AC 2010-730: DESIGN OF A PNEUMATIC VALVE FOR AUTOMATIC SEAT LIFTING OR DOOR OPENING MECHANISMS

Cheng Lin, Old Dominion University

Design of a Pneumatic Valve for an Automatic Seat Lifting or Door Opening Mechanism

Abstract

Design and fabrication using a designed 5/2 (five ports and two positions) pneumatic valve to automatically lift a cover is presented. Operation of the design utilizes only through mechanical means without using electrical power, electronic sensors, and controllers. Therefore, the system not only saves energy, but also increases operational safety. For light-duty operation, the air can even be supplied by a bellow foot-air pump through a foot pedal, which can also be acted as the single actuating button. When an operator hits the foot pedal, the cover will be opened and remain in the opening position until the food pedal is hit the second time. The operation can be repeated.

Introduction

The course of Automation and Controls offered in the Mechanical Engineering Technology Program of the Department of Engineering Technology at Old Dominion University has the objective of teaching students:

(1) Pneumatic components and pneumatic circuit designs.

(2) Feedbacks from electrical sensors and related ladder diagrams.

(3) Introduction to Programmable Logical Controllers (PLC) and PLC[1,2] programs.

(4) Integration of pneumatic, electrical, and/or hydraulic components with PLC programs.

To let students have hands-on applications in this course, a two-hour/week lab is also offered to train the students to integrate mechanical, pneumatic, and electrical components with ladder diagrams or PLC programs. The lab basically includes three main sessions: (1) four weeks of pneumatic applications, (2) four weeks of pneumatic components, electrical sensors, and ladder diagrams, and (3) five weeks of PLC programming using IDEC[3] and TRiLOGI[4] PLCs. In addition, the simulation software of Automation Studio[5] is used in each project so that students can check their designs before implementing their projects.

This design of this research project is to apply the knowledge learned from this course to provide a simple and safe mechanism for a person to lift a toilet cover in the rest room. The design can also be served as a door-opening device. For safety reason, a pneumatic system without using electrical power is required. The compressive air can be supplied by either a compressor or a bellow foot-pedal pump. Operation of the system is very simple. The person only needs to hit a foot pedal if the air is through the use of a foot pump. When the button or foot pedal is hit the second time, the cover will be dropped to the closed position. The operation can be repeated. The author provided the design idea for the valve and asked two MET seniors to work on their Senior Capstone Project for the implementation.

Design Approach Using Commercial Parts

The first approach is to use commercial parts in the design, as shown in Figure 1. When Button A is pressed, the compressive air goes through this 3/2 (three ports/two positions) valve[6] and pushes the spool of the 5/2 flow control valve to the right position. The air then moves the double-acting cylinder in the forward direction. The linear motion can be converted to rotational motion by using a gear rack and gear. The cylinder will remain in that position until Button B at another 3/2 valve is pressed. This design is functioning well except the operator needs to know which button is used for lifting and which button is used for lowering. This may cause problems when the operator is an aged or handicapped person. In addition, the design needs three valves and one air compressor.

