



AEROSPACE INFORMATION REPORT

AIR1228**REV. A**

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Reaffirmed 2014-09

Superseding AIR1228

(R) Standard Impulse Machine Equipment and Operation

RATIONALE

AIR1228A has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE

This SAE Aerospace Information Report (AIR) establishes the specifications and descriptions of the critical components and operational guidelines for the standard hydraulic impulse machine for testing hydraulic hose assemblies, tubing, coils, fittings and similar fluid system components.

This revision to the AIR1228 provides a description of a system that meets the requirements for specifications including: AS603, AS4265, and ARP1383. This impulse system utilizes closed loop servo control with specifically generated command signal waveforms.

Data accuracy and integrity are emphasized in this revision. Knowing the uncertainty of the pressure measurement is important whether using a resonator tube system, as described in the original release of this document, or a closed-loop systems as described in this release. The accuracy of the data measurement system and consistency of the pressure waveform are fundamental to test validity, regardless of the system type. This is discussed in more detail in Section 5.

The standard impulse test system is established for the following purposes:

- A. As referee in the event of conflicting data from two or more nonstandard impulse machines. Such a referee system might be built by an impartial testing activity.
- B. A design guide for future test systems being built by manufacturers and users, or the upgrading of present systems.
- C. A design guide for higher pressure test systems or special purpose machines being designed.

It is not the intention of this document to obsolete present resonator type machines. The specification for the resonator type machine is available in the original release of this document.

A simple block diagram of the revised system is shown in Figure 1.

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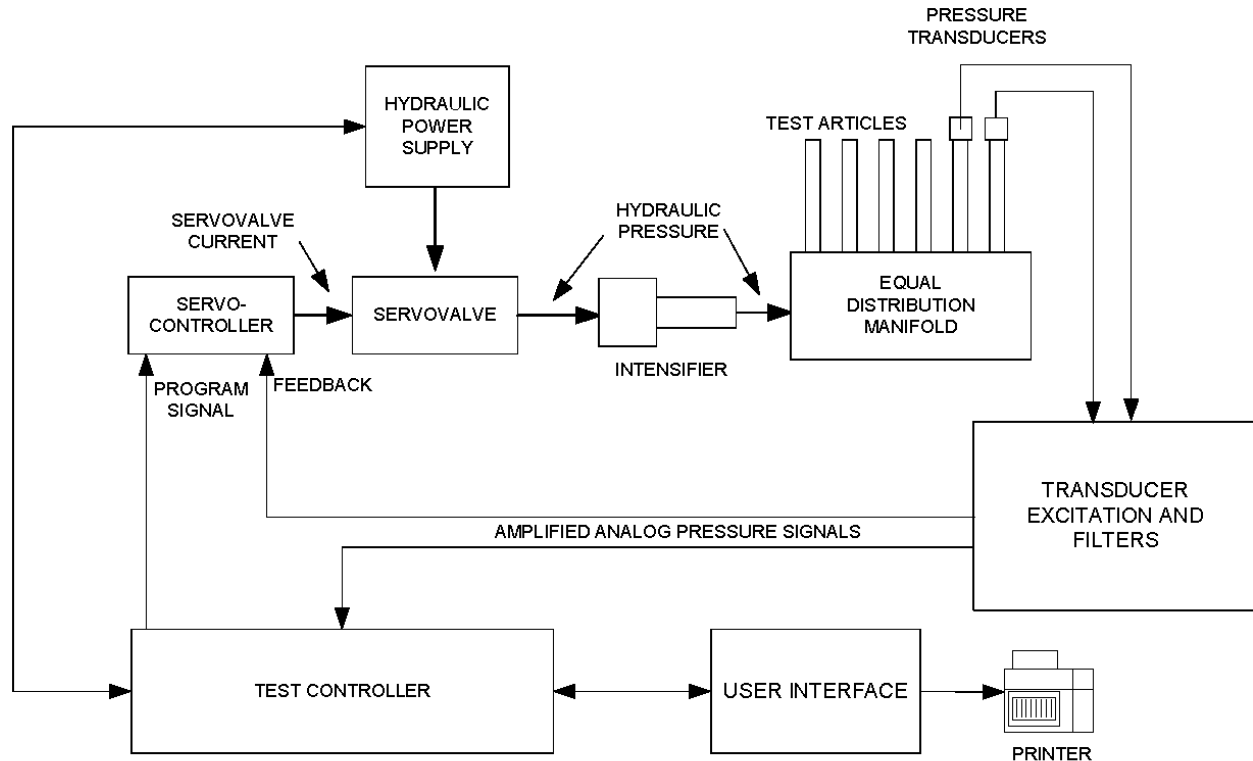


