5)^2$ x 25 x 10 = 18062.5 joules

So this is the amount of energy consumed by the tarpaulin sealing machine in the market

<u>The modeled sealing machine</u>

The horse power is 1 HP. (750 watts) using the same 220 volts.

Therefore the current is calculate as such,

I = W/V = 750/ 220 = 3.4

Calculating the energy consumed by the heater element using

I^2RT

Thus

$(3.4)^2$ x 15 x 10 = 1734 joules.

The energy different is much. Lets calculate the percentage difference of the two energy.

The energy changes for the two is

18062.5 -1734 = 16328.5

The 5 energy difference will be,

16328.5/18062.5 x 100 = 90.4 %

The percentage difference has been analyzed. The re-modeled machine's performance was found to be superior to market alternatives.
The welding strength was demonstrated to be higher in the re-modeled sealing machine compared to imported units.
At N850,000 versus N2.5 million, the locally modeled version was determined to be more economical.

Table 3.12 voltage / current relationship of the solenoid

S/N	Voltages	Current
1	1	0.11
2	2	0.22
3	3	0.33
4	4	0.44
5	5	0.56
6	6	0.67
7	7	0.78
8	8	0.87
9	9	0.98
10	10	1.11
11	11	1.22
12	12	1.33
13	13	1.44
14	14	1.56

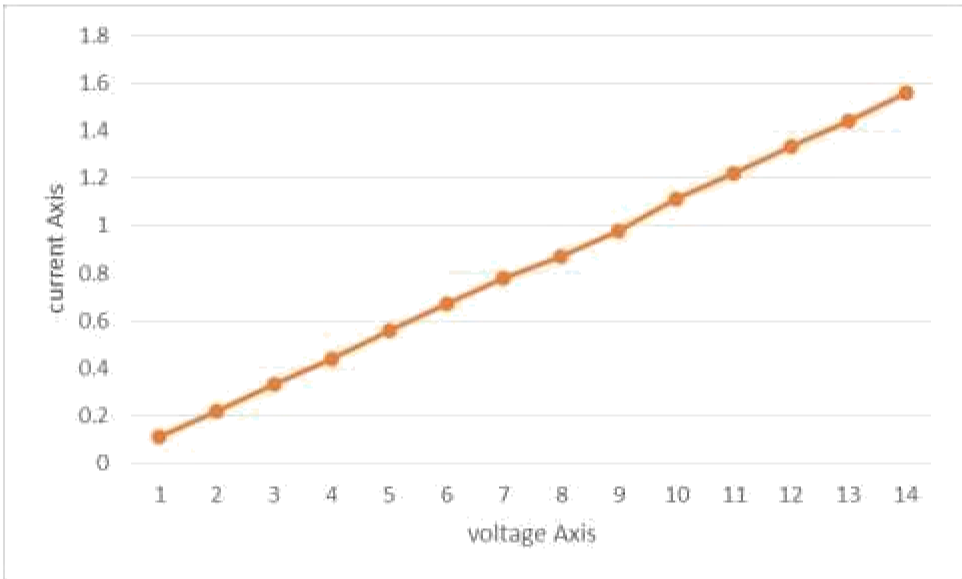

Figure 4.5 graphical representation of the voltage to current relationship of the soleniod.
From the graph, it can be observed that the solenoid's energizing current is proportional to the coil's applied voltage.

V. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Pressure elevation was observed to occur due to temperature increase, with volume variation remaining negligible. When tarpaulin temperature was elevated, enhanced electron mobility was noted, resulting in increased wall pressure during sealing conditions.
The following objectives were accomplished:

1. A solenoid mathematical model was formulated for pressure cylinder actuation.
2. Proteus was utilized for pneumatic system modeling.
3. An automatic pressure control device was implemented for enhanced welding speeds.
4. Various tarpaulin types were processed at specific parameters.
5. Hot welding was employed for folded tarpaulin joining.

5.2 Summaries of Findings

Optimal sealing was achieved within specific temperature and pressure ranges for tested materials. Perfect sealing was initiated after distinct time intervals, beyond which sealing quality was compromised.

5.3 Contribution to Knowledge

The system was successfully utilized for sealing materials within 110-170°C and 50-100 psi ranges. Temperature presets were incorporated, demonstrating superior energy efficiency compared to existing alternatives.
The feasibility of domestic machine fabrication was established, eliminating import dependency. Multiple tarpaulin varieties were effectively processed, advancing beyond single-material limitations.

5.4 Recommendations

The design is recommended for sealing diverse tarpaulin materials, considering international manufacturing predominance. Domestic production can render tarpaulin fabrication economically viable within national borders.

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