XI.6

PROBLEMS ASSOCIATED WITH LARGE SCALE HIGH PRESSURE TESTING

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By S. W. Garrett
Test Laboratory
Marshall Space Flight Center

In this Space Age, pressures and flowrates, as well as the cost of components, are going higher and higher. Not too many years ago, pressures over 150 p.s.i. were considered high. Then the era of Aircraft and Rockets caused the pressures to increase to 3,000 p.s.i. Now the normal operating pressure on space vehicle servicing facilities is 6,000 p.s.i. Even the 6,000 p.s.i. is not enough and many studies, test programs, and research programs of industry are being conducted in order to develop 10,000 p.s.i. and 15,000 p.s.i. space vehicle servicing facilities.

The first question which generally comes to mind when these high pressures are being discussed is : Why are these pressures required? The simple answer is that it is the most economical approach for the particular problem. Several economical studies have been conducted by and under the technical supervision of the recently renamed Kennedy Space Center to determine the most economical pressure for the Saturn Space Vehicle Launch Complex. The factors which governed this series of studies were:

1. The flowrates and volume of gas required to perform the necessary functions are the same regardless of the pressure.

2. Only pressure systems above 6,000 p.s.i. are considered.

3. Installation costs of storage bottles, cross-country transmission piping, battery interconnecting piping, primary pressure regulation, compressors and converters, and different materials for piping and battery storage bottles were considered in these studies.

Several manufacturers and governmental agencies which operate high pressure systems were contacted to determine the existance and reliability of operating equipment in this pressure range. Some of these organizations were: Hercules Powder,DuPont, John Deere, Mississippi Chemical, Nitro-Well, Inc. The continuous operating pressures of these organizations ranged from 7,500 to 15,000 p.s.i.

The results of these economical studies indicated the most economical pressure ranged from 7,500 p.s.i. to 12,000 p.s.i., depending upon the material used in the battery storage facility and the cross-country transmission piping.

In order to wisely spend the tax payers money by selecting the best component at the least price, a certain amount of research and development is required. This research is required to maintain the professional respect of industry as well as to evaluate the performance of industry.

The need to evaluate high pressure pneumatic components for ground support equipment and to maintain professional respect in the field are the underlying reasons for which the Marshall Space Flight Center's High Pressure Fluid Facility was constructed.

The test facility has a hydrostatic pressure capability of 100,000 p.s.i. This hydrostatic pressure is used to proof pressure test components insensitive to water and to burst components when this type of destructive test is required. This piece of equipment has a rather unique pressure measuring device - a Bulk Modulus Cell. This device is insensitive to shock pressures and is very valuable in burst tests. The unit works following the laws of modulus of compressibility. It has a hollow, enclosed end steel cylinder exposed on one side to the high pressure and on the other side to atmospheric pressure. The high pressure causes the cylinder of steel to be compressed; this compression is measured and is directly proportional to the pressure.

The test facility also has a gas intensifier capable of producing 25,000 p.s.i. at small volume with a 5,000 p.s.i. gas source. This gas pressure can be either nitrogen or helium. This pressure is used to proof pressure test components which are sensitive to water and to leak test components.

The Fluid Test Facility can also conduct pneumatic flow tests at 10,000 p.s.i. and an estimated maximum flowrate of nitrogen from 80,000 to 100,000 scfm. This flow facility consists of a compressor, storage bottles, and the discharge line.

Gaseous nitrogen is piped to the test facility at 3,000 p.s.i. and ambient temperature. This pressure is reduced through pressure regulators and fed to the compressor. The compressor is a six-stage air-cooled compressor which boosts the nitrogen gas to 10,000 p.s.i. and to within 20 degrees F of ambient temperature. This 10,000 p.s.i. gas is then passed through chemical dryers and oil absorbers to remove the oil introduced by the compressor. The gas is then discharged into a battery of storage vessels. The total volume of the storage vessels is 125 cubic feet water volume or approximately 80,000 standard cubic feet of nitrogen gas at 10,000 p.s.i.g. These storage bottles are manifolded and piped into the test cell. The system shutoff valve which isolates the bottles from the test cell is a remotely-operated, spring-loaded closed gate valve and is installed at the end of the flow line. From this point a test specimen and the required associated support equipment would be installed for a test series. Nitrogen is the normal flow medium; however, the system is also designed to flow helium.

Since this is an unusual facility, many problems have been encountered in design, construction, and operation. Some of the major problems are discussed in the following paragraphs.