FIGURE 1 - SIMPLE BLOCK DIAGRAM OF SERVO CONTROLLED IMPULSE SYSTEM

The simplified block diagram shown in Figure 1 does not use a resonator tube as in the original release of the specification. To eliminate undesired resonances the hydraulic system is as closely coupled as possible. In this design, the pressure waveform is created in closed loop proportional control via the command signal generated by the test controller system.

If the test controller is a computer with an impulse specific software application, it is possible to control all parameters of the specified waveform, within the capabilities of the hydraulic system. These parameters include things such as rise rate, damping, secondary oscillation amplitude, etc. In a resonator tube system, it is difficult to make adjustments to these parameters.

2. REFERENCES

2.1 Applicable Documents

- [1.] Keller, George R., Hydraulic System Analysis, Penton/IPC, 1969
- [2.] Merritt, Herbert E., Hydraulic Control Systems, John Wiley and Sons, Inc., 1967
- [3.] D'Azzo and Houpis, Linear Control System Analysis and Design, 1981
- [4.] Nelson and Englund "Proposed revisions to AIR1228, AS4265, and AIR4298", SAE G-3 Conference, 3/14/2005
- [5.] Mills Jr., Blake D., "The Fluid Column", American Journal of Physics, April 1960

2.2 U.S. Government Publications

Available from US Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, 202.512.0000, <http://www.gpo.gov/>.

MIL-PRF-5606	Hydraulic Fluid, Petroleum Base
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base
MIL-PRF-87257	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile

2.3 Definitions

General: The impulse test system can be divided into four subsystems.

HYDRAULIC SYSTEM

The hydraulic system provides the power for generating the impulse pressure waveform. Hydraulic components include the hydraulic power supply (HPS), supply and return lines, accumulators, servovalve, intensifier, and test manifold as described in Figure 2. If the test pressure is higher than the HPS output, the system utilizes an intensifier. If the test pressure is lower than the HPS output, the system operates without an intensifier (also called straight servovalve). The system shown in Figure 2 can be switched to either mode with three manual valves. This document will use "servovalve" to represent all types of valves that can be used in a proportional manner for pressure testing.

CONTROL SYSTEM

The control system includes the test controller and the servo-controller in Figure 1. Physically this can be one integrated unit, or it can be comprised of several interconnected subsystems. This system controls the HPS, generates the pressure waveform signal in accordance with standard specifications, closes the control pressure control loop (servo-controller), and ensures pressures are within the test specification.

INSTRUMENTATION SYSTEM

The instrumentation system consists of the pressure transducers, cabling, signal conditioning, amplifiers and filters used to convert the pressure measurement into electrical signals as shown in Figure 3. The amplifiers and signal conditioning may be integral with the pressure transducers. When using computerized data acquisition, the analog-to-digital converters and associated software application are also considered part of the instrumentation system.

TEST ENCLOSURE OR ENVIRONMENTAL CHAMBER

The test enclosure provides a safety barrier for testing high pressure specimens. When required, the enclosure may be an environmental chamber capable of controlling the test temperatures of the air surrounding the test specimens (and the fluid temperatures inside the test articles) within the parameters of the test document.

3. DETAILED DESCRIPTION OF HYDRAULIC COMPONENTS

Figure 2 shows the general arrangement of hydraulic components in the impulse system. The system shown is capable of straight servovalve operation for low pressure testing and intensifier operation for higher test pressures. Operation can be switched to either mode with three manual valves. The servovalve and intensifier are shown in a 3-way configuration as described in the servovalve section.

