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Experimental Investigation on the Effects of Changing the Inlet Air Temperature on the Performance of Servo Pneumatic System

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Abstract: **The investigation of the effects of changing the inlet air temperature on servo pneumatic system is experimentally demonstrated. The work studies the effects by heating the compressed air before it enters the system and measures different variables and the studies the effect of changing the inlet air temperature on it The cylinder used has a piston diameter of (50mm), rod diameter (20mm) and a stroke length of (200mm). The results shows a delay in the piston stoke up to (2.23%) and a pressure drop up to (2.26%) when the compressed air was heated to (343^{0}K).**

Keywords: **Pneumatic cylinder charging, pneumatic cylinder discharging, servo pneumatic system, temperature air flow rate relationship, temperature effects on pneumatic.**

I. INTRODUCTION

Pneumatic actuators have the advantages of (a) ease of maintenance; (b) high power-to-weight ratio; (c) low cost; (d) cleanliness; (e) having a readily available and (f) cheap power source. Pneumatic actuators are suitable for clean environments and safer and easier to work with. Pneumatic actuation systems have several advantages over hydraulic and electromechanical actuation systems in positioning applications which have caused their wide application in part handling, motion control of materials, packaging machines, industrial automation and in robotics [1, 2]. However, position and force control of these actuators in applications that require high bandwidth is somehow difficult, because of compressibility of air and highly nonlinear flow through pneumatic system components [3]. Burrows and Webb stated that in practice the temperature in the cylinder was not constant during the process but because they did not have any experimental data and to make the analysis as simple as possible the temperature of air in the cylinder was assumed constant [6, 7]. Also other earlier studies concerning air temperature refer the state change of the air as isothermal, adiabatic or related to pressure by a polytropic exponent [8, 9]. Massimo Sorli and Laura Gastaldi did theoretical work that studied how heat exchange affects pneumatic dynamic stiffness and indicated that an isothermal assumption is valid only for static condition [10].this paper describes the behavior of temperature and pressure inside a pneumatic cylinder operating with servo valve and the influence of temperature change on the system

Kagawa et. al. presented a study that showed the equilibrium velocity not only depends the control valve but on the discharge temperature also. Until now, pneumatic cylinder systems are designed considering the isothermal assumption and without considering the air temperature change [4].although many papers studied the pneumatic system concerning temperature but until now no study of the effect of changing the inlet air temperature on the pneumatic system was conducted.

II. EXPERIMENTAL APPARATUS

An air tank was used separately from the tank of the compressor the air would flow from the compressor tank into the separate tank. The separate tank is used to heat the air that goes to the pneumatic system, the separate tank was modified by adding a heater and a thermocouple (type k) in order to control the temperature of the air that goes into the pneumatic system.

A regulator valve is positioned at the exit port of a compressor tank with 10bar maximum pressure. A 5/3 Festo proportional directional servo valve type MPYE-5-1/8-LF-010-B was set to control the air flow and its direction and positioned between the pressure regulator and the pneumatic cylinder. The cylinder is of type CDA1-50-200 inner diameter (50mm), rod diameter (20mm) and stroke (200mm) and was set up horizontally. A position transducer of the type MLO-POT-225-LWG was positioned next the cylinder and was attached to the cylinder piston rod with a rod eye attachment the position transducer was used to measure the cylinder position.

The experiments needed an extremely high response time thermocouples to measure the fast temperature change inside the pneumatic cylinder chambers and because of that the thermocouple that was brought had a very fine diameter (75µ) which was very fragile and required very delicate handling, the thermocouples were positioned inside the cylinder chambers. The thermocouples were connected to an amplifier (AD594/AD595) to read the thermocouple readings.

As for the pressure sensors two Festo pressure sensors type SDE1-D10-G2-H18-C-PU-M8 were positioned at the two ports of the cylinder to measure the pressure inside each cylinder chamber. All the sensors were connected to a data acquisition device (DAQ) NI USB-6212 that convert the voltage signals to a computer with programmable software to read the measurements.

The procedure of the experiment was as follows

1. Compressing the air

2. In order for the compressed air to reach (343^0K) the compressed air was heated to a certain value by turning on the heater in the separate tank

3. After heating the air the heater is switched off and the system is stabilizes until it reaches the required temperature (343^0K)

4. The pressure regulator is set to (5bar).

5. The system is operated by a Simulink program that was designed to control and read the sensors readings taken from the data acquisition device. The Simulink program contained a (P) controller that took the Instantaneous position of the cylinder after that it sent the corrected signal to the valve to control the cylinder position. After system operation the cylinder extends and retraces and as the piston moves the area of the valve orifice is changed by the signal sent from the controller.

