Intelligent Magneto-Rheological Fluid Directional Control Valve

Maher Yahya Salloom

***Abstract*—There are many configurations of directional control valve. Directional control valve has complex construction, such as moving spool to control the direction of actuator and desired speed. Magneto-rheological (MR) fluid is one of controllable fluids. Utilizing the MR fluid properties, direct interface can be realized between magnetic field and fluid power without the need for moving parts like spool in directional control valves. This paper presents the design of multi configuration MR directional control valve. The construction and the principle of work of the valve are presented. The experiment was conducted to show the working principle of the valve functionally. The valve worked proportionally to control the direction and speed of hydraulic actuator. The result demonstrated the operation of MR directional valve in eight configurations. The MR directional valve can replace many types of the spool directional control valve for controlling hydraulic actuator.**

***Index Terms*—Magneto-rheological fluid, controllable fluid, MR directional control valve, MR valve design, smart material.**

I. Introduction

Magneto-rheological (MR) fluid is smart material which is composed of micro-sized magnetic particles suspended in hydrocarbon oil. The rheological properties of MR fluid can be fast and reversibly altered when an external magnetic field is applied. The suspended particles in the MR fluid become magnetized and align themselves like chains along the direction of the magnetic field. The formulation of these particle chains restricts the movement of the MR fluid, thereby increasing the yield stress of the fluids.

MR fluid is controllable fluid. MR fluid has received a great deal of attention over the past ten years, because it offers the promise in relation to valve with no moving parts, low-cost directional control valves, and miniature size. MR fluid can be interfaced between magnetic field and fluid power without the need for mechanical moving parts like spool in directional control valves.

Designs that take advantage of controllable fluids are potentially simpler and more reliable than conventional electromechanical devices. In addition, the MR fluid is one of the most efficient means to interface mechanical components along with electronic controls, offering fast speed switching and continuous variable control [1].

Some researchers did connect a set of MR valves in order to make it more useful. Yoo and Wereley [2], Yoo *et al*. [3] and Shaju *et al*. [4] have arranged a set of four MR valves implemented as Wheatstone bridge hydraulic power circuits to drive a hydraulic actuator using a gear pump as hydraulic power source. The performance of hydraulic system with MR valve is dependent on output load and driving current to MR valve.

Recently, the MR directional control valve was designed with absence of moving parts using the rheological property of MR fluid. The compact new design has been developed by Salloom and Samad [5]. They have proposed combining a set of single MR valves thus becoming a compact unit in order to simplify the design and manufacturability. They have presented the construction and the principle of work of MR directional control valve. Thus, the main objective of this paper is to present the possibility configurations of the newly designed MR directional control valve.

II. Design of MR Directional Valve and Its Working

Hydraulic valves have complex construction and moving parts, thus the characteristics and life of hydraulic proportional directional control valves are affected greatly by moving parts as shown in Fig. 1.

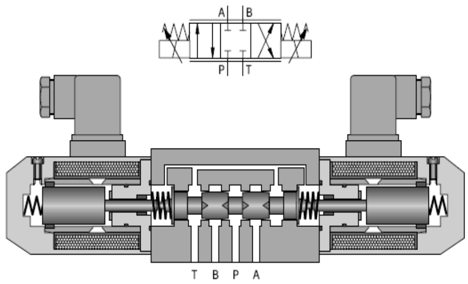

Fig. 1. Hydraulic (4/3) directional control valve.

Using the rheological property of MR fluid, the new type of MR flow directional hydraulic control valve can be designed with the absence of moving parts.

MR directional valve design is compact and easily installed in hydraulic systems along with the other hydraulic components. It consists of the following main parts: four single MR valve bodies, three insert partitions two covers and. Single MR valve was designed by Salloom and Samad [6]. The construction of single MR valve is shown in Fig. 2.

Four single MR valves (elements) is equips inside the valve body which were arranged one after another to make the desire configuration type as shown in Fig. 2. The input/ output ports were threaded by 1/8 Inch BSP thread, so that standard pipe fittings can be connected easily to them. The terminals of the coil can be easily fed to the hole available in the body.

When the coil of single MR valve is energized with DC current, the magnetic field is induced in MR valve. In the presence of magnetic field, the single MR valve can control

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the fluid flow by controlling the strength of the magnetic field. Magnetic field is controlled by adjusting the current control. Maximum current means maximum magnetic field which closes the MR valve, and vice versa. In the absence of magnetic field, MR valve is fully open.

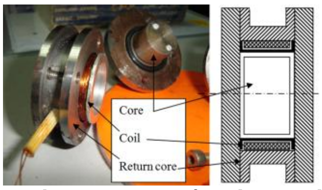


Fig. 2. The construction of single MR valve.