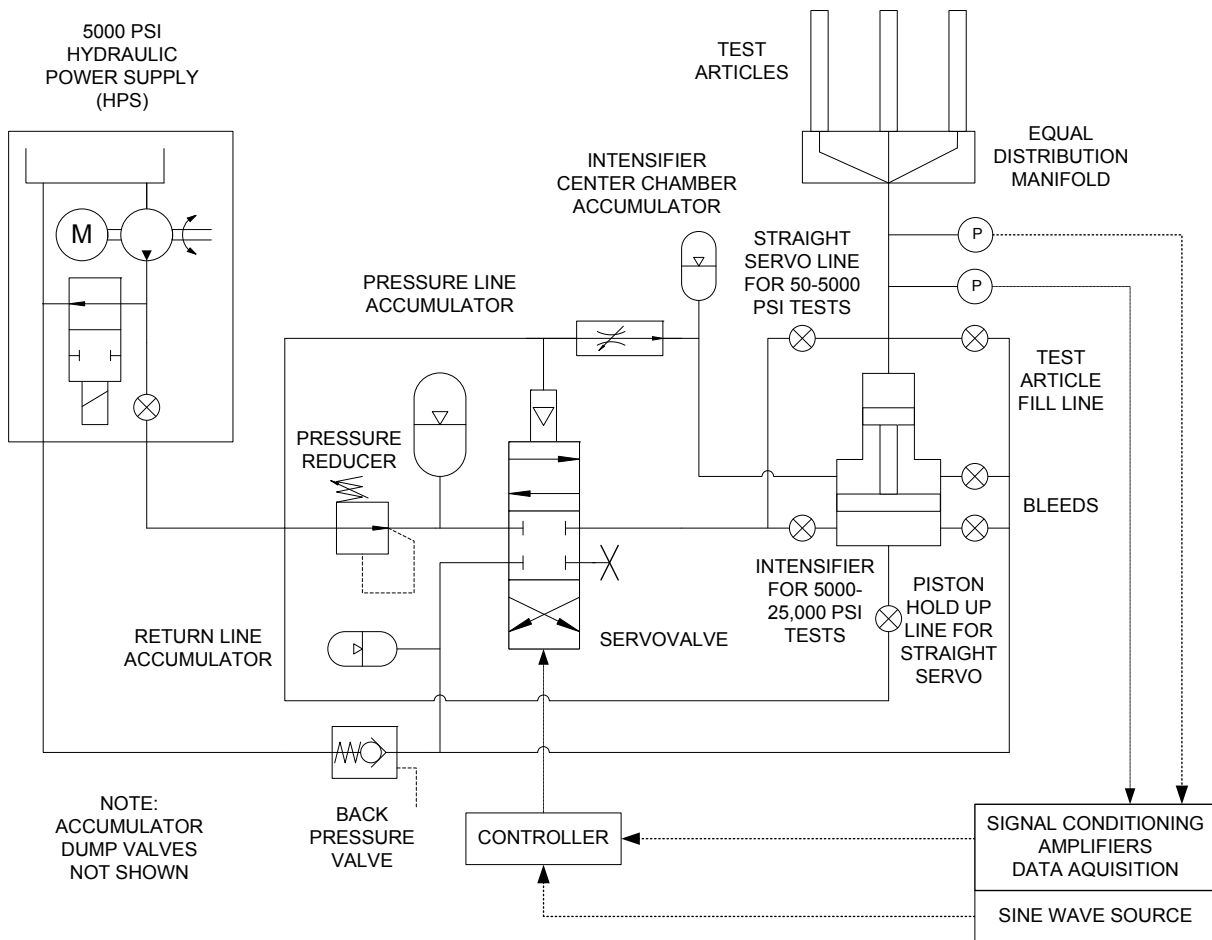


FIGURE 2 - HYDRAULIC SCHEMATIC

3.1 Hydraulic System Sizing

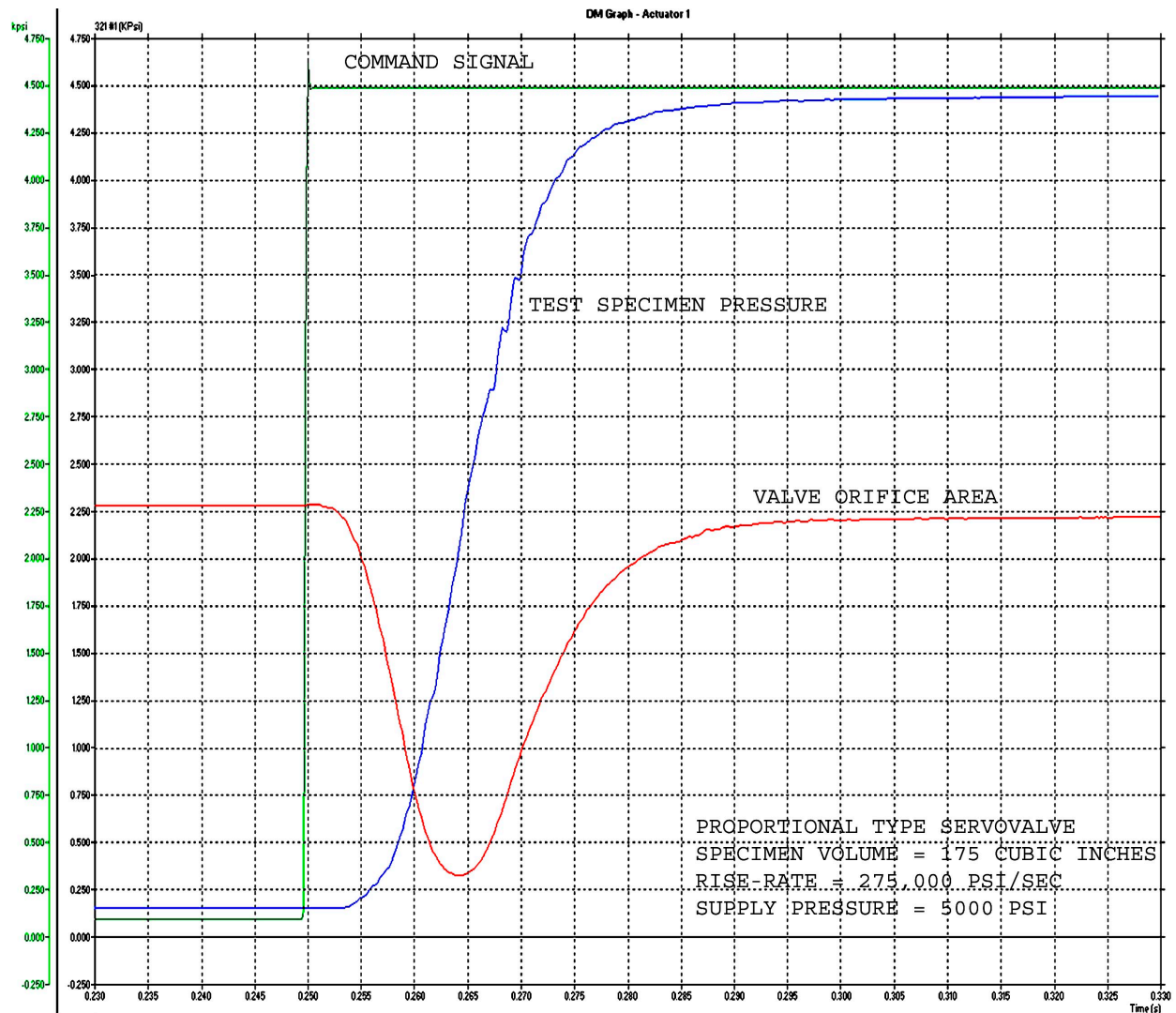
The test system size is typically determined by desired test volume, by available power for the HPS or by cost. One of these three factors typically determines the other two. In determining the test volume, or "specimen load" one must consider the quantity required by the test specification and how many specimens can be run concurrently. From an operational standpoint, it is most efficient to maximize the number of specimens run under a single condition which leads to larger test system size.

All components need to be sized relative to each other. Undersized components will limit desired performance, while oversized components cost more and may have adverse effects on performance. The system must be designed for both pressure and flow requirements.

