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Copy of Talk by F. V. Buckingham, FLH Corp.
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(2/13/53)

FLUID POWER SYSTEMS OF TESTING MACHINES

Hydraulically-operated testing machines have been in use for more than a century. The most notable machines on record are a 130 ton unit built in 1829 in Wales, a 1,000,000 lb. machine built in 1865 for a commercial testing laboratory in London, and a 1,000,000 lb. testing machine built in 1879 by the A. H. Emery Company for Watertown Arsenal. Most of the manufacturers, however, utilized a mechanical drive for most of their standard testing equipment, and not until during the last generation has the hydraulically-operated units reached their peak in popularity. Today hydraulically-operated testing machines hold the majority over the former nut-and-screw combination powered units. This, of course, accounts for my interest, as a testing machine engineer, in a society dealing with fluid power systems. I feel that an exchange of ideas and proper discussion will be of benefit to us all.

Fluid power units as used in testing machines are generally quieter in operation, more flexible in control, and more durable, with less maintenance than the former mechanical drives. However, they do have one disadvantage. It is difficult to maintain a constant deformation, because of leakage, without some elaborate controls.

Machines for the mechanical testing of materials usually contain elements for gripping the specimen, for deforming the specimen, and for measuring the load required in the performance of this deformation. In most general purpose testing machines, the deformation is controlled as the independent variable and the resulting load measured.

In order to understand the problems relating to a testing machine fluid power system, will you refer with me to a schematic arrangement of the machine as shown on Slide 1? You will notice that the cylinder and ram form a base for the machine. A work table is mounted on the top of the ram and rising from this table are a pair of columns connected at their top by a crosshead,

which we normally term a tension crosshead. Rising from the cylinder is another pair of columns which are connected at their top by another intermediate crosshead. This pair of columns are often made in the form of screws so that this crosshead may be positioned for various lengths of test specimens. You will notice that as pressure is applied to the underside of the ram, the tension crosshead, the table, and the ram will raise as a unit. Since the intermediate crosshead is a part of the fixed portion of the machine, a specimen placed between the table and intermediate crosshead will be compressed, and a specimen placed between the intermediate and top crosshead will be tensioned. In either test, the pressure in the cylinder may be transmitted to a precision gauge and this unit calibrated to read the load on the specimen directly in pounds. In this arrangement the cylinder and ram must be precision ground and lapped, and constructed without packing so that the inherent friction between these two units is held to a minimum.

Another form of this testing machine is shown in Slide 2. This scheme is used when we must meet a specification requiring that the load measuring system have no hydraulic connection with the load producing system. The upper portion of this machine is the same as the one in the previous sketch but the cylinder and ram may be built with a conventional stuffing box and packing. The cylinder head is formed by a hydraulic capsule. This hydraulic capsule is backed up by a lower crosshead to which the columns or screws carrying the intermediate crosshead are attached. These screws are then stayed to the cylinder with flexure plates so that they are restrained to move in a vertical plane only. The hydraulic capsule is a frictionless device containing a thin film of oil, sealed by a diaphragm. The reaction of the load on the specimen is picked up by this hydraulic capsule and the pressure then transmitted to the measuring device. You will notice that the friction of the

packing on the ram or between the ram and cylinder does not affect the weighing system. In each of these machines the load measurement is a function of hydraulic pressure. The main difference between the two schemes is in the method of indicating the load on the specimen; i.e., whether the weighing system is connected or not connected hydraulically with the load producing system.

As we mentioned before, in most of the fluid powered testing machines the load measuring system also becomes a hydraulic system. The instruments used for indicating this load on the specimen are of the precision Bourdon tube gauge type or a pendulum driven by a small cylinder and piston, or one of the more recent null-balance indicators having multiple ranges on the same dial. Any of these loading indicating systems may be used with either arrangement of the testing machine.

In the load producing system, sensitivity of control is of great importance. Other factors are range of loading speeds, constant discharge under varying pressures and freedom from loading pulsations. Controlling and discharge of the pump will permit an unbroken gradation of speed variations, from zero to maximum, and the maximum is entirely dependent on the capacity of the pump in relation to the ram diameter of the testing machine.