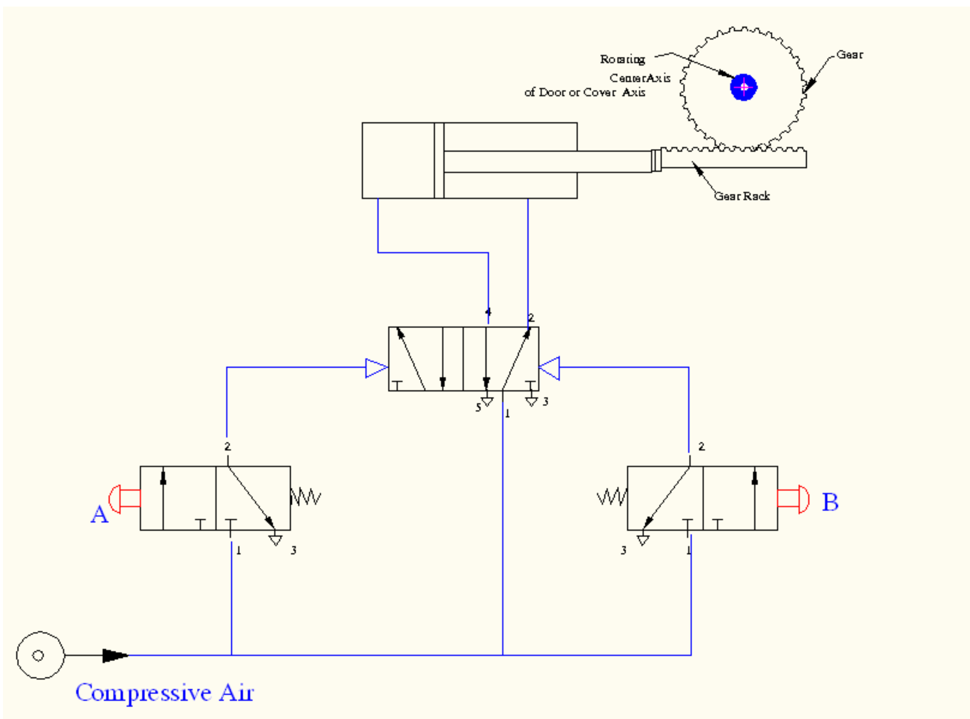

Figure 1: Schematic Diagram for a Two-Push-Button Mechanism

Innovative Memory-Latch Valve

Figure 2 shows the design of using a single newly designed 5/2 valve. There are three rings on the spool with four drilled holes on the right-most ring. The valve is designed with one side roller activated and the other side with spring return. When the piston cylinder is in the retract position, the weight of the cover pushes the left-most ring of the ring against the spring and is stopped by the position block. There is no air supply during this stage.

Figure 3 shows the air cylinder moving in the forward direction when a bellow-foot-air pump is activated. The compressive air enters the valve through Port 1 and leaves the valve through Port 2 to push the piston in the forward direction, as shown in the blue color of the Figure 3. The air on the right-hand side of the cylinder returns to the valve through Port 4 and exhausts the air to the atmosphere through Port 5. To prevent the spring from pushing the spool to the right direction so that the air cylinder can keep pushing the piston in the forward direction, four holes are made on the right-most ring of the spool. The air inside the valve, as shown in Figure 4, passes through the holes of the right-most ring and exerts a force, which is greater than the spring force, to latch the spool remaining in the same position.

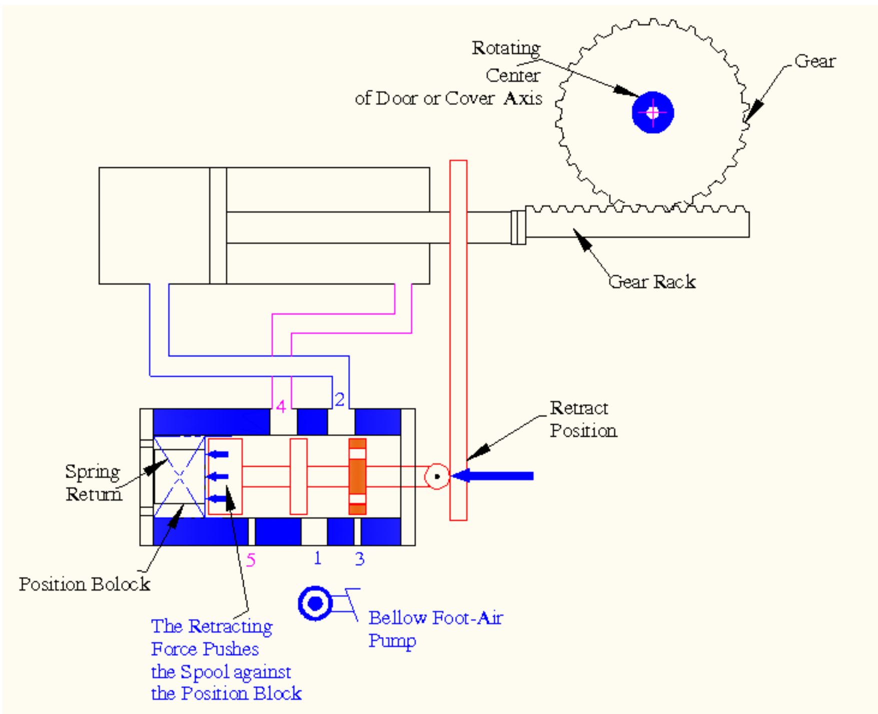

Fig. 2: The 5/2 Valve in the Retract Position.