3.2 Closed Loop Control

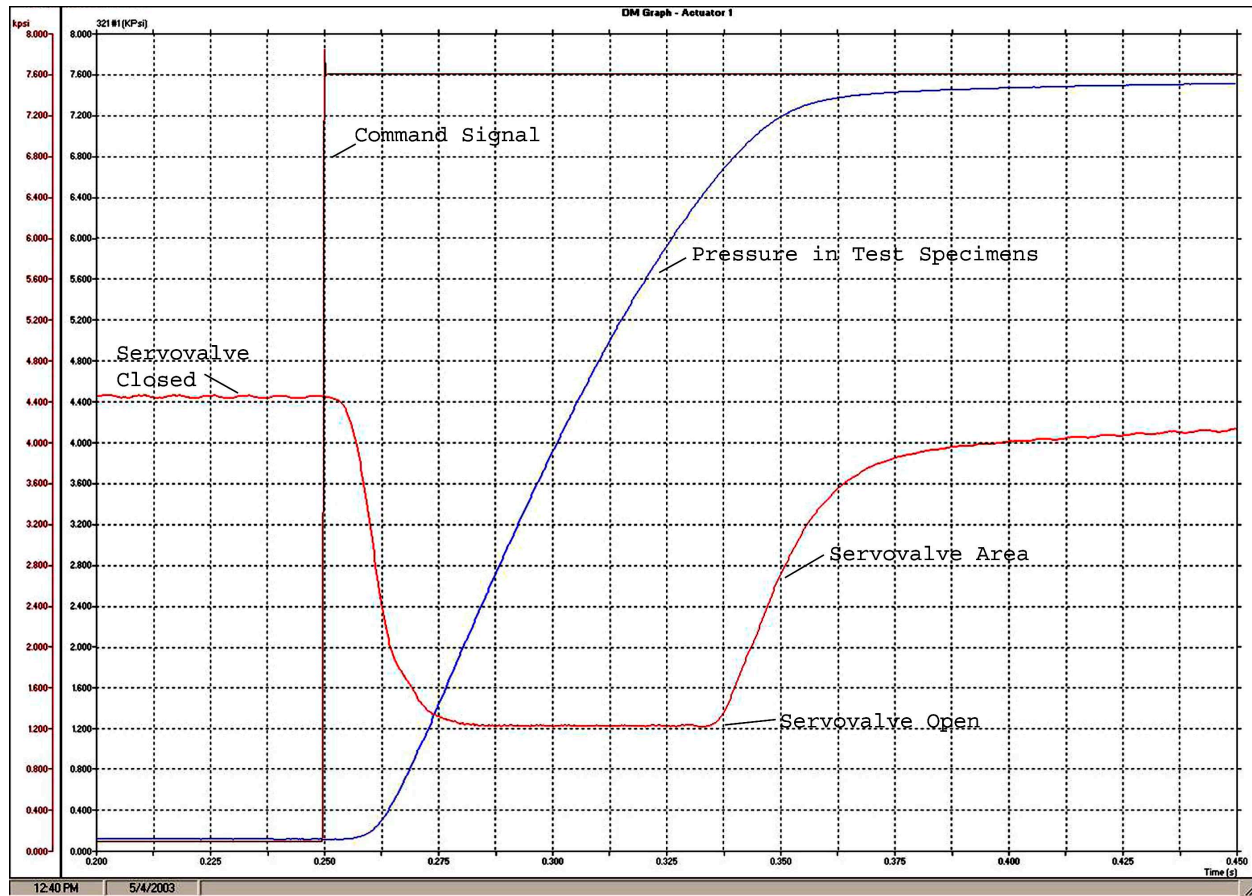
In the resonator impulse system designed for AS603 type testing, a solenoid valve is used and the supply pressure to the solenoid is the same as the desired plateau pressure. To start the waveform the solenoid valve is turned on, and goes to the fully open position until the end of the plateau pressure waveform timing and then completely closes. In a closed-loop system, a servovalve is used instead of a solenoid valve. The servovalve opening can be controlled precisely and varied in accordance with the difference between the desired pressure output and the actual pressure output.

