

Investigation into the Cause of Pneumatic Actuator Failure on the HypoSurface

by

Darren M. K. Chun

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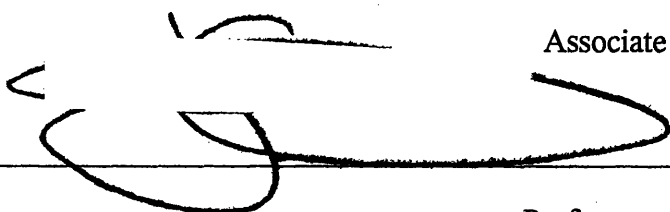
Department of Mechanical Engineering
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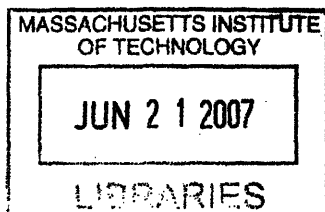


Mark Goulthorpe
Associate Professor of Architecture
Thesis Supervisor

Accepted by: _____



John H. Lienhard V
Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee



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ABSTRACT

An investigation into the failure of pneumatic actuators on the HypoSurface was conducted to provide information on the current HypoSurface prototype. Using a systematic approach throughout testing, piston components were found to have been subjected to fatigue-failure, causing pressure leaks from the piston. Through further analysis, the increase in wear on the piston gaskets was caused by exceeding the recommended loads during operation of the HypoSurface with its skin. Furthermore, vibrations from piston actuation may be the cause of loose electrical connections in the control panel, resulting in voltage problems in the solenoids.

Thesis Supervisor: Mark Goulthorpe
Title: Associate Professor of Architecture

1. Introduction:

HypoSurface is the world's first dynamic surface display system. Using a powerful information bus technology, more than 500 moving actuators are controlled to deform a pliable surface, allowing high-speed movement of the screen surface. A wide-range of effects, such as waves, patterns, images, and text, can be generated and choreographed for entertainment and information display. HypoSurface is made to also be responsive to sound and movement to create an engaging and interactive environment with its audience.¹ The current prototype of the HypoSurface uses pneumatic pistons to actuate the surface. During each prototype stage, information is essential for improvement, such as actuator limitations. This purpose of this thesis is to research into why the pneumatic components are failing within the current prototype, and to develop a systematic approach to finding problems.

2. Pneumatics background:

A pneumatic system is a system that uses pressurized gas, usually air, to generate power. With a variety of advantages, pneumatic powered systems are generally used in a wide range of applications. Pneumatic advantages include high reliability due to few moving parts, low cost, the availability of a large selection of sizes and capacities, easy installation and maintenance, and the capability of being easily integrated with other systems. Also, with air as the working fluid, pneumatic systems have advantages over hydraulic systems, such as having relatively lightweight supply hoses, not needing fluid return lines, and having leaks that tend not to be messy. However, pneumatic systems still have a few drawbacks compared to other systems.

Pneumatic systems always need at least a compressor and distribution lines, which takes away from spatial efficiency for large systems with hundreds to thousands of actuators. In regards to speed of response to control signals, electronic systems are much faster than

pneumatic systems by bypassing the speed of airflow and valve shuffling speed. By using a fluid that is nearly incompressible, hydraulic systems are able to have higher energy densities, leading to much higher working pressures than pneumatic systems. For example, for applications needing power on the order of magnitude of ten horsepower, the increasing size and cost of pneumatic devices begin to exceed the basic cost of a hydraulic power generation and transmission system.

Despite some disadvantages, a pneumatic system is more than adequate for testing prototype concepts of the HypoSurface. The physics behind the pneumatic actuators in the current HypoSurface prototype are straightforward. The thrusting force of the pistons is directly related to the cross-sectional area within the piston and the pressure within the tube. Since the cross-sectional area will always remain constant, forces will vary relative to varying internal pressures. Speed of actuation is dependent upon mass and duration. Given the thrusting force, F_T , the mass of a skin element, m_s , the mass of the piston shaft, m_p , and the total time of actuation, t , the average velocity, v , of the actuation is shown below in Equation (1).

$$v = \frac{F_T \cdot t}{(m_s + m_p)} \quad (1)$$

With the thrusting force and average velocity of the piston, the power generated from a single piston is given in Equation (2).

$$P = v \cdot F_T \quad (2)$$

where P is the average power generated in a stroke, v is the average velocity, and F_T is the thrusting force. These calculations are good estimates to describe the system and define certain power and pressure requirements. More precise calculations for stroke velocity would need to include sliding friction and static friction generated from beam bending.