6. After reaching the number of stokes which are previously set in the Simulink program the valve closes the orifice area and the cylinder motion stops

This work of this experiment included working under tow inlet temperature, a- (310^0K) which was the ambient temperature b- (343^0K) which was the temperature of the heated compressed air and comparison between the results obtained from each inlet temperature was made.

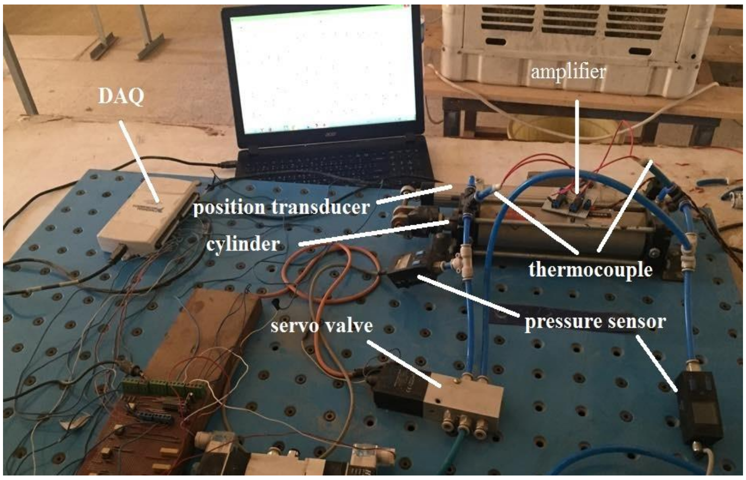

Fig. 1. Pneumatic system apparatus

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.... Digital signal