In a closed-loop control system where the desired pressure rise times are less than twice the time it takes the servovalve to open, the orifice area when plotted versus time will resemble an inverted "V" as shown in Graph 1. In this graph the loop gain of the control system was set as high as possible without causing over-shoot of the pressure wave. The command signal is a step (square wave) 4500 psi input. The servovalve appears to open 0.0025 s after the command and the pressure begins to rise within a millisecond after that. At the start of the commanded rise, the orifice area will start increasing, and mid-way through the pressure rise it will start to close again. The supply pressure to the servovalve is usually at least 500 psi higher than the maximum desired pressure. When the desired pressure in the test volume is reached, the servovalve will once again be closed, trapping the added volume of fluid inside the test specimens. This sequence will be referred to later in this document when an example is presented with rough calculations for sizing the servovalve and related components. It is apparent from examining the valve area trace in Graph 1, that the valve dynamics play a significant role in the ability to meet pressure impulse rise times that are up to twice the time it takes to fully open the valve.



GRAPH 1 - CLOSED LOOP CONTROL WITH SHORT RISE TIMES

When the servovalve is used in a closed-loop control system where the rise times are more than twice as long as the time it takes the servovalve to open, the valve will open completely and stay in that position while the pressure increases and then it will begin to close again. In tests with this range of rise rates, the maximum flow rating of the servovalve becomes more important than the valve dynamics in determining rise rate. This is shown in Graph 2.



GRAPH 2 - CLOSED LOOP CONTROL WITH LONG RISE TIMES

Graphs 1 and 2 show that the servovalves need to be sized in terms of their maximum ratings as well as their response. This is true of other components as well. One purpose of this document is to help choose the components that will provide the specified parameters for a wide variety of test applications.

Table 1 shows an example of a 35 gpm HPS system with a variety of specimen volumes, typical component sizing and test system performance.

TABLE 1 - HYDRAULIC SYSTEM SIZING

Specimens			Test Specifications					Test System Sizing					
Qty	Type and size	Volume (cu in)	Spec	Peak Press (psi)	Temp (F)	Test Rate	Rise Rate (psi/sec)	Total HP volume (cu in)	Supply Press (psi)	SVV (qty & gpm)	SVV operation	Intensifier (HP/LP dia, ratio)	HPS Flow Flow (gpm)
12	AS5620-16 X .051 X 25"	190	AS603	4,500	amb	70 cpm	180,000	220	5,000	(1) 60 gpm	3-way	None	7
11	AS5620-16 X .065 X 25"	150	AS603	7,620	amb	70 cpm	180,000	190	3,000	(2) 60 gpm	3-way	4 X 7, 3:1	23
4	AS5951-16 X 23" hose	55	AS603	7,620	400	70 cpm	180,000	95	3,000	(2) 60 gpm	3-way	4 X 7, 3:1	23
2	AS5620-16 X .065 X 10"	0.5	AS4265	20,000	amb	14 Hz	820,000	10	3,000	(2) 60 gpm	3-way	1.75 X 5, 8:1	35
12	AS5620-16 X .065 X 10"	3.5	AS4265	20,000	amb	10 Hz	600,000	13	3,000	(2) 60 gpm	3-way	1.75 X 5, 8:1	35

Notes:

Hydraulic oil in the system is Mil-PRF-83282

Ambient temperature condition assumes the hydraulic oil is 100 F

AS603 test articles are AS5620 S-tubes and a similar length 90 degree hose for comparison purposes

AS4265 test specimens are supported by AS4298 internal stiffeners which fill their volume

Pressure accumulator is 2.5 gallons, return and intensifier center chamber accumulators are both 1 gallon

Servo valve has a 0.016 second step response

Intensifier stroke is 2 inches. Start position is .5 inches from the bottom and the stroke during impulse is between .4 and .7 in these cases

HPS flows include approximately 2 gpm leakage flows without intensifier and 6 gpm with intensifier

AS4265 cases are maximum speed as allowed by a 75 HP 35 GPM HPS resulting in the given frequency and rise rate

The hydraulic pressure in a typical impulse system runs at two levels, the pump output pressure (supply pressure), and peak impulse pressure at the test specimen which is controlled by the servovalve. The pump will typically run at a constant value between 2000 psi (minimum pressure for servovalve pilot stage in most impulse applications) and 5000 psi. This supply pressure should not vary more than a couple hundred psi or it will affect the operation. A large variation may be eliminated with the proper accumulator. See the "accumulator section" for more information on accumulator sizing. By maintaining a separate supply pressure to the servovalve pilot stage, the supply pressure to the servovalve final stage may be adjusted for the type of component that is being tested.

