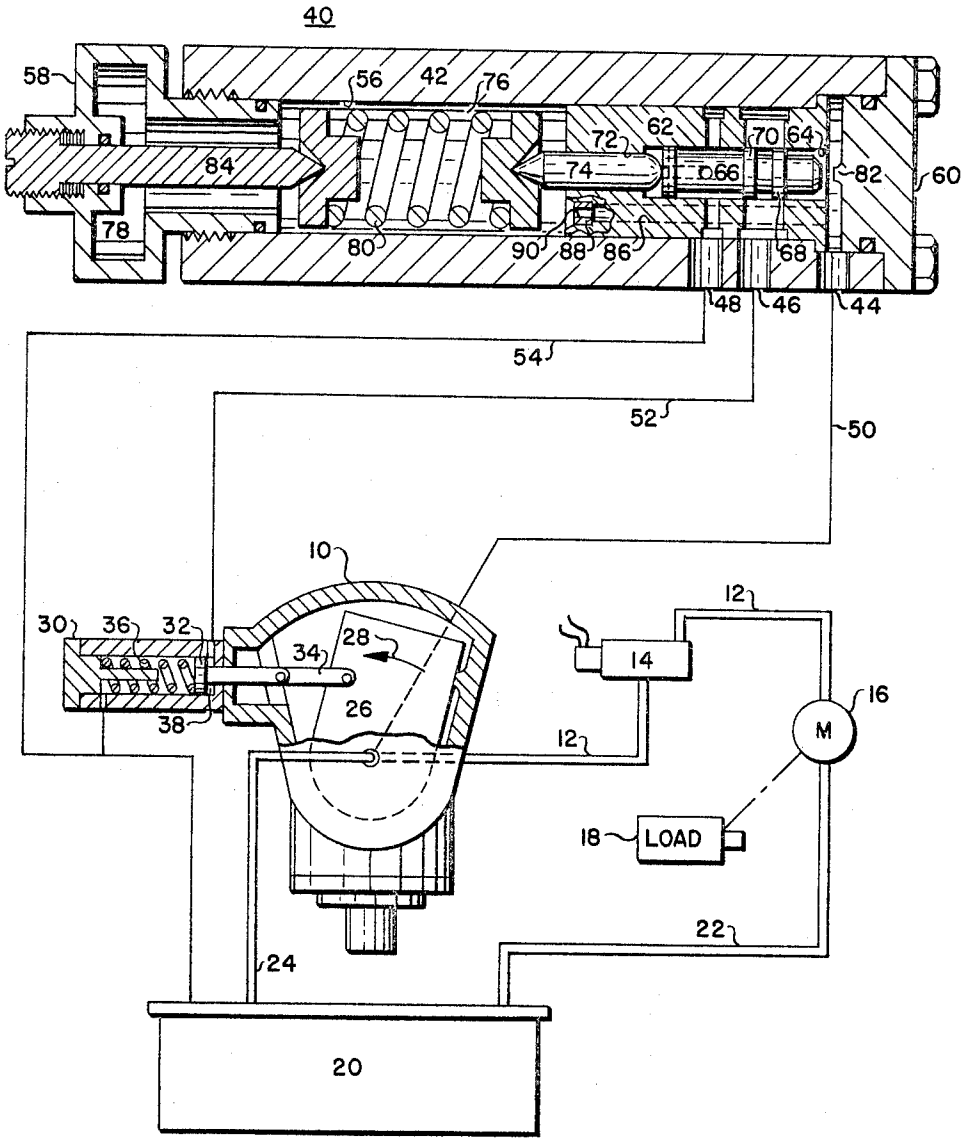
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POWER TRANSMISSION

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POWER TRANSMISSION

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This invention relates to power transmissions, and more particularly to those of the type comprising two or more fluid pressure energy translating devices, one of which may function as a pump and another as a fluid motor.

The invention particularly relates to such a transmission employing a pressure compensated variable displacement pump, the pump displacement being reduced in response to an increase in outlet pressure.

The conventional pressure compensating control includes a simple pilot valve having a pressure effective area on which pump outlet pressure is imposed to act in opposition to a biasing spring, the force of which spring establishes the point at which pump displacement reduction begins. Such a conventional control is shown in U.S. Patent No. 2,834,297 to Postel et al., FIGURE 9. Since the conventional compensator employs only proportional feedback of pump outlet pressure, stability of control is not adequate for more demanding applications.