___ Analog signal

1.1 Pressure source

1.2 Compressor tank

1.3 Pressure regulator

1.4 Flow sensor

1.5 5/3 proportional valve

1.6 thermocouple

1.7 Pressure sensor

1.8 Single rod double acting cylinder

1.9 Position sensor

1.10 voltage amplifier

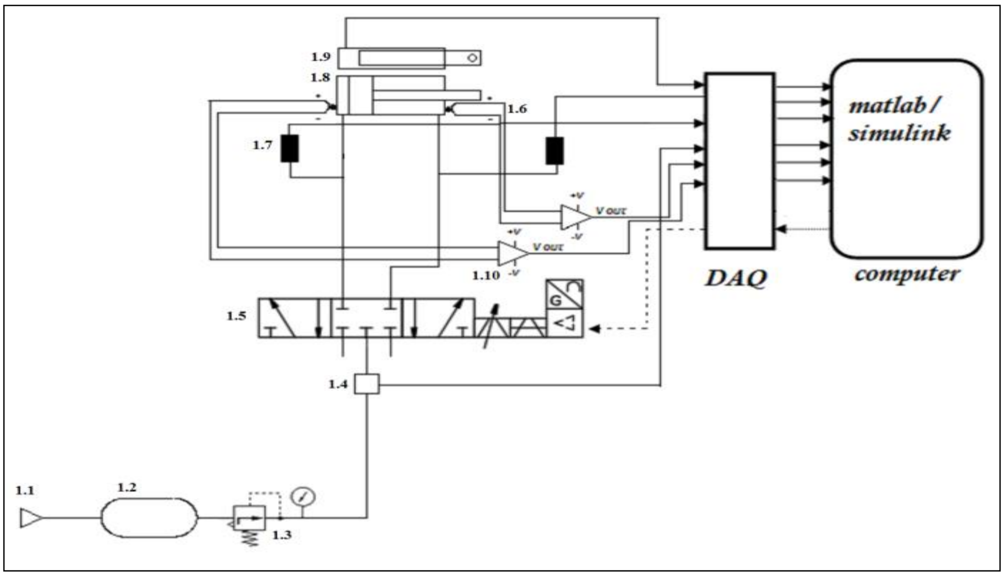

Fig. 2.pneumatic circuit with proportional valve

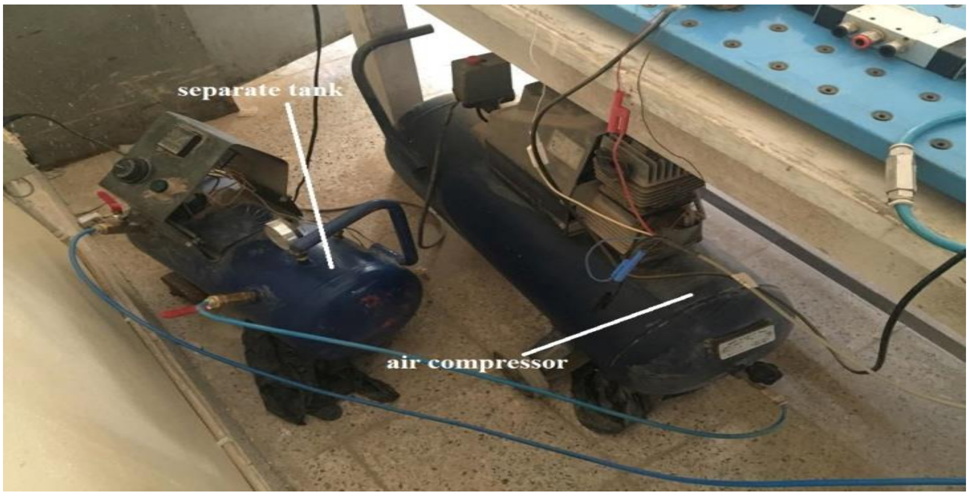

Fig. 3. Air compressor and the separate tank

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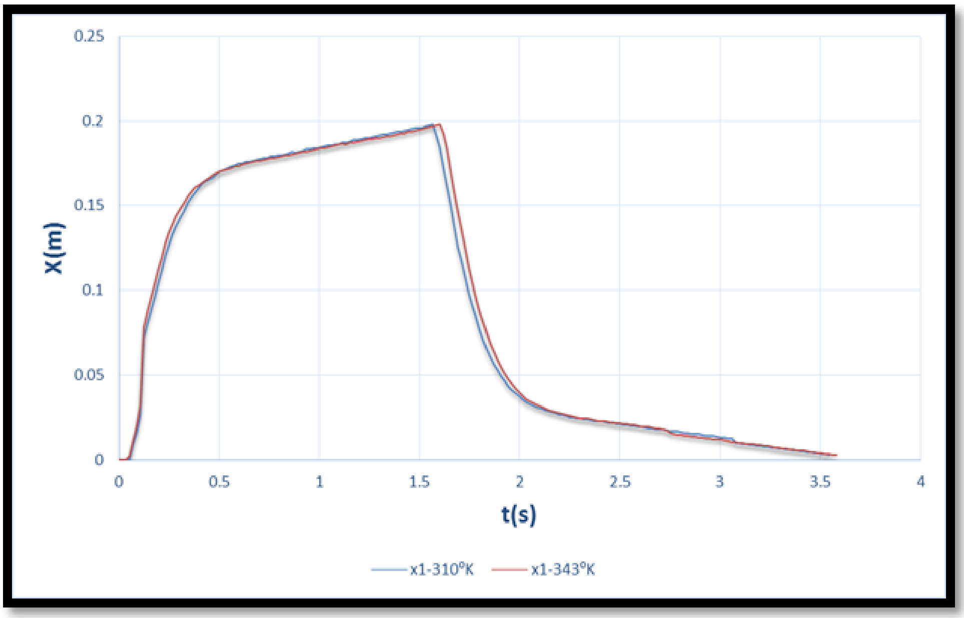
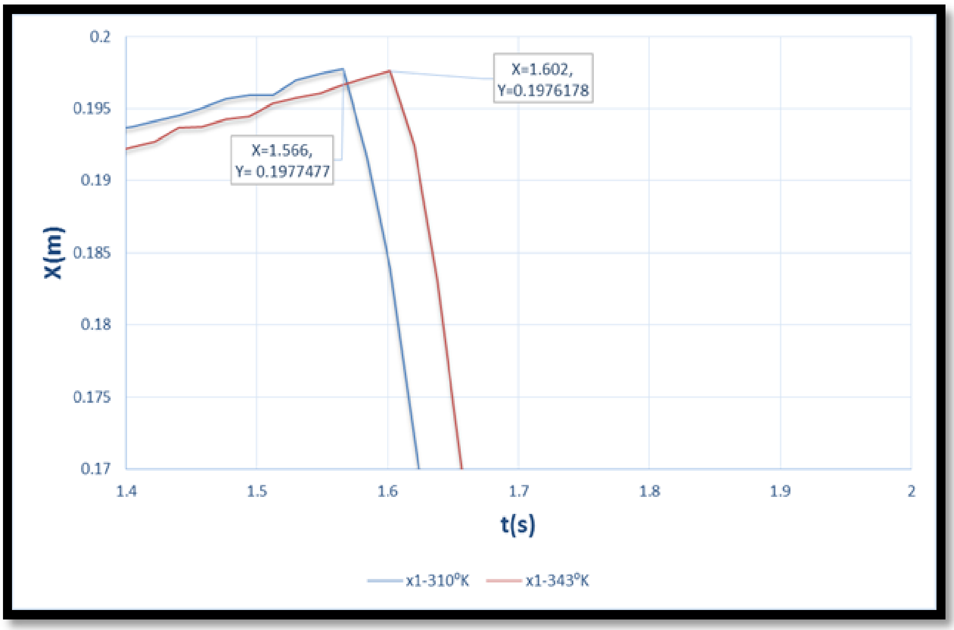
III. EXPERIMENTAL RESULTS