If we will refer now to Slide 3, we will review some of the typical circuit diagrams of fluid powered testing machines. In the early days, a motor driven fixed stroke pump was directly connected to the cylinder of the testing machine. A manually controlled by-pass valve bled the pump discharge to the tank. With this by-pass valve, the operator could apply loads to the specimen slowly or rapidly in increments or decrease the load on the specimen merely by opening or closing the orifice the proper amount. In the second

diagram a motorized variable discharge pump was connected to the cylinder and, as before, a by-pass valve provided. A main control wheel was provided for displacing the crosshead of the multiple piston pump and thereby varying the flow from the pump and the application of load to the specimen. In some cases, a cam of uniform lift per unit of rotation was used to stroke the pump. In both instances, the use of the by-pass valve added some refinement to the control of the ram speed. In each of these cases, an operator had to become very adept in the manipulation of these valves or pump stroking devices, in order to follow uniformly the deformation of the specimen. A difficulty arose from the fact that there was a minute amount of oil leakage in the pumps directly proportional to the pressure. This amounted to only four or five per cent of full discharge or less and ordinarily could be neglected, except that in testing machine work extremely slow speeds of ram movement are required, such as down to possibly $1/100$ inches per minute, which called for an almost infinitely small discharge from the pump. Consequently 4% of discharge capacity looked up as a large loss and at some pressure in the test the effective discharge from the pump became zero. This was overcome, of course, by manual adjustment of the by-pass control or pump control but this was soon changed by the development of automatic adjusting control devices.

The diagrams then changed to those appearing on Slide 4. These are the circuit diagrams of most of the fluid powered testing machines produced in the United States today. In one case, the flow from a constant volume pump passes through an adjustable orifice to the cylinder. Inserted in this system is a compensating valve operated by differential pressures and dependent upon the setting of the adjustable orifice. Whenever the balance becomes disturbed by leakage in the pump, the compensating valve operates automatically to maintain

this differential pressure across the orifice, and allowing the excess discharge to return to the oil reservoir. Some of the testing machine manufacturers designed and built their own particular version of this compensating valve and in these cases the compensating valve and needle valve are two separate units. Other manufacturers, however, use commercially available flow control units as built by Vickers, Incorporated, Double A Products, or Racine.

In addition to these controls our company developed the diaphragm type of control for application to a variable discharge radial piston pump as manufactured by American Engineering Company or the Northern Ordnance Company. This control is mounted on the side of the pump and connects directly with the sliding ring in which the pistons of the pump rotate. This is also a differential pressure device controlled by the position of an adjustable orifice, but we increase or decrease the discharge from the pump by changing the stroke of the pump directly, in order to maintain this differential across the orifice. With these systems, constant discharge under varying pressure is automatically maintained without hunting or any visible adjusting effects which might otherwise disturb the smooth course of load application. In our circuit a control valve is built with a needle stem in the main valve stem. The needle valve is then used for low speed ranges and the main valve stem for higher speed ranges. The needle valve is very useful for setting testing speeds and the main valve for positioning speeds or for speeding up the machine after the yield point has been reached. The two speeds are additive, one upon the other.

In addition to this speed control valve, the by-pass valve is still used as in the circuits shown previously, and this valve adds a large measure of flexibility to the machine. The by-pass valve can be used for releasing the

cylinder pressure to bring the ram back to its starting point, or can be used as explained before, to raise or lower the loads at the will of the operator. The speed of these operations depends upon the speed control valve setting. Oscillating or repeated loadings can be applied manually with this by-pass. In fact, surprising flexibility of load application can be thus obtained by proper manipulation of this valve.

Loads can be brought up to any desired point and held there for a reasonable length of time, either by the use of the flow control or speed control valve, gradually closing it to a cut-out position or else by use of the by-pass valve. Any setting of the by-pass also gives a balanced hydraulic system of some pressure whereby just enough oil is pumped into the cylinder to maintain that pressure, the remainder wasting to the reservoir. This will maintain itself until the oil viscosity changes due to the heat of the oil when it will take some lower position. It should be noted that as long as the by-pass is opening or closing, load will rise or fall, but when the by-pass is closed, the flow remains fixed and the ram will follow deformation of the specimen.

The arrangement of these valves and compensating devices in the circuit together give a remarkable degree of flexibility, permitting the machine operator to manipulate the load on his specimen with a high degree of sensitivity.

An automatic by-pass release valve completes the control system. This may be set to automatically discharge when the pressure reaches any desired point but ordinarily serves as a safeguard against involuntary overloading.

In the larger capacity testing machines used for testing complete structures or large scale components, the arrangement is slightly different, as shown in Slide 5. The work table forms the bed of the machine, with the

cylinder and ram mounted below the bed in a pit. The downward movement of the cylinder pulls the intermediate crosshead with it, thereby apply loads to the specimens as before. However, with this scheme a pull-back cylinder is necessary in order to return the main ~~ram~~^{cylinder} to its starting position. In these machines, large structural or cast side housings stand vertically from the table to carry the tension crosshead at the top and to give added stability to the sensitive crosshead. In this arrangement the load weighing capsule is mounted on the underside of the sensitive crosshead and a loading yoke surrounds the complete assembly.