The pressure at the test specimens can run at radically different ranges to give a wide spectrum of test flexibility. The pressure at the test specimens can be varied from 100 psi (straight servovalve) to 20 000 psi (with an 8:1 intensifier). With the straight servovalve configuration, the pressure down stream of the pressure reducer (shown between the servovalve and the pump in Figure 2) can run as low as 100 psi for reservoir testing (ARP1383) or fuel system component testing. With the reducer set at the 1000 to 2000 psi range, aluminum hydraulic return lines can be tested with the AS603 wave form. With the HPS running at the 2000 psi range, 1500 to 2000 psi titanium return tubes can be tested with the AS603 wave form. With the HPS running at 5000 psi, all 3000 psi components can be tested at 4500 with the AS603 wave form. With an 8:1 intensifier in the system, test pressures up to 20 000 can be achieved for the AS4265 wave form. The components used in the impulse test systems must be sized with these pressures in mind.

The flow in the system also runs at two rates, the low steady state flow due to accumulator recharging and system leakage, and the peak flow due to the pressure impulse rise rate. The pump and lines leading to the pressure accumulator and the lines from the return accumulator back to the pump reservoir all run at the low speed flows. For the 35 gpm system sized in Table 1, the peak flows can be over 200 gpm across two servovalves in a parallel configuration. Impulse test system components must be sized with these flows in mind, because it is the peak flow capability that determines the performance of the system.

3.3 Fluid

The fluid in the system must be compatible with the type of testing that is being conducted. For high temperature testing, a high flash point fluid such as MIL-PRF-83282 should be used. For lower temperature testing a less expensive petroleum based fluid such as MIL-PRF-5606 may be used. Impulse testing of commercial aviation components with O-rings typically requires the use of a phosphate ester hydraulic fluid. Many other types of fluid are used and it is sometimes necessary to use a fluid separation device (see below) when the required test fluid can not be used in the HPS.

Each fluid has its own unique bulk modulus characteristics which affect the stiffness of the system and thus the test system demand. As the bulk modulus decreases, the system requires more flow to meet the same pressure waveform profile. The fluid bulk modulus changes with both temperature and pressure. The bulk modulus can change 50% between the pressure ranges required for AS603 and AS4265. The bulk modulus can change by a factor of 3 through the range of temperatures required for hose testing. When sizing a system, the fluid specifications, temperature and pressure ranges need to be taken into consideration.

Entrapped air dramatically affects the effective bulk modulus of the fluid and thus the system demand. The flow requirement to achieve a desired rise rate is directly proportional to the inverse of the effective bulk modulus. Provisions must be made to bleed the air out of the system. This may be accomplished by flushing all the passages with high velocity flows or by orienting all the hydraulic passages so that the air rises to a bleed port at the highest point. When hydraulic fluid is un-pressurized, the air that attaches to the fluid is called entrained air. After the test system is started and warmed up, the remainder of un-bled entrapped air and the entrained air is dissolved into solution and the system becomes slightly stiffer.

The effective bulk modulus is used to calculate the stiffness, hydraulic natural frequency and pressure in a closed volume. The formula for the effective bulk modulus (from Reference [2]) in psi is shown in Equation 1:

$$\beta_e = \frac{1}{\frac{1}{\beta_f} + \frac{V_g}{V_t} \left(\frac{1}{\beta_g} \right) + \sum \frac{V_c}{V_t} \left(\frac{1}{\beta_c} \right)} \quad (\text{Eq. 1})$$

where:

β_f is the fluid bulk modulus (psi)

β_g is the bulk modulus of the entrapped gas (psi) for air (this is 1.4 * Pressure)

β_c is the component (tube, hose, etc.) bulk modulus (psi)

V_g is the volume of gas in the system (cubic inches)

V_t is the total volume of the system (cubic inches)

V_c is the volume of the component in the system (cubic inches)

In the summation of the denominator in Equation 1, the bulk modulus of each component or tubing section, β_c , is multiplied by the ratio of that parts volume to the total volume, V_c / V_t .

