MEASUREMENT OF FORCES DEVELOPED BY A DOUBLE-ACTING PNEUMATIC CYLINDER

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ABSTRACT

For a fluid power technology curriculum, pneumatic laboratory experiments have been designed to demonstrate the use of common pneumatic components, the relationship between pressure and forces developed by the components, and properties and behavior of compressed air circuits. Specifically, a pneumatic circuit was constructed to measure the forces generated by a pressurized double-acting cylinder with its piston rod connected to a force gauge. This experiment utilizes a wide range of components, including a pneumatic breadboard, tubing, laboratory air supply, pneumatic cylinder, pressure regulator, 3-way shut off valve, force gauge, and pressure gauge. Students are required to assemble the circuit, obtain experimental force readings, and compare the experimental results with theoretical predictions.

This force experiment aids students in understanding the relationship between pressure and the force generated by a pneumatic cylinder. Pressure is supplied at nominal values of 20, 30, 40, 50, and 60 psig to a ¾" diameter pneumatic cylinder (actuator); the cylinder rod is directly attached to the force gauge. Measurements include the pressure in the cylinder, the area of the piston, and the force of the rod. For each pressure supply, the theoretical force is also calculated and compared to the readings. The experimental data are in general agreement with the predictions with a typical absolute deviation of a few percent, ranging from 5% to less than 1%. Discrepancies may exist due to the accuracy of the pressure gauge.

1. INTRODUCTION

All Manufacturing Engineering Technology students at Northern Illinois University are required to complete a course in Fluid Power Technology (TECH 326). This is a three credit-hour course that meets in lecture three hours a week with an additional two hours in lab. The course covers fluid power principles, devices, systems, and materials, and includes hydraulic and pneumatic systems with emphasis on compressors, pumps, motors, actuators, fluids, fluid distribution, protective devices, and control components. As prerequisites, students must have already taken basic physics and calculus courses. To augment the classroom instruction, students construct hydraulic and pneumatic circuits and perform experiments using these circuits.

The hydraulic experiments utilize two state-of-the-art hydraulic training benches. The experimental activities are designed to illustrate the fundamental principles of hydraulic circuits, pressure and force, power, pumps, fluid transmission, valves, actuators, fluid power symbols, fluid storage, and fluid conditioning (Daines, Wright 2000). More specifically, students are assigned fourteen different laboratory exercises. Each requires the assembly of a circuit and serves to illustrate a concept such as Pascal's Law; temperature effects on the hydraulic fluid; control of hydraulic pressure, flow, and direction; work and power for hydraulic linear and rotary actuators; and circuit sequencing. An example of an advanced activity would be a two stage sequential operation where, as the pressure builds up through a cylinder in the first stage, a motor is powered in the second stage of operation. This complex circuit uses a relief valve, 4-way directional valve, sequencing valve, double-acting cylinder, hydraulic motor, and pressure gauges among other components.

Recently, in order to increase the scope of the laboratory, three pneumatic experiments were developed. The first is a standard pneumatic circuit in which the basic principles are discussed to familiarize the students with pneumatic components and their safe use. The second laboratory exercise demonstrates pressurized tanks as reservoirs of stored energy. The third experiment, which is the focus of this effort, develops an understanding of the relationship between pressure and force. This calls for a double-acting cylinder to be powered at five different pressures while comparing the actual and theoretical forces produced. The theoretical force output of a cylinder is the applied piston area multiplied by the air pressure:

$$\text{Force} = (\text{Pressure})\ (\text{Area}) \qquad (1)$$

The main objective is to demonstrate the relationship between force and pressure while measuring and recording force and pressure readings. In doing so, the students become familiar with the use and function of pneumatic components, the assembly of circuits, and the symbols and nomenclature of pneumatic systems.

2. COMPONENTS REQUIRED

2.1 Pneumatic Breadboard

This is a large piece of flat stock with drilled and tapped holes so the pneumatic components can be safely secured. There are three breadboard units so the students can be divided into three groups.

2.2 Pneumatic Cylinder

A pneumatic cylinder or actuator is a mechanical device that converts the energy of pressurized air into useful work. Double-acting cylinders are defined as actuators that can be powered by pressurized air in two directions. In complex circuits, not all the available energy can be converted to useful work due to internal friction produced by seals, bushings, wear bands, etc.; the loss usually ranges anywhere from 1 to 10 psig of pressure output of the cylinder (Malloy, 2000).