One of the most important is the problem of safety both to personnel and equipment. This problem is of paramount importance since the storage bottles pressurized at 10,000 p.s.i. have the equivalent ft.-lbs. of energy as 250 lbs. of TNT. For this reason, the test bay was constructed to give good protection for personnel and the operating procedures were established to perform as many operations remotely as possible .

The most disastrous type of failure would be the complete structural failure of a large component which is pressurized with the gas. This would create two serious safety hazards: shrapnel and increase in pressure within the test cell.

The test facility was constructed in an existing building which created problems of building a suitable protective barrier with materials which could be handled inside the building. The test cell was built of 1/4-inch steel plate, welded on each side of 6-inch columns, and then filled with sand. This type wall is on three sides of the 40'X20'X10' test cell. The remaining wall is a corregated asbestos wall for weather protection only. This wall was left unprotected to serve as a blowout wall in the event of a large component failure. The area immediately behind this unprotected wall is fenced to prevent accidental entrance to this area.

The ceiling of the test cell is covered with three overlapping layers of heavy gauge chain link fence. This type ceiling is to catch any pieces of a component which may fail during a test, but to relieve any possible over pressure due to the sudden release of gas.

The control station is located outside of the test cell on the 40-foot wall.section. From this point outside the cell all of the operations are controlled within the test cell. All of the test cell control valves are fail-safe in that they are spring-loaded to their normal positions. In an emergency all that has to be done to return the test cell to a safe condition with all of the components vented is to turn off the electrical power on the control panel.

The fact that no disastrous type failures have occurred in the operation of the test facility is due primarily to the preliminary tests conducted on a component before it is installed in the flow line. Before a component is installed for flow tests, it must successfully pass a leakage test with nitrogen gas at the rated working pressure of the component. If it passes this test, it may be subjected to a leakage test using helium as the test medium and at the rated working pressure. It is then subjected to a proof pressure test from 150% to 200% of the rated working pressure. The test medium is either nitrogen or water, depending on the component's sensitivity to water. This proof pressure is maintained on the component for at least ten minutes. Any sign of leakage or structural deformation due to the proof pressure test is grounds for rejection of that component.

A typical test program would be difficult to broadly define since many types of components are tested; however, one test would be common to each component mounted in the flow facility, this being a maximum flow test. This test is the most notable because it creates a high noise level. This noise level can, at times, be painful to the human ear without proper ear protection. The estimated decibel level ranges from approximately 125 to 160DB; therefore, ear protection devices are used during high flow tests.

The analysis of the test data reveals one of the most interesting of the problems encountered in this type of test facility - the flow measurement.

As it has been stated, the maximum flowrate of the test facility is 80,000 to 100,000 scfm and the maximum storage capacity is 80,000 scfm at 10,000 p.s.i. It is obvious that these maximum flow tests occur for short periods of time, 5 to 10 seconds. This short time period creates an unusual demand on all instrumentation - that it respond within milliseconds and be accurate within 1/2% to 1%. The types of measurements required are temperature, pressure, and flow.

Probably the most frustrating problem with this test facility or any test facility which deals with a compressible fluid is the measurement of flow. This flow measurement difficulty is compounded by the lack of experience in measuring these flowrates at these pressures.

There are certain perimeters which are required of the flow measuring devices:

1. The measuring device should create a minimum flow restriction and pressure loss.

2. The device should cover the range from 50 to 100,000 scfm range with an accuracy of 1%.

3. The device should be capable of giving an instantaneous flow reading.

4. The device should have a minimum start-up time and a minimum coast downtime after a run.

There are three methods presently employed to measure the flow in the test facility:

1. The temperature and pressure is measured just prior to a test run and again one hour after the test run. The mass of nitrogen is calculated from the thermodynamic properties of the gas at the start of a test run and then again from the conditions one hour after the run. The difference in the mass is the amount of nitrogen flowed during the test. The time of the test run is taken from the instrumentation charts. The mass difference is then divided by this run time to give the average flowrate for the test.

This method is considered to be the most accurate for determining the total flow and the average flow for a test. It does not allow for start-up time or decay time during a run and, therefore, an instantaneous flow measurement will be slightly higher. This method does have the disadvantage of having the test facility idle for at least one hour after a test run to allow the bottle pressure and temperature to stabilize.

2. A second method flow measuring is a turbine flowmeter. This device has been giving amazing results for the conditions to which it has been subjected. It has been operating at approximately four times its rated range and has been comparing very closely with the mass flow calculations. This type of a device has the disadvantages that it cannot measure the complete range of flows, and it has a start-up time delay and a coast down time.