Referring to Fig. 3, the general configuration MR directional valve consists of four adjacent single MR valves a, b, c, d. In the null position (closed configuration), coil of all single valves are energized with maximum current. In extended position of MR directional valve, the coils of two single MR valves (a and c) are energized with maximum current, while the coils of two other single MR valves (b and d) are set at low current (0- maximum designed current). Under this condition, the flow of MR fluid pass through port **P** to port **A** and returns through port **B** to port **T**, hence, moving the actuator extended. In retracted position of valve, the coils of two other single MR valves (**b** and **d)** are energized with maximum current, while the coils of two single MR valves (**a** and **c)** are set at low current (0- maximum designed current). Under this condition, the flow of MR fluid pass through port **P** to port **B** and returns through port **A** to port **T**, hence, moving the actuator retracted. The coils of MR directional valve can be connected with particular electrical circuit using many ways. These connections give different types of operation to the MR directional valve [7].

The new type MR flow-directional hydraulic control valve can be designed with absence of moving parts. The construction and working principle of the new type valve will be introduced. Next work, the new type valve will be used to replace a three position four-way (4/3) directional control valve with various center positions. Using an arrangement similar to the Wheatstone bridge circuit concept, the hydraulic system will be shown in Fig. 3 and Fig. 4. The speed and position control for hydraulic actuator will be studied, by using the proposed flow-directional hydraulic control valve.

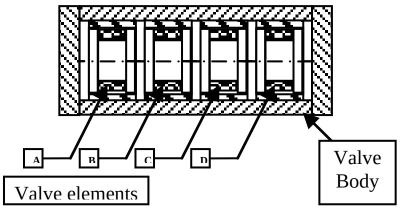


Fig. 3. Basic drawing of MR directional control valve.

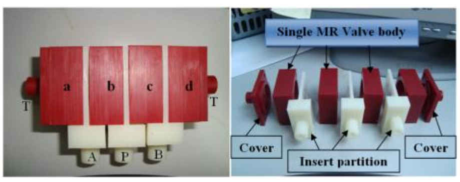


Fig. 4. The construction of MR directional control valve.

III. The Experiment

An experiment to test 4/3 MR valve has been performed. In fact, the purpose of the test is to confirm the functional principle of work. Arrangement and setup of the overall hydraulic control circuit for valve test is shown in Fig. 5. The experimental rig includes hydraulic cylinder, MR fluid tank, MR valve, DC power supply, particular electric circuit, and all necessary instruments such as pressure gage as shown in Fig. 6. The variable current is achieved using the rheostat connected in series with the valve's coil.

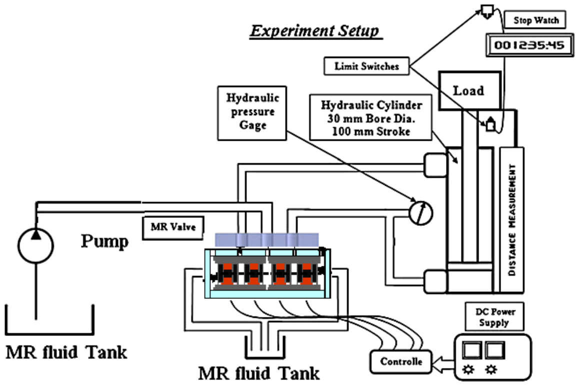


Fig. 5. Hydraulic control circuit for valve test.

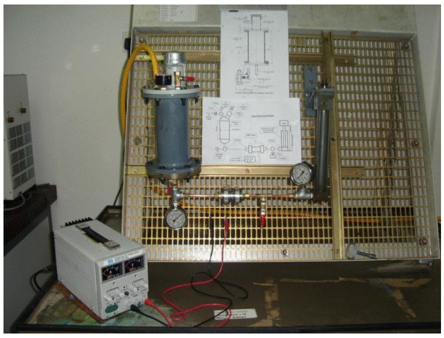


Fig. 6. The test rig.

The experiment test shows the working principle of the valve and how to change the direction using the proposed electrical circuit. The valve can be used to replace a four way three position (4/3) directional control valve. The experiment test was done according to the procedure explained by Salloom and Samad [8].

IV. Results and Discussion

As a result, there are eight configurations, fully closed, only pressure port closed, only return port closed, only port A closed, only port B closed and fully open, (see Table I). The flow of the MR fluid depends on which type of configuration chosen. Fully closed configuration is when all ports of MR directional valve are closed, while fully open configuration is when all ports of MR directional valve are opened. Other configuration one port is closed, while three other ports are open. The valve can be operated not only as an ON-OFF directional control valve, but also as a proportional directional control valve. Thus, the valve can also be utilized to control the speed of hydraulic actuator.