When the bellow-foot-air pump is inactivated, as shown in Figure 5, the spring inside the 5/2 valve pushes the spool to the right direction. The right-most ring on the spool is acted as the position block which will re-direct the air direction during the following motion. Figure 6 shows the air cylinder moving in the retract direction when a bellow-foot-air pump is activated again. The compressive air enters the valve through Port 1 and leaves the valve through Port 4 to push the piston in the retract direction, as shown in the blue color of the Figure 6. The air on the left-hand side of the cylinder returns to the valve through Port 2 and exhausts the air to the atmosphere through Port 3. When the operator sees the cover moving downward, he may just de-activate the air and the Retract Position (shown in Figure 6) automatically pushes the spool back to the left-most position, which is shown in Figure 2. The operation then completes the whole cycle.

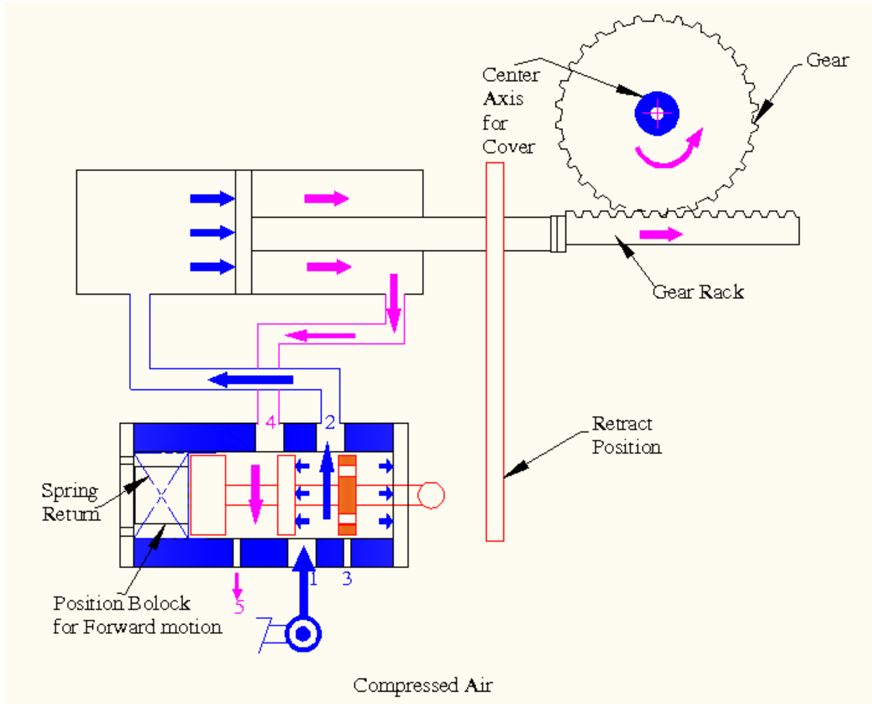

Fig. 3: The 5/2 Valve in the Forward Position

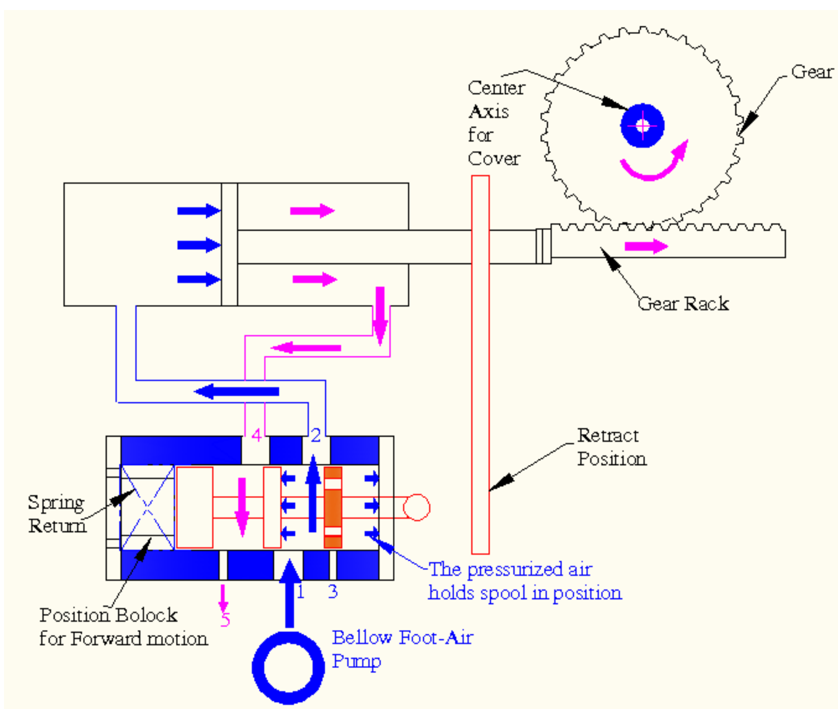

Fig. 4: The Pressurized Air on the Middle Ring Holds the Spool in the Retract Position.

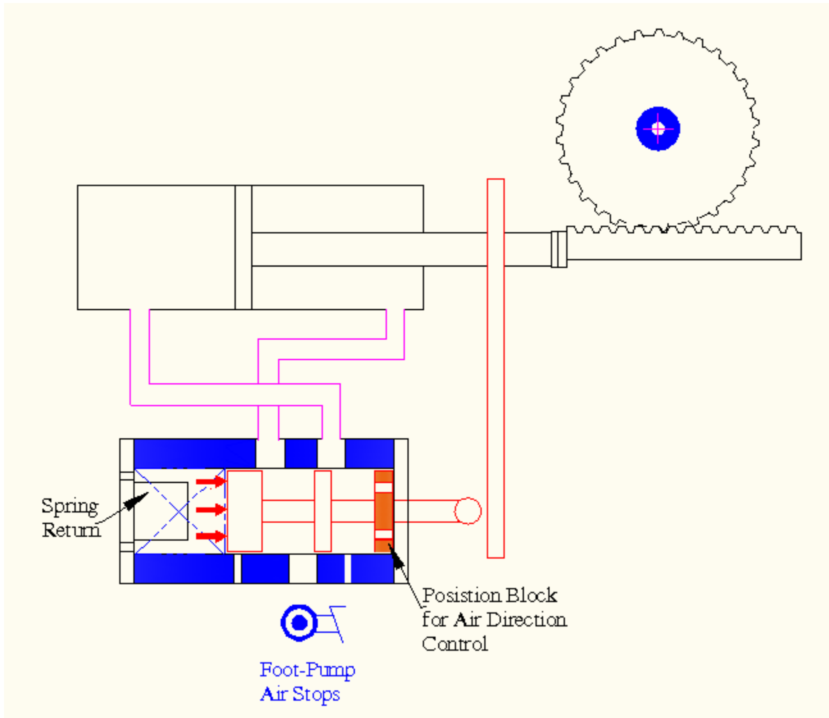

Fig. 5: The Spring Pushes the Spool to a Different Position.

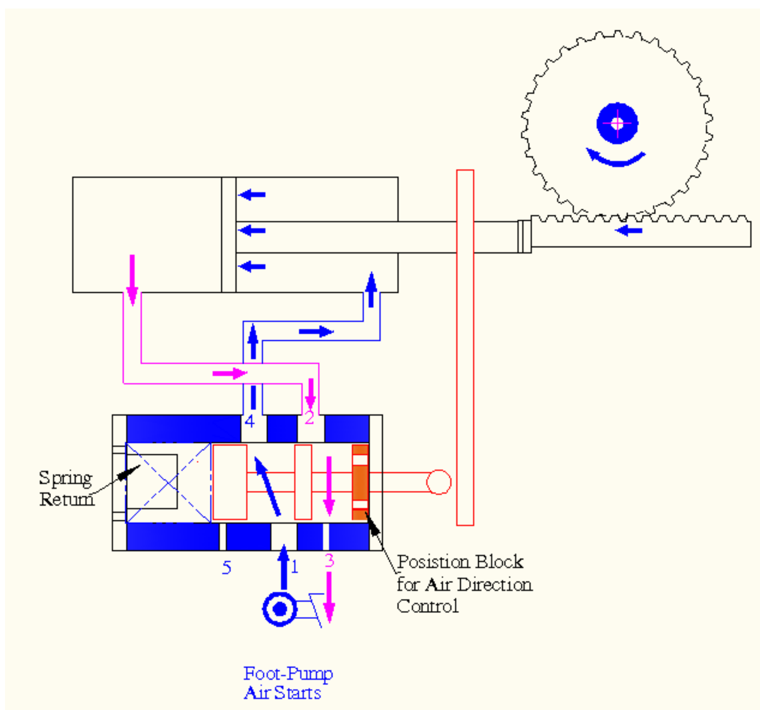

Fig. 6: The Air Cylinder Is Moving to the Retract Position.

