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Experimental Investigation of a Temperature Change inside Pneumatic Cylinder Chambers

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Abstract

The investigation of the existence of a temperature change with pressure inside the pneumatic cylinder chambers during the charging and discharging strokes in the pneumatic cylinder is experimentally demonstrated. Three different variables (pressure, piston displacement and temperature) were measured in this work while operating with a servo pneumatic system and a discussion of the relationship between these variables was presented. The cylinder used has a piston diameter of (0.05m), piston rod diameter (0.02m) and a stroke length of (0.2m). The results show a temperature rise of 23 K above atmospheric temperature at chamber (1) while air compressing and a temperature drop of 17 K below atmospheric temperature at chamber (2) while air expansion and measures other temperature changes also.

Keywords: Pneumatic system; Pneumatic cylinder charging and discharging; Servo pneumatic system; Temperature and pressure measurement;

1. Introduction

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. 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 [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]. Horlock and Woods published “the thermodynamics of charging and discharging processes” they gave a thorough analysis of the charging and discharging processes. Their analyses were based on the assumption that the process were rapid with negligible heat transfer (adiabatic), and they assumed the discharge process was isentropic [4]. 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 [5, 6]. 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 [7, 8]. 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 [9]. Also. J. F. Carneiro and F. Gomes de Almeida presented an experimental and theoretical work which evaluated the heat transfer inside the pneumatic cylinder [10].this paper investigates the temperature change inside the pneumatic cylinder chambers experimentally and describes the behavior of temperature and pressure inside a pneumatic cylinder operating with servo valve and the influence of temperature change on the system

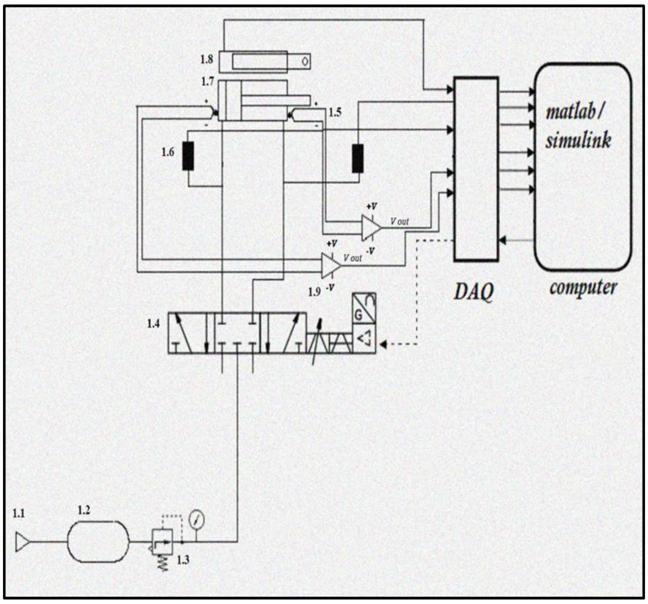
2. Experimental apparatus

A schematic diagram and a picture of the pneumatic system is shown in figure (1) and figure (2). A regulator valve is positioned at the exit port of a compressor tank with 10bar maximum pressure. A cylinder type CDA1-50-200 of inner diameter (0.05m), rod diameter (0.02m) and stroke (0.2m) was set up horizontally and used. And 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.

As for the sensor two Festo pressure sensors with an accuracy of 2% and 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. The experiments of this work needed an extremely high response thermocouple to measure the fast temperature change inside the pneumatic cylinder and because of that a type (T) thermocouple with an accuracy of 0.75% was brought. It 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. The thermocouples connection is shown in figure (3). 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. 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 experiment procedure was as following

1. Compressing the air
2. The pressure regulator is set to (5bar).
3. 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.
4. After reaching the number of stokes which are previously set in the Simulink program (two strokes in this case, for extension and retraction) the valve closes the orifice area and the cylinder motion stops.



……. Digital signal
___ Analog signal
1.1 Pressure source
1.2 Compressor tank
1.3 Pressure regulator
1.4 5/3 proportional valve
1.5 thermocouple
1.6 Pressure sensor
1.7 Single rod double acting cylinder
1.8 Position sensor
1.9 voltage amplifier

