Leakage Measurement Systems

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The measurement of very low flow rates i.e. leakage, is one of the most difficult tasks in fluid power component testing. Typically, the allowable leak rate is very low compared to the normal flow through the same ports. The wear and tear of production testing tends to degrade the sealing capabilities of the test rig which must be far better than the component under test. In some cases it is not physically possible to isolate the leakage path in question. The environmental factors such as temperature and fluid viscosity may overwhelm the observed measurement.

Several techniques for measuring leakage have evolved. All have some drawbacks and some special advantages but only a few are suitable in a production test environment. The most common method and the one requiring the least expensive equipment is to pressurize the required port(s) and either block or collect the leakage from all other ports of the component. The volume collected divided by the collection time gives the flow rate. There are several sources of inaccuracy in this method. First, the test conditions may not adequately simulate the operating conditions. Blocking some of the ports may alter the performance of the test unit. Generally, the reason for testing leakage in valves is to measure load holding ability and this is leakage into the valve. It is possible that the leakage in the application is worse if the inlet is pressurized but if this is done during the test, there may be a leakage path from the inlet to the collection port which would confound the test. The length of time required to stabilize the leakage rate may be unacceptably long if there are voids in the component which must be filled before the leakage appears outside the component. Perhaps most important, this test method is nearly impossible to automate and frequently degenerates into a visual test in which the operator assesses the stream of oil to determine acceptance. It is widely held that an experienced operator can quickly determine a leakage rate to a very high degree of accuracy. The author has conducted numerous double blind tests to determine the limits of this type of testing. The results do not agree with the common wisdom. An experienced operator develops a surprising degree of repeatability. What he calls 50 cc/min today will be very nearly the same rate as that which he calls 50 cc/min tomorrow. Unfortunately, it may be twice or half what his fellow operator on another shift calls 50 cc/min and neither may be very close to the actual rate. If the apparatus (which greatly influences the appearance of the flow stream) and the fluid properties are held constant, a thorough and frequently repeated training program can "calibrate" the operators sufficiently for good test results, but this is seldom done. At very low rates of flow, it is generally conceded that the fluid must be collected and measured. In these cases, the amount of oil which adheres to the measuring containers, the difficulty in handling extremely small containers and other factors make it necessary to collect the sample over a fairly long time.

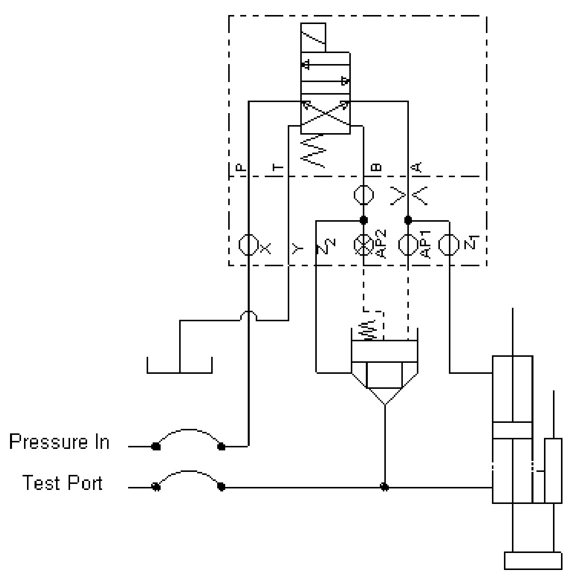
Environmental effects on this method are insidious. If the temperature of the component is lower than the incoming oil, there will be a reduction in the volume of oil after passing the leakage point which will result in a lower than actual leakage measurement.

Evaluating the leakage rate by measuring the loss of trapped pressure in a component is advocated by some instrument manufacturers. This method is generally very fast and is best applied to situations where essentially zero leakage is allowed. The accuracy of the measurement is highly dependent on fluid bulk modulus and requires very stable temperatures of fluid and component. The technique can be automated but it is necessary to calibrate such a system for every component to be tested as the results are dependent on the internal volume of the component under test.

The most widely used technique for precise leakage measurement is to connect one end of a hydraulic cylinder to the component under test and the other to a pressure source. If any fluid leaks from the unit under test, fluid enters from the cylinder to replace it, and the piston moves. The movement of the piston over a known time period is a measure of the leakage. The most common application, e.g. load holding, is accurately simulated and the method can be readily automated.

In the early attempts to automate this method, velocity transducers were connected to the rod of an ordinary hydraulic cylinder. This was not satisfactory because a velocity transducer with sufficient sensitivity to detect low leakages does not have sufficient range to cover the requirements of most testing situations. At very low leakage rates the velocity varies greatly and very long filtering periods are required. Velocity transducers also exhibit very poor electromagnetic interference characteristics. The use of a single rod cylinder results in a pressure amplification which prohibits pre-charging the test unit to full pressure. The resulting surge at the start of the test further taxes the filtering of the velocity signal. Finally, the instantaneous leakage rate is usually of very little interest; it is the average leakage that is important.