Designing the Air Cylinder

Figure 7 shows the gear used to raise the cover. Here assume the weight of the cover is *W*; the distance from the centroid of the cover to the distance is *L*; gear diameter is D_g; force generated from the air cylinder is *F*. The following torque equation is applied:

$$T = WL = F\frac{D_g}{2} \qquad (1)$$

As *W, L*, and D_g are known, the force *F* needed to generate from the air cylinder can be determined from the following equation[7]:

$$F = \frac{2WL}{D_g} = P\frac{\pi d_a{}^2}{4} \qquad (2)$$

Where the diameter of the air cylinder is d_a and the air pressure generated from the bellow foot-air pump is *P*. The diameter of the air cylinder can be determined from the following equation:

$$d_a = \sqrt{\frac{8WL}{\pi P D_g}} \qquad (3)$$

To lift the cover, the gear needs to rotate at least 90˚. The following equation is applied to calculate the stroke, S_a, of the air cylinder:

$$S_a = \frac{D_g}{2}\frac{\pi}{2} = \frac{D_g \pi}{4} \qquad (4)$$

Assuming *W= 8 lbs, L=12", P=20 psi,* D_g *=3"*, d_a can be found as *2.0"* from Equation (3). From Equation (4), S_a is found as *2.4"*.

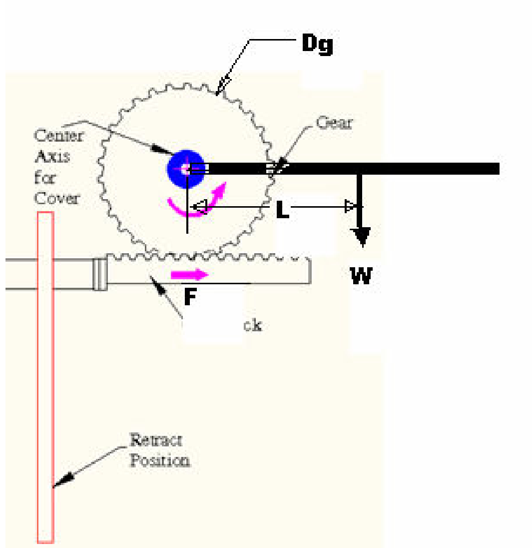

Figure 7: Dimensions for Equation (1)

Fabrication and Tests

Figure 8 shows the fabrication of the spool for the valve. As stated in Session 3, four drilled holes are made to latch the spool position when the cylinder is moving in the forward direction. To prevent the air leaks between the spool positions, Figure 9 shows that three O rings are used to achieve this purpose. The figure also shows the ports connected to air tubes. Figure 10 shows the design using AutoDesk Inventor. A clamp assembly is applied to attach the design to a door or a cover with the rotation center located at the center axis of the gear. Figure 11 shows the fabrication of the whole system. In the implementation of this project, one student focused on the fabrication of the valve and the other student focused on developing all other auxiliary devices. When the bellow-foot-air pump is activated, the opening device, which is linked to the gear, rotates about 93° as expected. The opening motion remains until the bellow-foot-air pump is hit the second time.