3. The third flow measuring device is a pitot tube which has been manufactured to withstand the 10,000 p.s.i. pressure. This pitot tube has been instrumented with a thermocouple, a pressure transducer, and a differential pressure transducer. The thermocouple is to give the temperature of the flow medium, the pressure transducer is to measure the static pressure in the line, and the differential pressure measures the pressure differential between the static pressure and the pressure caused by the velocity of the medium in the flow line. A pressure differential measurement is used to give a more accurate reading and it is easier to work with in the calculations.

The differential pressure is very small compared to the static pressure, and is very difficult to measure accurately. This differential pressure is approximately 130 p.s.i.d. with a 4,200 p.s.i. static pressure and a flowrate of 40,000 scfm. This differential pressure is presently being measured with a pressure transducer rated for a 0 to

5,000 p.s.i.g. It is obvious that the 130 p.s.i.d. is on the low end of the range and the signal is amplified to the extent that it far exceeds the accuracy limits of the pressure transducer.

Pressure transducers designed to measure this small differential pressure at the high static pressure should enable this flow measuring device to become the best of the three methods.

There are thermocouples installed in the storage bottles to measure the average temperature. There is also a pressure transducer monitoring the storage facility pressure. This temperature and pressure information is used in one of the methods to determine the gas flow. These temperature and pressure instruments are not required to respond as rapidly as the other instrumentation since these readings are taken under equilibrium conditions (before and after the test runs).

There are two to three temperature measurements required within the flowline to measure the gas temperature as the gas flows. These temperature measurements have to respond within 50 to 100 milliseconds to give the desired speed needed to correspond with the flow measurements. The flow measurements are taken instantaneously; therefore, the temperature must respond as rapidly as the flow measurement to give an accurate correction factor for the flow calculations.

This temperature measurement is one problem which has not, to date, been satisfactorily resolved. For a thermocouple to respond as rapidly as is required in this application, it should be made of small wires with the junction of these wires exposed. There are two large problems which are created by this simple statement: (1) the small wires may bend, break, or fatigue due to the velocity of the gas in the pipe, therefore, they should be supported within the pipe. This support would cause a restriction within the pipe and because of the restriction give a false temperature reading and a pressure drop in the line, and (2) the wires have to be sealed to withstand the 10,000 p.s.i. pressure. This pressure seal must be positive to prevent leakage and movement of the wires; it also must be non-conductive.

One possible solution to this temperature measurement is some relatively new developments in the solid state electronic temperature sensors. At the present time these devices have not been evaluated at this facility.

Another problem area is measuring pressure differentials of small magnitude with a high static pressure. An example is to measure a pressure drop across a component of 0-100 p.s.i.d. with a 10,000 p.s.i. pressure on the inlet of the component. This type of measurement is used: (1) to measure the friction losses in a length of pipe, (2) to measure the pressure drop across a component, and (3) to measure the velocity pressure in a pitot tube. The state of the art is adequate to measure pressures of 10,000 p.s.i. with pressure transducers of the variable reluctance or strain gauge type within 1/2% accuracy; however, the requirement for the small differential pressure at the high static pressure has been special enough to require special manufacture.

Another problem which retards the testing program is the limited number of components which have been developed to meet the requirements of a Space Vehicle Launch Complex.

Most of the valves, pressure regulators, relief valves, and other components which operate at 10,000 p.s.i., with equivalent orifices greater than one inch, are available only on special order. These special components are very expensive and require a lengthy delivery time.

Pipe and pipe couplings are also problem items. The pipes with internal bores greater than one inch and operating at 10,000 p.s.i. are generally special mill runs with high strength alloy steels. Tests have proved that a clamp type coupling will hold greater pressures, are lighter, less expensive, take excessive bending, and hold much higher pressures than the ASA flange designs. These clamp-type pipe connections are used exclusively in the test cell for high pressures.

High pressure components of the tubing sizes, less than one inch, are readily available and are economically priced. In this area there are a number of manufacturers which produce quality products. The safest and most practical tubing and tube connections are of the Bureau of Standards super pressure design.

American Industry has the ability and will produce components to meet these rigid requirements. To complement this ability, industry has also developed the finest techniques of persuasive salesmanship to sell these products. In order to determine the difference between salesmanship and workmanship in these components, this test facility will be conducting component evaluation tests for the Space Vehicle Launch Complexes during the next few years.

The problems which have been encountered during the design, buildup, and operation of this test facility have not all been resolved. They are not hopeless, in fact, they will probably be replaced with greater problems with the trend going to higher pressures and larger line sizes.