The bulk modulus component equation for thin wall tubes or intensifier barrels is approximated (from Reference [2]) as shown in Equation 2:

$$\beta_{tn} = T * E / ID \quad (\text{Eq. 2})$$

where:

T = wall thickness (in)

E = modulus of elasticity (psi)

ID = inside diameter of the component (in)

The bulk modulus component equation for a hose can be approximated (from Reference [2]) as shown in Equation 3:

$$\beta_h = V_h * \Delta P / \Delta V_h \quad (\text{Eq. 3})$$

where:

V_h = volume of the hose (in³)

ΔP = the pressure range which will be applied to the hose (psi)

ΔV_h = hose volumetric expansion (typically supplied as volume per unit length)

3.4 Hose Bulk Modulus

Hose volumetric expansion is a non-linear relation with pressure. The understanding of this relationship may be extremely critical when designing a system for testing hoses. It is best to use the manufacturer's specifications to determine the exact value at the specific pressure where the hose is used or tested. If that data is not available, a simple test can be run by pressurizing the hose to the maximum pressure specified in the test, and bleeding off the pressure in increments into a measuring beaker. By recording the pressure increments and volume increments, the hose volume can then be plotted versus pressure and the volumetric expansion can be predicted for the specific pressure range. The bulk modulus of hoses varies significantly depending on size and pressure and is usually much lower than metal tubing.

3.5 Tubing Bulk Modulus

A 3000 psi system comprised only of metallic components and tubing, such as titanium or steel will be much stiffer than a system with hoses. A total effective bulk modulus around 100 000 psi can be used as a starting point, but this varies with temperature, pressure, test specimen compliance and the amount of entrapped air so it should be calculated for the specific application.

When determining an approximate value for effective bulk modulus it may be necessary to average the values between peak and low pressures, high and low fluid temperature, etc. The change in bulk modulus with variations in other parameters can be very significant.

3.6 Fluid Separation

There are impulse applications where specific fluids must be used to test the component properly. For example, phosphate ester fluid must be used for commercial airplane components with O-rings. Jet fuel or fuel substitute (such as, Stoddard solvent) may be required in fuel system component testing.

For testing with phosphate ester fluids, the entire impulse system can be made with phosphate ester compatible components. In that case, special attention must be paid to those seals installed inside of the industrial hydraulic components of the impulse machine. In some O-ring testing, compatibility with several different fluids is necessary and the O-ring must be tested with each fluid. In this case, the "three chamber" intensifier makes a good oil separation device. Fluid from the HPS to the bottom of the intensifier can be any mix of phosphate ester and the fluid in the top intensifier chamber up to the specimens can be the specific phosphate ester under test. The leakage across the high pressure intensifier seal will usually be insignificant so the integrity of the fluid under test will be preserved. The phosphate ester under test can then be removed and replaced with the next test fluid. If an intensifier is not necessary for the impulse machine, a 1:1 piston accumulator will accomplish the same fluid separation task. This must be sized with the principles given in the accumulator section.

For impulse testing of fuel system components with jet fuel or fuel substitute (Stoddard solvent), a hydraulic impulse system may also be used with a fluid separator. In this case, two actuators with mechanically coupled rods physically separate the hydraulic fluid from the fuel or solvent while providing visibility of leakage if the actuator seals fail. If this low pressure testing is accomplished with a multi-purpose high pressure impulse system, the actuator areas can be sized to provide a de-intensified ratio. For example, a 1:4 de-intensification ratio run at 1600 psi supply pressure will provide 400 psi to the test specimen.

3.7 Hydraulic Power Supply

The hydraulic power supply (HPS), commonly referred to as a hydraulic bench, provides the required pressure and flow of hydraulic fluid. It should be equipped with adequately sized oil filtration and cooling, high temperature and low reservoir shutoffs, current overload protection, and a fast pressure dump valve. In advanced test system designs, the hydraulic supply alerts the test failsafe system when it shuts down (in any HPS failure mode) activating all other failsafes in the system.

The hydraulic power supply needs to be sized with consideration for all system flows including flow due to peak impulse pressure at test frequency, leakage flows (for example servovalve and piloted valves which have continuous flows to tank) and recirculation flows (for test fluid temperature conditioning and intensifier recirculation).