3. Apparatus and Schematics:

The current HypoSurface prototype consists of ten modules, with each module housing 56 pneumatic pistons. Each module has a height of 12 ft 2 in, a width of 3 ft 3.5 in, and a depth of 2 ft 3.5 in. Air is supplied for the entire pneumatic system through a compressor into a main tank and a dryer, which is used to remove the moisture accumulated from air compression. From the main tank, each module is supplied high pressure, low volume air through is supplied through a hose with a diameter of 0.175 inches. The air pressure is then regulated down to supply every module with low pressure, high volume air through a 2 inch diameter hose. Within a module, both high pressure and low pressure air is shared with every valve-piston assembly through a series of loops. Figure 1 below is a flow chart showing the air flow from the compressor to a piston.

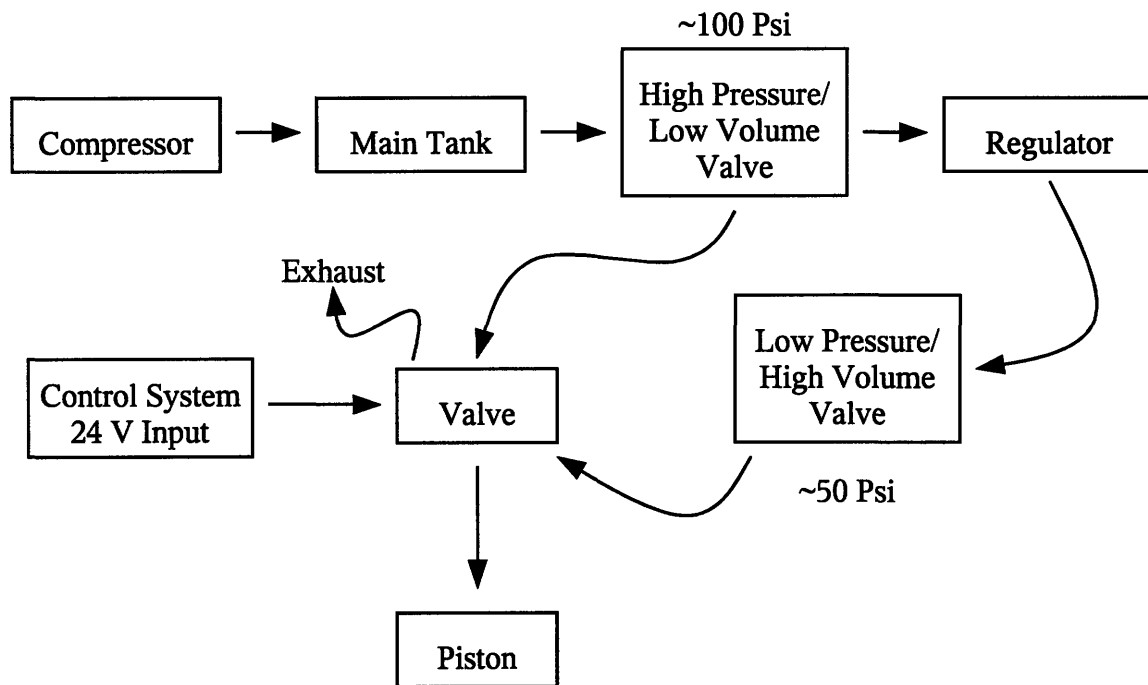
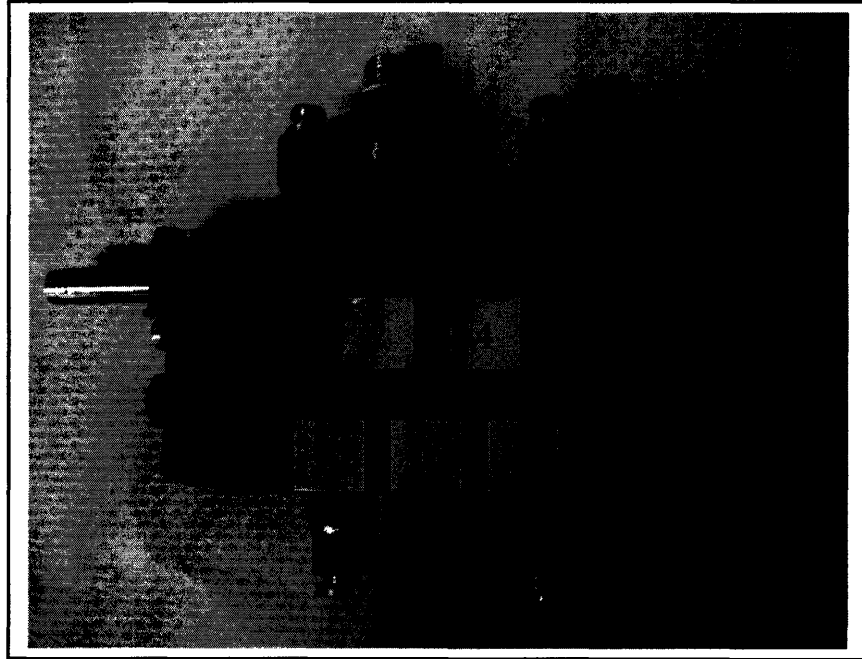
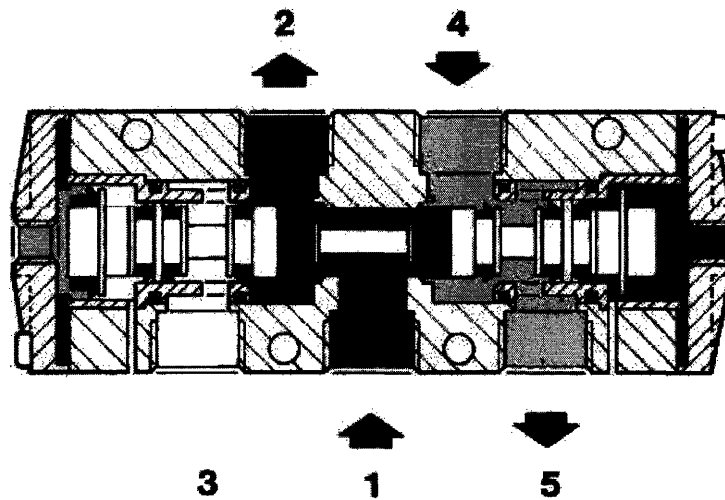