Figure (4-a) shows that at the initial condition the cylinder piston was at (0mm). A feedback signal of the piston position enters the Simulink program as shown in (figure (2)) that calculate the voltage signal (giving that the set point in this condition is (197mm)) and send it to the proportional valve to open its orifice area causing a substantial pressure rise at chamber (1) and a pressure drop at chamber (2) which causes the piston to extend unitl it reaches the desired set point (197mm) after this a new set point is set (3mm) and the simulink program sends a signal to valve to revers the flow direction thus charging chamber (2) and rasing the pressure in it and discharging chamber (1) and causing a prssure drop in it thus retracting the piston to the new set point. In this work two stroks are applied in this case the extending and retracting stokes as illustrated in figure (4).



(a)



(b)

Fig. 4. Piston displacement vs. time at different inlet temperatures

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Figure (4) shows that the cylinder reached the set point at (1.566s) but when the inlet air temperature was heated to (343^0K) it reached the set point at (1.602s) which is about a (2.23%) increase in time

The results shows that the cylinder piston motion was delayed as the temperature in the compressor tank was increased and that is because of the relationship between the air mass flow rate and air temperature that is Inversely proportional (this relationship stems from the relationship of air viscosity which increases with temperature and density which decreases with temperature).

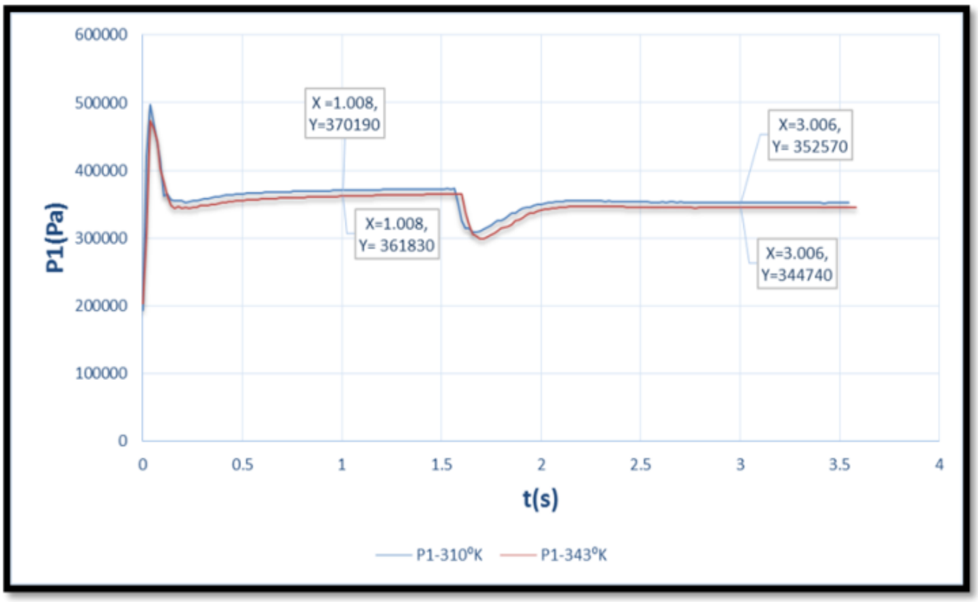

Fig. 5. Pressure change vs. time in chamber 1 at different inlet temperatures

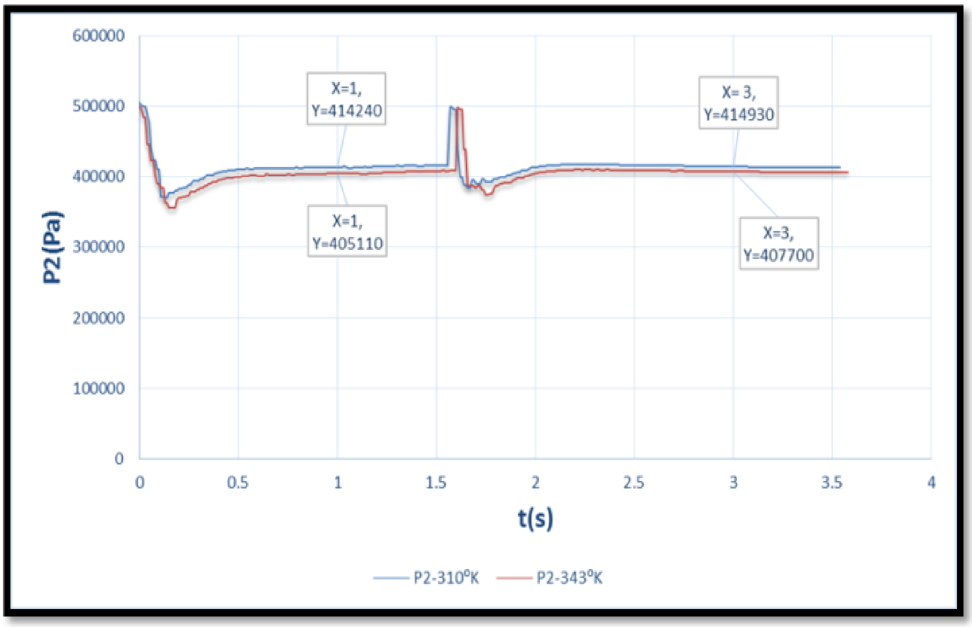

Fig. 6. Pressure change vs. time in chamber 2 at different inlet temperatures

From figure (5) in the extending stroke there is a pressure drop of 8360Pa (2.26%) and in the retracing stroke there is a pressure drop of 7830Pa (2.22%). Figure (6) shows that in the extending condition there is a presser drop of 9130Pa (2.2%) and a pressure drop of 7230Pa (1.74%) in the retracting condition .Figure (5) and figure (6) shows that when the inlet air temperature was heated to (343^0K) a pressure drop occurred which stems from the air mass flow rate decrease due to the mass flow rate inversely proportional relationship with temperature which affected the pressure.