Figure 1: Pneumatic circuit with proportional valve

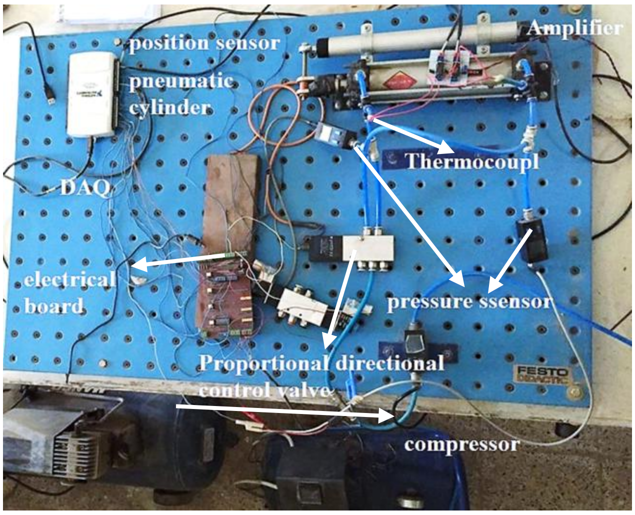


Figure 2: Pneumatic system apparatus

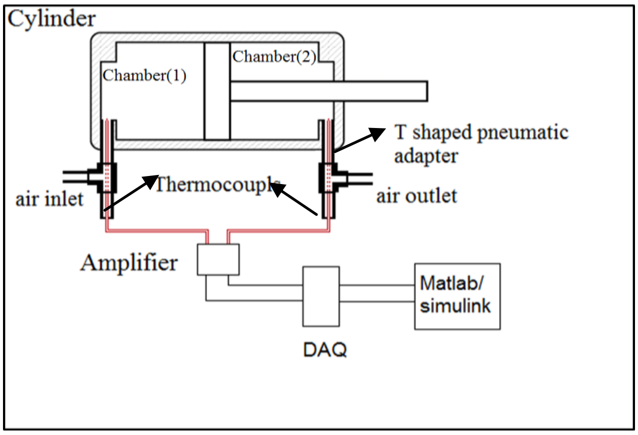


Figure 3: Schematic diagram that shows thermocouples connections

3. Experimental results

Figure (4) shows that at the initial condition the cylinder piston was at (0m). A feedback signal of the piston position enters the Simulink program as shown in (figure (1)) that calculate the voltage signal (giving that the set point in this condition is (0.197m)) 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 until it reaches the desired set point (0.197m) after this a new set point is set (0.03m) and the simulink program sends a signal to valve to reverse the flow direction thus charging chamber (2) and raising the pressure in it and discharging chamber (1) and causing a pressure drop in it thus retracting the piston to the new set point. In this work two strokes are applied in this case the extending and retracting stokes as illustrated in figure (4).

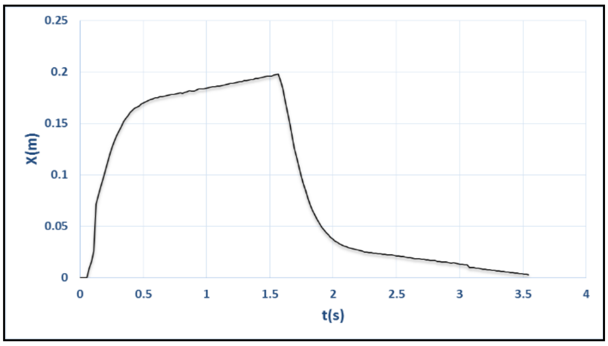
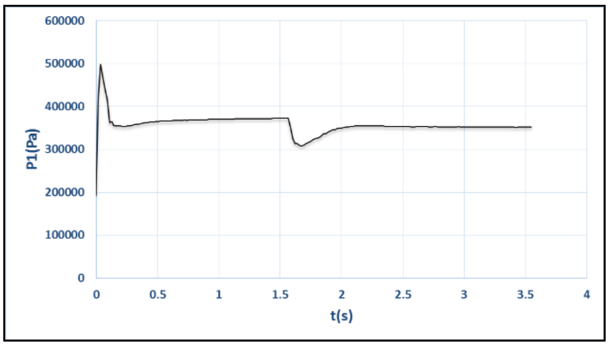
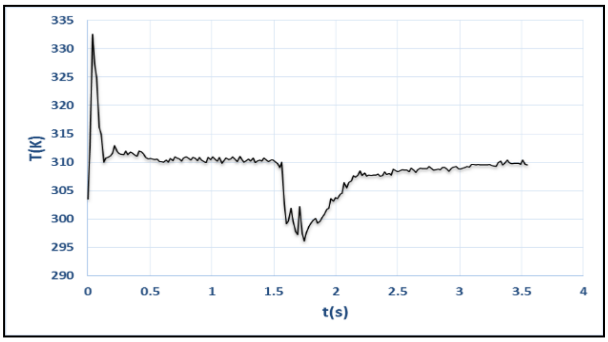


Figure 4: Piston displacement vs. time



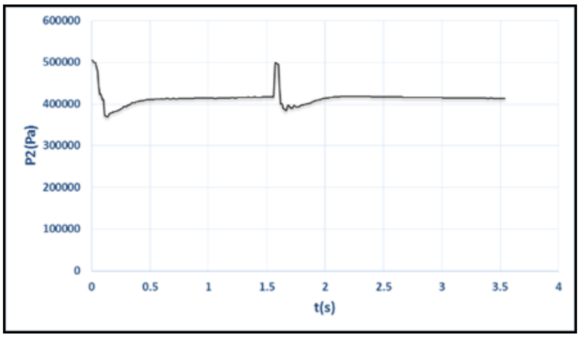
(a)