Figure 1: Flow chart of the air flow throughout the pneumatic system.

The fabrication of the HypoSurface modules and its components is done by a British company called Univer. A valve is manufactured out of die-cast aluminum, and contains an internal piston, which is actuated indirectly by two solenoids. There are five main external ports on a valve, one for the low pressure air supply, two for air consumption by the piston, and two for exhaust, that are used to transport air to and from the piston. Also, to minimize leaks, the threads of the valve connections are wrapped with Teflon tape. Figure 2 shows a valve assembly (a) and the cross-section of a valve during the extension of a piston (b).



(a)



(b)

Figure 2: Valve assembly. (a) Photo of a full valve assembly with numbers corresponding to the ports shown in the cross-section diagram. (b) Diagram² of the cross-section of a valve showing how the ports are controlled by the internal piston. Port 1 is the low-pressure supply, ports 3 and 5 are the exhaust, port 2 provides air to the back of the piston, and port 4 provides air to the front of the piston.

High pressure in the valve is used to shift the internal piston. During the activation of a solenoid, a magnetic field is generated, pushing a cap and displacing the piston just enough to let the high pressure air through. Figure 3 reveals the high pressure air path to the internal piston.

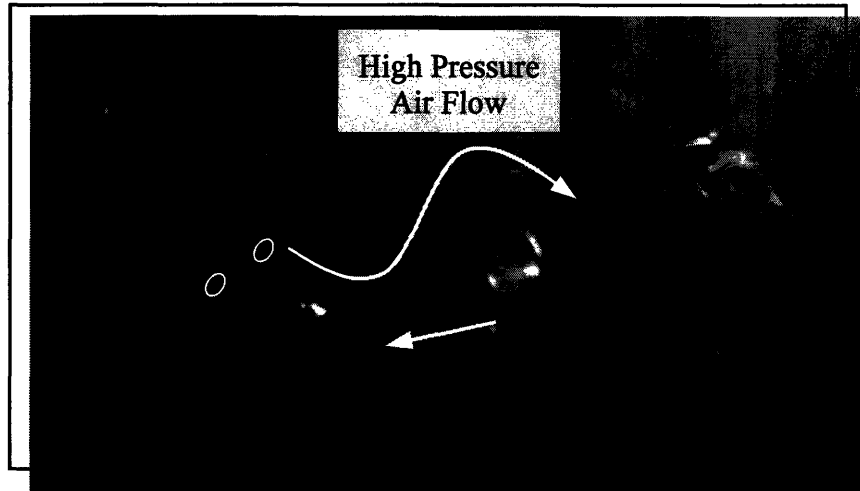


Figure 3: Revealing the high pressure path to the internal valve piston.