REN Corporation pioneered the use of double rod cylinders with precision linear displacement transducers in conjunction with the quartz crystal timing capabilities of the microprocessor to provide a wide ranging, very accurate leakage measuring system. To perform a leakage measurement, the cylinder is first forced to the head end. Pressure applied to the rod end during testing will accomplish this since the head end is vented to tank through the directional valve. This also pressurizes the test component to the desired pressure. The leakage flow is actually started at this time. The shutoff valve is closed and because it is a 2:1 ratio cartridge valve, the pressure on the top of the poppet provides excess sealing force for the leakage side of the valve. When the directional valve is shifted, the test pressure is applied to the cylinder. The only pressure differential across the piston is that required to overcome the drag of the seals and any leakage into the ports must be supplied by movement of the cylinder rod. There is no change in pressure when the cylinder is activated so there is little stroke required to reach test conditions.



The microprocessor is programmed to take position measurements of the cylinder rod and to determine the elapsed time since the last measurement. There is an inherent trade-off between high resolution and the time required for the test. The adaptive programming resolves this conflict. At the highest leakage rate, the cylinder will be allowed to use the entire available travel. If the elapsed time is large enough that the variations in the time fetch algorithm could not induce an error of more than 0.5%, the computed leakage is reported as a valid reading. If the time is too short, the overrange condition is raised. At lower leakage rates, the time becomes the limiting factor. A digital system can only resolve to one count, so if at the maximum allowed time, the cylinder has not at least 200 counts, the underrange condition is raised. The usable range is therefore a function of the cylinder dimensions, the transducer accuracy and the maximum interval allowed, but 1000:1 is easily achieved. It should be noted that in some applications it is necessary to place a restrictor and an accumulator is the supply line. The combination of this filtering with the natural damping of the cylinder will provide a ripple-free pressure to duplicate the holding of a static load.

In more than 50 system-years of experience, only one significant problem has shown up in this system. Since most of the components being tested show very little leakage, the piston operates mostly in a very small portion of the bore. As this area wears oversize, the seals expand into it and when a high leakage rate is encountered, the seals are sheared at the neckdown point of the bore. Although the wear rate has not been excessive, new models of the leakage system incorporate improved materials. The problem was serious not because of frequency of occurrence, but because if cross piston leakage occurs, this portion of the leakage into the component is not measured. This violates the first law of test equipment i.e. to always fail in the direction of increasing the producer's risk rather than the consumer's.

Recent development efforts have been directed toward simplifying the system and creating a standardized package for add-on applications to existing test facilities. These models incorporate all supporting hydraulic components into a manifold which also serves one of the cylinder caps. The circuit is simplified as shown in the adjacent drawing. The system is designed for 5000 PSI operation. The LVDT has been replaced by a digital measuring device which provides a tenfold improvement in resolution and eliminates the need for an analog to digital converter. This increases reliability and makes possible a significant reduction in price for the basic unit.
The size of the cylinder and rod were chosen to optimize the usable range for hydraulic valve testing. The maximum practical leakage measurement is dependent on the time required to stabilize the component, but in a typical application it is greater than 2500 cc/min. The minimum detectable leakage amount is .003 cc. If the criteria for a 0.5% uncertainty described above are applied to the system, the amount measured must be at least .5 cc. If the test is limited to 30 seconds, the minimum measurable flow would be 1 cc/min. The concept of underrange and overrange as it is used here is somewhat misleading. If the system is restricted to a 10 second test, and the computed leakage is 0.2 cc/min, the actual leakage observed by the system could have been no less than 0.18 nor more than 0.22 -- probably far less than the actual repeatability of the component under test but not within the stated 0.5% of measured value. In this situation the calculated value is displayed together with a warning that the data is outside the normal working range of the instrument. The same principle applies at the upper end of the scale where the theoretical maximum measured value is on the order of 25,000 cc/min.

Installation and operation of standalone leakage systems is simple. The basic system requires only that the measuring cylinder be mounted securely, and the pressure, return and test lines be connected. The system operates from 115 VAC electrical service and requires no special transformers. When the system is first turned on (or if the setup mode is selected for modification) the operator is prompted through all required data entry. If none of the optional features are used, the computer requires only that the maximum allowable test time be entered. Leakage measurements require only that the operator establish the required test conditions and then press a single button. A message appears showing that the test is in progress and when completed, the data appears on the display. If the measuring cylinder is not in position, a warning is displayed but if possible, a measurement is completed.

The system is essentially maintenance free with only regular cleaning of the digital transducer and periodic seal replacement needed to assure long life. The unit is factory calibrated and, requires no adjustments. Verification of Calibration is performed by testing first with the system blocked and with a known leakage device installed. In both cases, the results must meet the required accuracy specifications. The culmination of nearly 10 years of development and field experience, the REN 5100 series leakage measurement system is the most accurate and reliable method available for production testing of hydraulic components.