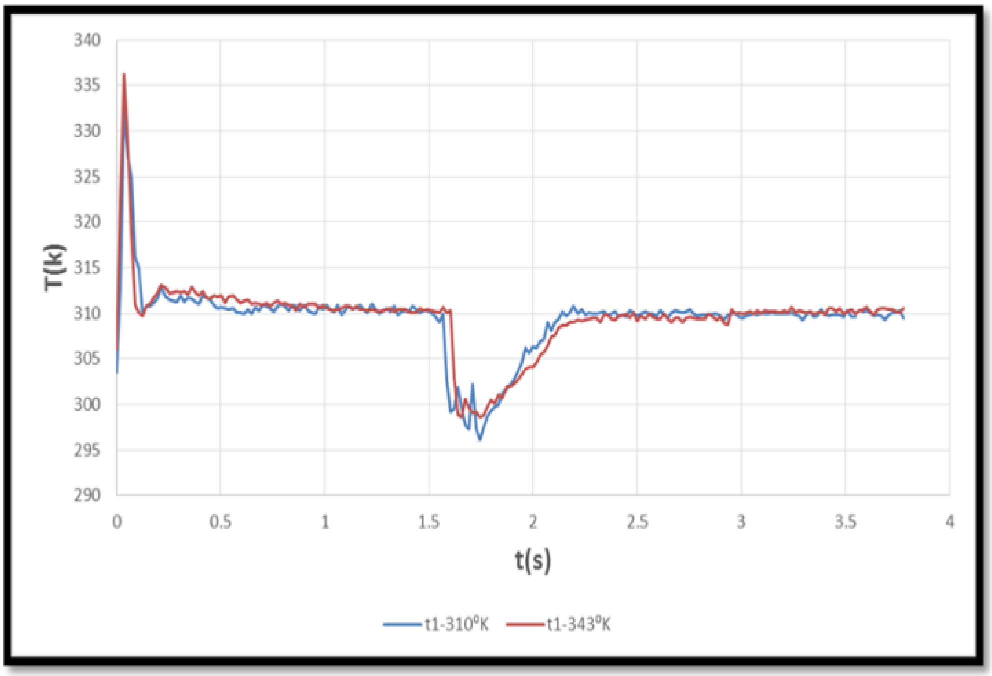

Fig. 7. Temperature change vs. time in chamber 1 at different inlet temperatures

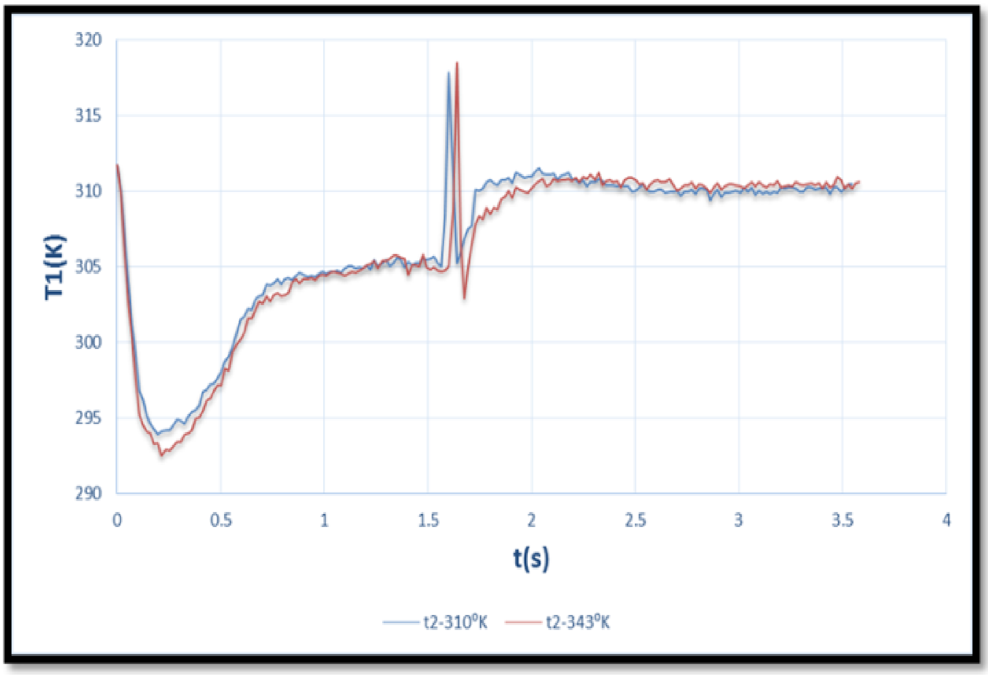

Fig. 8. Temperature change vs. time in chamber 2 at different inlet temperatures

From Figure (7) and figure (8) it is clear that the temperature follows closely to the pressure inside the chambers and the temperature change would increase with pressure increment or decrement. The thermocouple readings was easily affected by the electrical noise thus causing the results to be rattled as shown in figures (7) and (8)

Is was observed that although the temperature in the compressor tank was raised to (343^0K) the initial temperature read by the thermocouple was (306^0K) which is lower than the atmospheric temperature (310^0K) and the reason for that is that as the compressed heated air flowed out of the compressor it expanded causing the temperature to be decreased extremely, This also confirms that the temperature in the pneumatic systems changes considerably with pressure.

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IV. CONCLUSION

In conclusion the work of this paper proved the following points:

1- Increasing the inlet air temperature affected the performance and variables of the pneumatic system causing the stroke to delay as the inlet temperature increased which is due to the inversely proportional relationship between the temperature of air and the air mass flow rate. This delay raised and important issue for controlling the pneumatic cylinder in which if the number of stoke was to increase so was the delay which allows errors to increase

2- The results also shows the temperature inside the pneumatic cylinder chamber changes considerably with the change of pressure and follows closely to the change of pressure inside the pneumatic cylinder

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