2.3 Pressure Regulator

The pressure regulator controls pressure within the pneumatic circuit; the pressure determines the force generated by the actuator. The regulator adjusts the air pressure to meet the performance requirements of the system. Here, the pressures are set at 20, 30, 40, 50, and 60 psig.

2.4 3-Way Shut Off Valve: The 3-way shut off valve is referred to as a 3/2 manual valve. This hand-operated valve has three ports and two states or operating positions. One port is connected to the pressurized air supply; another port is connected to the circuit and supplies the circuit with pressure when the valve is turned on; and the third port vents or exhausts the circuit when the valve is closed and serves to depressurize the circuit.

2.5 Force Gauge

Figure 1: Force gauge.

The force gauge (Figure 1) features an accuracy of +/- 1% of full capacity. The load is applied against a hardened ball that rotates to maintain vertical alignment as force increases. The ball is held in place with a spring clip. This gauge may be mounted horizontally, vertically, or flat. The gauge has a baked enamel finish that resists corrosion and will operate in temperatures up to 120^{o}F. The rod end of an actuator cylinder can be fastened to a threaded mounting hole at the bottom of the force gauge.

2.6 Pressure Gauge

A pressure gauge is used to measure the pressure in the pneumatic cylinder. The pressure gauge has a range of 0 to 100 psig.

2.7 Tubing

The tubing used to connect the components is flexible plastic tube. The tubing has a nominal ¼" diameter and is available in precut lengths.

3. FORCE GAUGE CIRCUIT

In the experiment, a circuit schematic diagram (Figure 2) is available for the students. All the components are provided, and the circuit is assembled by the students. Reading schematic diagrams is another important aspect and requires the students to process what they visualize on paper.

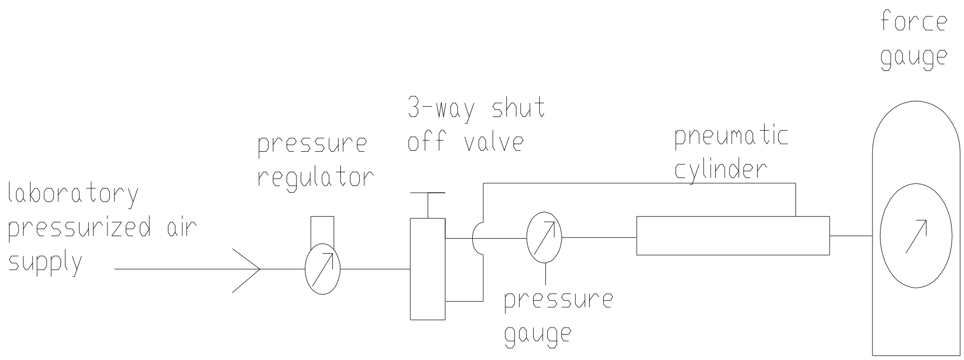

Figure 2: Force gauge circuit.

Although the cylinder has a potential 6" stroke, for this activity it is bolted directly to the force gauge in the fully retracted position. The force gauge is fixed to the pneumatic breadboard.

4. RECORDING RESULTS

The students record the actual forces from the cylinder at supply pressures of 20, 30, 40, 50, and 60 psig; the actual cylinder pressure is measured by its upstream gauge. Then the theoretical forces are computed using Equation 1. This allows a comparison between the theoretical and experimental forces. Table 1 presents a representative data set taken during actual circuit operation.

Table 1: Comparison of experimental and theoretical cylinder forces.

Laboratory Pressure (psig)	Cylinder Pressure (psig)	Experimental Cylinder Force (lbf)	Theoretical Cylinder Force (lbf)	Percent Deviation* (%)
20	18	7.6	8.0	-5.0
30	28	12.5	12.4	0.8
40	38	17.0	16.8	1.2
50	48	22.0	21.2	3.8
60	58	25.0	25.6	-2.3

$$\text{* Percent Deviation} = \frac{\text{Experimental - Theoretical}}{\text{Theoretical}} (100\ \%)$$

The experimental data are in general agreement with the predictions with a typical absolute deviation of a few percent, ranging from 5% to less than 1%. Discrepancies may exist due to the accuracy of the pressure gauge. Overall, this exercise introduces students to pneumatic components and principles. Furthermore, the students record data and then must relate the data to theory, reinforcing the concepts.

REFERENCES

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