It is, therefore, an object of the present invention to provide an improved control for a pressure compensated pump, in which overshoot and transient fluctuations in pump displacement and outlet pressure are minimized.

It is a further object of this invention to provide such a control having improved stability without impairment of response time and without appreciable increase in size and weight as compared to the conventional compensator.

Further objects and advantages of the present invention will be apparent from the following description, reference being had to the accompanying drawing wherein a preferred form of the present invention is clearly shown.

In the drawing:

The single figure is a diagrammatic view of a power transmission system incorporating a preferred form of the present invention.

Referring now to the drawing, the hydraulic transmission comprises a variable displacement pump **10** having its outlet connected through a pressure conduit **12** to a control valve **14** and a fluid motor **16** driving a load **18**. Exhaust fluid from motor **16** is returned to a reservoir **20** through a low pressure conduit **22**. The inlet of pump **10** is supplied with fluid from reservoir **20** through a conduit **24**.

Pump **10** is of the well-known swinging yoke type which is shown in detail in the aforementioned Postel, et al. patent and is therefore merely schematically represented in the drawing. The displacement of pump **10** is varied by varying the position of yoke **26**. With yoke **26** in the position shown, pump displacement will be at its maximum. Swinging yoke **26** in the direction of arrow **28** will reduce pump displacement.

An actuator **30** is provided for the yoke **26** and comprises a control piston **32** connected to yoke **26** by linkage **34**, piston **32** being biased by a spring **36** so as to induce maximum pump displacement. It will be seen that pressure in chamber **38** will act on piston **32** in opposition to spring **36** and induce reduced pump displacement.

The pressure compensating control valve generally designated **40** includes a body **42** having three ports **44**, **46** and **48** therein. These ports are connected respectively by lines **50**, **52** and **54** to the pump outlet, the control piston chamber **38** and reservoir **20**. Lines **50**, **52** and **54** schematically indicate connections which would normally be effected by passages within the pump housing

terminating in a mounting pad upon which valve body **42** would be mounted, in the same manner as shown in FIGURE 9 of Postel et. al.

The body **42** of valve **40** includes a central bore **56** closed at one end by a plug **58** and at the other by a cover **60**. A sleeve **62** is inserted in bore **56** and contains a valve bore **64** in which a valve spool **66** is slidably inserted. Spool **66** carries a first land **68** which controls communication between ports **44** and **46**, and a second land **70** which controls communication between ports **46** and **48**.

A bore **72** extends through the end of sleeve **62** and slidably receives a sensing spool **74** which projects into chamber **76**. Chamber **76** is formed in part by the bore **56** and in part by a cavity **78** in the plug **58**. Sensing spool **74** has a smaller diameter than valve spool **66**. A spring **80** normally urges the sensing spool **74** into abutment with the valve spool **66** which in turn abuts stop **82** on cover **60**. In the normal, spring biased position of valve spool **66**, the land **68** isolates port **44** from port **46**, while the land **70** permits communication between ports **46** and **48**. The biasing force imposed by spring **80** can be adjusted through the support rod **84**, and the volume of chamber **76** can be adjusted by threading the plug **58** further into or out of body **42**. If even greater volume is desired for chamber **76**, a plug similar to plug **58** but having a larger cavity **78** can be substituted.

Sleeve **62** includes a drilled passage **86** extending in an axial direction from end to end, in which is inserted a plug **88** having a sharp-edged orifice **90** therein. Prior to operation of the system, the chamber **76** is filled with the same hydraulic fluid used in the pumping system, which fluid will have a bulk modulus (B) which may be expressed in terms of pounds per square inch.

The volume of chamber **76** may be expressed in terms of cubic inches and is hereinafter referred to as V_0. The right-hand-end projected area of spool **66**, which is exposed to pump outlet pressure, may be expressed in square inches and is hereinafter referred to as A_e. The projected area of sensing spool **74** exposed to pressure in a chamber **76** may be expressed in square inches will be referred to as A_k. The rate of spring **80** expressed in pounds per inch will be referred to as K_s.

It will be seen that with a slowly increasing pump outlet pressure a point will be reached at which outlet pressure acting on area A_e will overcome the force of spring **80** plus pressure in chamber **76** acting on the smaller A_k, causing spool **66** to shift so that land **68** will permit communication between ports **44** and **46**, thus porting high pressure fluid to the chamber **38** to cause reduction in displacement of pump **10**. In the case of a slow increase or decrease in pump outlet pressure the restrictive effect of orifice **90** and the compressibility of the volume of fluid V_0 will not be significant factors and operation of the control will be very similar to a standard compensating control of the type shown in Postel, et. al., in which the effective feedback is proportional only to pump outlet pressure.