A typical circuit diagram of one of these larger machines is shown on Slide 6. A reversing variable discharge pump is used which is stroked manually by a handwheel. The speed of testing is controlled by varying the stroke of the pump or by a manipulation of the by-pass valve, or a combination of the two controls. The direction of the machine movement is changed by reversing the flow from the pump. A foot valve must of necessity be added to the circuit in the pull-back line in order to support the weight of the moving parts.

These, then, are the general hydraulic circuits used today for most of the general purpose testing machines. I hope that you have noticed that all of these circuits are very elementary, but with this very simple arrangement, we are able to produce amazing sensitivity of control.

Of course, there is always the exception to the rule. Starting with these simple circuits and with the addition of solenoid or pilot operated valves, timers, relays, etc., testing machines have been built for fatiguing materials by applying alternating loads. The reversing of the load has been controlled by either the load on the specimen or the deformation of the specimen. Machines have been manufactured with either manual or automatic

programming control, whereby the specimen is loaded at pre-selected speeds and at pre-determined intervals during a cycle; the ram being automatically returned to its starting position upon failure of the specimen.

Fluid power has become the major drive for most types of material testing machines and we believe it will continue to hold that position. As hydraulic components are improved or new ones developed, the over-all system will naturally improve to the point where the few disadvantages of the present hydraulic systems will be reduced greatly or eliminated entirely.

Comments on Paper by F. S. Buckingham - 2/18/53

I - General

- A - Mr. Buckingham covered subject well.
- B - Cut away drawing of Navy's large machine available for inspection.
- C - Audience has seen diagrams, now some slides of actual equipment.
- D - Note about repeat load machine not shown in slides.

II - Specific Comments

- A - Advantageous items
 - 1 - Hydraulic backlash eliminator on big machine is noteworthy accessory.
 - 2 - Crosshead motion more linear with hydraulic than with screws (at least on big machines with screws stabilized).
- B - Disadvantageous items - some over come on small machines but not attacked yet on large machines
 - 1 - Large machines - no automatic compensators for losses with pressure, so more dependency on operator skill.
 - 2 - Large machines, control with load below dead weight of loading frame difficult
 - a. Increasing load and holding load constant; leakage always present from pullbacks (because of pressure from loading frame dead weight they hold up) through foot valve, packing, etc. Thus hard to keep load from moving up faster than desired when loading or from moving up when holding constant.
 - b. Decreasing load - Decrease through use of bypass stops when load equals frame dead weight and main cylinder pressure is zero. Then pullbacks are required for further decrease.
 - c. Result - below dead weight, control difficult. Must go back and forth between main and pullback cylinders. Each takes long time to get operating, and has very delicate control at such small loads, so tendency is to overcontrol without sufficient reversal speed on control response to stop overcontrol in desired time.
 - 3 - Large machines, load maintainers (which bleed from main cylinder) are ineffective below dead weight of loading frame. Also in Navy's case, speed of maintainer too slow.
 - 4 - Large machines, deformation rates possible are good but time to accelerate to desired high rate quite long and the rate desired cannot be predetermined by control setting but must be gotten by pacing. Result - test may be over before desired rate is obtained.
 - 5 - Large machines, no safety devices in case of loss of pull-back pressure.

III - Future needs other than overcome specific criticisms above are - mainly increased speed and control

- A - General - In aircraft work two main structural problems arising are aerodynamic heating and fatigue.
 - 1 - Fatigue - Repeat load machine being speeded up. Static machines, adaptation to fatigue advantageous. Requires faster loading speeds on large machines, load reversing devices, more sensitive deflection reversing devices than those now built. Built in limit of static machines, - cannot cycle thru tension-compression.

- 2 - Heat - Either constant load on rapidly deflecting specimen and/or rapidly varying well controlled load required to coordinate with heat application. Both primarily control problems.
- B - Specific - Adapt existing machines as much as possible cheaply as possible for these purposes by changing components of hydraulic systems.
- 1 - Quicker response to controls, perhaps higher maximum speeds of deformation.
 - 2 - Programming to have machine automatically move at pre-determined rate, or to be able to control rate to coordinate with another measurement - such as temperature.
 - 3 - Constant load devices for rapidly deforming specimens.
 - 4 - Reversing devices for fatigue - both deflection and load reversing.
 - 5 - Response and accuracy of indicating systems with increased speeds may be a problem so changes may be necessary.
 - 6 - Many of these changes will be competing cost and performance wise with hydraulic jacks used in jigs setup on a test floor. Also if testing machines are to compete there is a widespread idea to be overcome that machines are not adaptable for the rapid and fatigue type of testing contemplated and being started.

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