The pneumatic pistons are 26 inches long and have a 22 inch displacement. The outer casing is made out of aluminum and houses a stainless steel shaft, which has an 8 mm OD and a 5 mm ID. Pistons on a module are radially and axially constrained in the back with a threaded rod and nut assembly. The front of a piston is free to displace, but will return to its original position due to 4 springs. Low pressure, high volume air is sent from the valve to the front and the back of the piston for retracting and extending the piston shaft respectively.

4. Piston and Valve Failures with General Troubleshooting Procedure:

During testing, pistons that don't move or pistons that respond slowly were the first indications of a problem. With pneumatic systems, it is currently not feasible to eliminate all leaky sources because of the lack of perfect seals or sealing techniques available. Therefore, the next step was to check all of the connections, since the source of the problem in either case could

have still been the piston, the valve, or even both of them. After all the connections have been checked, meaning there was nothing loose or disconnected, the first thing to check is the piston.

The first thing to look for, while checking the piston, is whether or not it has a bent shaft. In most cases, a bent shaft would explain why the piston during testing was either really sluggish or unable to move. However, aside from bent shafts, the most common problem with the piston was a faulty head gasket or internal gasket, which both caused unwanted pressure leaks within the system. With the piston extended, a faulty head gasket would let out a loud hiss while displacing the piston shaft in the radial direction. A faulty internal gasket was detected when the piston shaft could be displaced axially without a significant restoring force, while both high pressure and low pressure was still active throughout the system. Figure 4 shows the wear and tear of an internal gasket from general use of the HypoSurface.



Figure 4: Wear and tear of a gasket inside of a faulty piston.

After checking the piston for problems and the piston is still “dead,” the only thing left to be checked was the electrical connections to the valve. To check the electrical connections, one needed to disconnect the solenoids from the valve and expose the wires from the housing. Using a multimeter, set to measure DC voltage, the voltage across each solenoid was measured. In order for the internal valve piston to properly shift, only one solenoid should measure 24 V,

while the other solenoid should have 0 V. If this was not the case, then the problem lied anywhere along the wiring between the control system to the module's control panel or along the wiring between the control panel and the valve solenoids. However, if the voltages were fine, then the solenoids needed to be checked whether or not they do their job in shifting the valve piston. This could be done by applying 24 V, one at a time, to both solenoids and listening for a "click" sound from the valve piston shifting.

5. Discussion and Conclusion:

The current HypoSurface prototype is not capable of handling the demanded loads and cycles, shown by the high failure rate in both the skin components and the pneumatic components. For future prototypes, improving the piston and piston shaft constraints and reducing the mass of the skin will greatly improve the life of the components. Piston and piston shaft constraints are important because with future prototypes having larger and larger piston strokes, the deflection at the end of the shaft and moment felt on the piston housing will drastically increase if not properly constrained. Then again, increasing the diameter of the piston shaft will also help to reduce deflection. Mass could be effectively "reduced" by having more pistons per given area of skin, which will minimize the end load on the piston shaft.

The next generation module, with the valve assembly separated from the piston and placed in the control panel, will be an improvement in maintenance and troubleshooting difficulty and will eliminate problems caused from lengthy electronic wiring. Also, piston actuation speed and timing will not be affected by the variable length tubing. Using a fluid dynamics model, with the current running pressure and as long as the diameter of the tubes is kept small, the time it takes the air to travel the extra distance is negligible and on the order of magnitude of a millisecond.

For the next generation skin design, the current durability problems with the current “squids” should be taken into account. If rubber is still to be used, it should be flexible enough to withstand stretching between a piston at its maximum stroke and a surrounding piston at its minimum stroke. This is most important when an adjacent piston is unable to move to relieve the stress on the skin.

6. Acknowledgments

This thesis was conducted with the help of thesis advisor and founder of HypoSurface, Prof. Mark Goulthorpe.

7. References

¹from notes and materials provided by Prof. Mark Goulthorpe

²UNIVER homepage <<http://www.univer-group.com/eng/indexeng.html>>