However, in the case of step changes in pump outlet pressure or high frequency signal modulation from the control valve **14** the conventional pressure compensator induces overshoot and a gradually decaying hunting condition before stabilization is finally achieved. In systems demanding a high degree of compliance and rapid response the standard compensator has been found inadequate. The present invention provides greatly increased stability and reduces both pressure overshoot and response time by producing a leading feedback relative to pump outlet pressure at oscillation frequencies. The lead circuit comprises the compressible volume V_0, sensing spool area A_k and orifice **90**.

The formula:

$$\frac{\frac{A_e}{A_e-A_k}}{1+\frac{A_k^2B}{K_sV_0}}=\phi$$

is a dimensionless measure of the leading phase angle of feedback (ϕ) to be obtained from a given set of parameters. It has been found that a ϕ of approximately 2.0 is sufficient to provide adequate stabilization for most applications. However, ϕ values in the range of 1.5 to 5.0 have been employed effectively in particular circuits. A large ϕ not only increases the maximum obtainable leading phase angle, but the leading phase angle is provided over a larger frequency range. It will be seen that a fine adjustment of ϕ can be obtained by threading plug 58 farther in or out of the body 42 and thus varying the quantity V_0.

In a particular compensator, components and a fluid having the following parameters were employed.

$$A_e=0.0491 \text{ in.}^2$$
$$A_k=0.0371 \text{ in.}^2$$
$$B=2\times10^5 \text{ lb./in.}^2$$
$$K_s=333 \text{ lb./in.}$$
$$V_0=1.0 \text{ in.}^3$$

resulting in a ϕ value of 2.21.

V_0 volumes in the range from .75 to 3.0 cubic inches have been found to be effective and are recommended although it should be noted that it is the relation between the various parameters that is of primary importance, rather than the absolute value of any one parameter.

The optimum diameter of orifice 90 is to some extent a function of particular pump characteristics, and the volume of working oil under compression in communication with the pump outlet. This volume will vary in different applications and the proper orifice size may best be determined by experimentation. In general, the larger the volume under compression, the smaller the orifice size.

In testing the particular compensator whose parameters are set forth above, it was found that sizes of orifice 90 in the range from .010 to .050 inch in diameter were effective. On a specific pump, an orifice of .0125 inch in diameter was optimum for a volume of 20 cubic inches under compression. On the same pump, an orifice of .010 inch in diameter was optimum for 80 and more cubic inches under compression. On another pump, an orifice diameter of .015 inch was optimum for 80 cubic inches under compression and .010 inch was optimum for 300 and more cubic inches under compression.

Pressure compensators incorporating the present invention have been directly substituted for conventional pressure compensators in a number of hydraulic systems with remarkable improvements in compliance and in response and stabilization times. It will thus be seen that the present invention has provided an improved pressure compensating control for variable displacement pumps.

While the form of embodiment of the invention as herein disclosed constitutes a preferred form, it is to be understood that other forms might be adopted, all coming within the scope of the claims which follow.

What is claimed is as follows:

1. In a hydraulic power transmission employing a variable displacement pump having an outlet connected by a pressure conduit to a load, and actuator means for varying the displacement of said pump, control means for said actuator comprising: shiftable valve means for directing fluid to said actuator; resilient means biasing said valve means in one direction; means forming a first area associated with said valve means and exposed to pressure from the outlet of said pump so as to urge said valve in a direction opposite to said one direction; means forming a second area, smaller than said first area, associated with said valve means so as to urge said valve in said one direction in response to pressure thereon; means forming an enclosed chamber, pressure in which is imposed on said second area; continuously open passage means extending between said first area and said chamber and forming the sole means of egress for fluid from said chamber; and a restriction in said passage means.

2. In a hydraulic power transmission employing a variable displacement pump having an outlet connected by a pressure conduit to a load, and actuator means for varying the displacement of said pump, control means for said actuator comprising: shiftable valve means for directing fluid to said actuator; resilient means biasing said valve means in one direction; means forming a first area associated with said valve means and exposed to pressure from the outlet of said pump so as to urge said valve in a direction opposite to said one direction; means forming a second area, smaller than said first area, associated with said valve means so as to urge said valve in said one direction in response to pressure thereon; means forming an enclosed chamber, pressure in which is imposed on said second area; continuously open means for adjusting the size of said chamber; passage means extending between said first area and said chamber and forming the sole means of egress for fluid from said chamber; and a restriction in said passage means.