Figure 8: Fabrication of the Spool

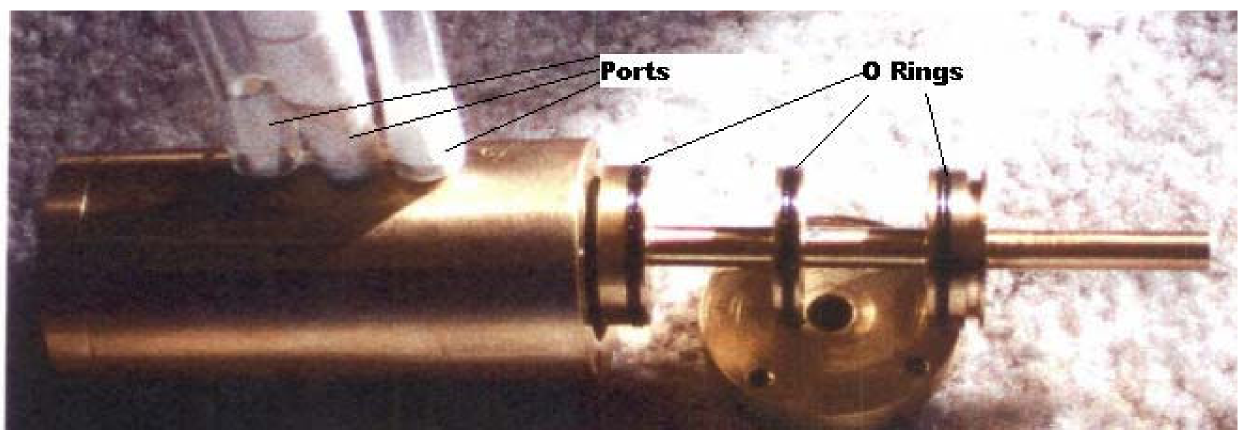

Figure 9: Fabrication of the Valve and Air Ports

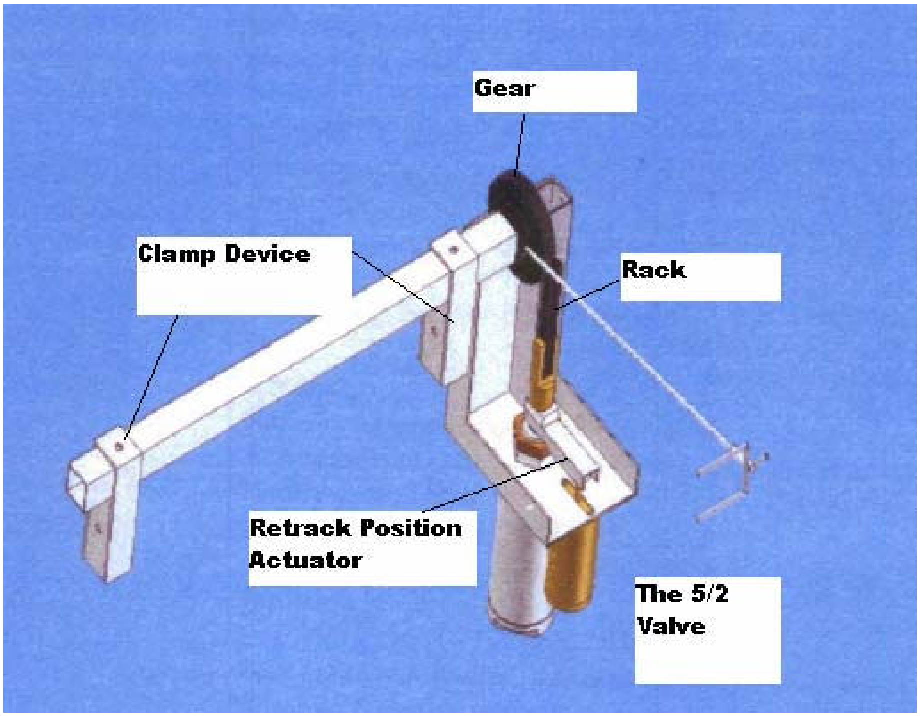

Figure 10: The whole assembly designed Using AutoDesk Inventor

Figure 11: Fabrication of the System

Summary

Tests show that the system achieves the design objectives. From the design, fabrication, and tests, students gain the following practical experiences:

(1) Functions of the air control valves.

(2) Pneumatic circuit design.

(3) Auto-latch concept.

(4) Design calculations for the air cylinder.

(5) Design drawings for the 5/2 valve and whole system using a CAD system.

(6) Manufacturing and procuring the components.

(7) Assembly of the whole system.

(8) Field tests.

The two MET students worked very hard to complete the project in one semester. Materials used in the design are basically the scrap metals whatever available in the machine shop of the university. To achieve more practical application of the fabrication, lighter materials should be selected.

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