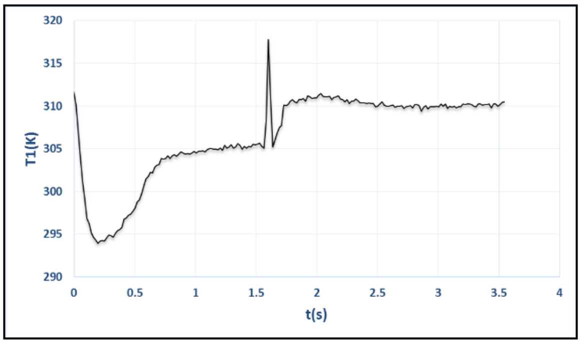
(b)

Figure 5: (a) Pressure and (b) temperature change in chamber 1 vs. time

Figure (5) illustrates pressure and temperature changes inside chamber (1) while the piston extends and retracts these figures shows that the temperature was not isothermal (noting that the atmospheric temperature in this work is (310 K)) and it reached a maximum value of (333 K) when the pressure was increased in the air charging phase at the beginning of extending stoke which is about (23K) higher than the atmospheric temperature also the temperature was dropped to a value of (296 K) when the pressure was dropped in the discharging phase at the beginning of the retracting stroke which is about (14 K) lower than the atmospheric temperature



(a)



(b)

Figure 6: (a) Pressure and (b) temperature change in chamber 2 vs. time

Figure (6) illustrates pressure and temperature changes inside chamber (2) while the piston extends and retracts these figures shows that temperature dropped to a value of (293 K) when the pressure was decreased in the discharging phase at the beginning of the extending stoke which is (17 K) less than atmospheric temperature. And the temperature was increased up to value of (318 K) when the pressure was increased in the charging phase at the beginning of the retracting stroke which is about (8 K) above the atmospheric temperature. Previous figures also shows that due to heat transfer between air and cylinder walls the temperatures inside the cylinder chamber will always tends to return to atmospheric temperature (310 K). Also the raise and drop of temperature in the chamber is directly proportional to pressure change raise or drop. It should be noted that the graph lines for temperature figures (5) and figure (6) seemed to be extremely unsettled unlike the other results obtained and the reason for that is the temperature readings was easily affected by electric noise that interfered with the original signal of the thermocouple causing the signal from the thermocouple to be rattled.

4. Conclusions

In conclusion the work of this paper shows the following:

1-in the extension stroke the results shows a temperature rise of 23 K above atmospheric temperature at chamber (1) while air compressing and a temperature drop of 17 K below atmospheric temperature at chamber (2) while air expansion. In the retraction stroke the results shows a temperature rise of 8 K above atmospheric temperature at chamber (2) while air compressing and a temperature drop of 14 K below atmospheric temperature at chamber (1) while air expansion.

2-The process of charging and discharging of air in pneumatic cylinders are neither isothermal nor adiabatic

3-Due to heat transfer the temperature of air in the chamber will always tends to return to the atmospheric temperature

4-The drop of temperature raises an important issue which is that at lower atmospheric temperate or extreme temperature drop, the temperatures would reach values lower than (273 K) and usually such low temperatures cause condensation or freezing which will affect the cylinder performance and causes it to rust and may cause the cylinder to malfunction

5-The change of temperature follows closely to the change of pressure inside the pneumatic cylinder.

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تحقيق عملي في تغير درجة الحرارة داخل اسطوانة النظام المضغوط

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الخلاصة

التحقيق حول وجود تغيير لدرجة الحرارة مع الضغط داخل غرف اسطوانة الهواء المضغوط اثناء اشواط الشحن والتفريغ لاسطوانة الهواء قد بين عمليا. ثلاث متغيرات مختلفة (الضغط, حركة المكبس و درجة الحرارة) تم قياسها في هذا العمل اثناء العمل بنظام الهواء المضغوط المؤازر وتم تقديم مناقشة حول العلاقة بين هذه المتغيرات.الاسطوانة المستخدمة تحتوي على مكبس بقطر (0.05m),قطر ذراع المكبس (0.02m) وطول شوط (0.2m). النتائج تظهر ارتفاع لدرجة الحرارة ب 23K فوق درجة حرارة الجو في غرفة رقم (1) اثناء انضغاط الهواء و انخفاض لدرجة الحرارة ب 17K تحت درجة حرارة الجو في غرفة رقم (2) اثناء تمدد الهواء وتم قياس تغييرات اخرى لدرجة الحرارة ايضا.