3. In a hydraulic power transmission employing a variable displacement pump for pumping a fluid having a bulk modulus B and having an outlet connected by a pressure conduit to a load, and actuator means for varying the displacement of said pump, control means for said actuator comprising: shiftable valve means for directing fluid to said actuator; resilient means having a spring rate of K_s biasing said valve means in one direction; means forming a first area (A_e) associated with said valve means and exposed to pressure from the outlet of said pump so as to urge said valve in a direction opposite to said one direction; means forming a second area (A_k), smaller than said first area, associated with said valve means so as to urge said valve in said one direction in response to pressure thereon; means forming an enclosed chamber having a volume V_0, pressure in which is imposed on said second area; continuously open passage means extending between said first area and said chamber and forming the sole means of egress for fluid from said chamber, the aforementioned parameters being so related that

$$\frac{A_e}{A_e-A_k} \text{ divided by } 1+\frac{A_k^2B}{K_sV_0}$$

is 1.5 or greater; and a restriction in said passage means.

4. In a hydraulic power transmission employing a variable displacement pump for pumping a fluid having a bulk modulus B and having an outlet connected by a pressure conduit to a load, and actuator means for varying the displacement of said pump, control means for said actuator comprising: shiftable valve means for directing fluid to said actuator; resilient means having a spring rate of K_s biasing said valve means in one direction; means forming a first area (A_e) associated with said valve means and exposed to pressure from the outlet of said pump so as to urge said valve in a direction opposite to said one direction; means forming a second area (A_k), smaller than said first area, associated with said valve means so as to urge said valve in said one direction in response to pressure thereon; means forming an enclosed chamber having a volume V_0, pressure in which is imposed on said second area; continuously open passage means extending between said first area and said chamber and forming the sole means of egress for fluid from said chamber, the aforementioned parameters being so related that

$$\frac{A_e}{A_e-A_k} \text{ divided by } 1+\frac{A_k^2B}{K_sV_0}$$

is 1.5 or greater; and a restriction in said passage means,

said restriction comprising a sharp-edged orifice having a diameter in the range from .010 to .050 inch.

5. In a hydraulic power transmission employing a variable displacement pump for pumping a fluid having a bulk modulus B and having an outlet connected by a pressure conduit to a load, and actuator means for varying the displacement of said pump, control means for said actuator comprising: shiftable valve means for directing fluid to said actuator; resilient means having a spring rate of K_s biasing said valve means in one direction; means forming a first area (A_e) associated with said valve means and exposed to pressure from the outlet of said pump so as to urge said valve in a direction opposite to said one direction; means forming a second area (A_k), smaller than said first area, associated with said valve means so as to urge said valve in said one direction in response to pressure thereon; means forming an enclosed chamber having a volume V_0 in the range from .75 to 3.0 cubic inches, pressure in which is imposed on said second area; continuously open passage means extending between said first area and said chamber and forming the sole means of egress for fluid from said chamber, the aforementioned parameters being so related that

$$\frac{A_e}{A_e - A_k} \text{ divided by } 1 + \frac{A_k^2 B}{K_s V_0}$$

is 1.5 or greater; and a restriction in said passage means.

6. In a hydraulic power transmission employing a variable displacement pump for pumping a fluid having a bulk modulus B and having an outlet connected by a pressure conduit to a load, and actuator means for varying the displacement of said pump, control means for said actuator comprising: shiftable valve means for directing fluid to said actuator; resilient means having a spring rate of K_s biasing said valve means in one direction; means forming a first area (A_e) associated with said

valve means and exposed to pressure from the outlet of said pump so as to urge said valve in a direction opposite to said one direction; means forming a second area (A_k), smaller than said first area, associated with said valve means so as to urge said valve in said one direction in response to pressure thereon; means forming an enclosed chamber having a volume V_0 in the range from .75 to 3.0 cubic inches, pressure in which is imposed on said second area; continuously open passage means extending between said first area and said chamber and forming the sole means of egress for fluid from said chamber, the aforementioned parameters being so related that

$$\frac{A_e}{A_e - A_k} \text{ divided by } 1 + \frac{A_k^2 B}{K_s V_0}$$

is 1.5 or greater; and a restriction in said passage means, said restriction comprising a sharp-edged orifice having a diameter in the range from .010 to .050 inch.

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