Regarding experimental results of MR directional valve operation with actuator can be discussed the following: when the valve is used as ON-OFF, it can change the directions of moving actuator but with maximum break pressure 12 bar that is limited by high current (e.g. 1.5A) . When the valve is used as proportional control, it can change direction and speed of actuator using different level of current (0.08 to 0.5 A) for break pressure 12.7 bar.

TABLE I: CONFIGURATIONS FOR MR DIRECTIONAL VALVE (ON-OFF OPERATION)

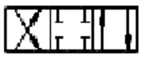
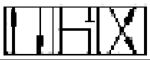
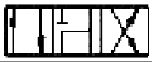
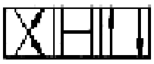
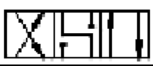
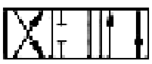
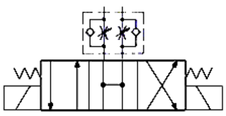
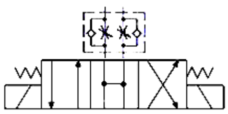
Configurations	Coil operation (1= Null, 2= Extended and 3= Retract)
	1. Coils **a,b,c** and **d** ON at max.current 2. Coils **b** and **d** ON at max.current **a** and **c** OFF (no current) 3. Coils **a** and **c** ON max.current **b** and **d** OFF (no current)
	1. Coils **b** and **c** ON at max.current **a** and **d** OFF (no current) 2. Coils **b** and **d** ON at max.current **a** and **c** OFF (no current) 3. Coils **a** and **c** ON at max.current **b** and **d** OFF (no current)
	1. Coils **a** and **d** ON max.current **b** and **c** OFF (no current) 2. Coils **b** and **d** ON at max.current **a** and **c** OFF (no current) 3. Coils **a** and **c** ON at max.current **b** and **d** OFF (no current)
	1. Coils **c** and **d** ON at max.current **a** and **b** OFF (no current) 2. Coils **b** and **d** ON at max.current **a** and **c** OFF (no current) 3. Coils **a** and **c** ON at max.current **b** and **d** OFF (no current)
	1. Coils **a** and **b** ON max.current **c** and **d** OFF (no current) 2. Coils **b** and **d** ON at max.current **a** and **c** OFF (no current) 3. Coils **a** and **c** ON at max.current **b** and **d** OFF (no current)
	1. Coils **a,b,c** and **d** OFF (no current) 2. Coils **b** and **d** ON at max.current **a** and **c** OFF (no current) 3. Coils **a** and **c** ON at max.current **b** and **d** OFF (no current)
	1. Coils **b,c,d** ON at max.current and **a** OFF (no current) 2. Coils **b** and **d** ON at max.current **a** and **c** OFF (no current) 3. Coils **a** and **c** ON at max.current **b** and **d** OFF (no current)
	1. Coils **a,b,c** ON at max.current and **d** OFF (no current) 2. Coils **b** and **d** ON at max.current **a** and **c** OFF (no current) 3. Coils **a** and **c** ON at max.current **b** and **d** OFF (no current

TABLE II: CONFIGURATIONS FOR MR DIRECTIONAL VALVE (PROPORTIONAL OPERATION)

Configurations	Coil operation
	1. Coils a,b,c and d OFF (no current)....null 2. Coils a and c ON at max.current, d at control current and b OFF (no current) ....retract with meter out 3. Coils b and d ON at max.current, a at control current and c OFF (no current) ....extended with meter out
	1. Coils a,b,c and d OFF (no current) ....null 2. Coils a and c ON at max.current, b at control current and d OFF (no current) ....retract with meter in 3. Coils b and d ON at max.current, c at control current and a OFF (no current) ....extended with meter in

The possible operating types of MR proportional directional valve are shown in Table II. This can be done easily using different connection between valve's coils with particular electric circuit, whereas hydraulic control valves need to change the spool which is not easy and should be done in the factory.

V. CONCLUSION

In the present work, the construction and principle of work for a proposed MR directional valve was introduced. The valve will be used to replace a four-way three position (4/3) directional control valve, using four elements arrangement similar to the Wheatstone bridge circuit concept. The proposed design of MR directional valve enables its configurations and types of operation to be changed easily. This change can be done only by reconnecting the coils with particular electrical circuit. On the other hand, traditional directional control valve which has three positions is limited to only three different configurations unless its spool is changed. Furthermore, MR directional valve can be used as proportional directional control valve, as well as ON-OFF valve, while in traditional valve, the designs of proportional and ON-OFF valve are different. The flow rate induced by the MR directional valve decreases when the increase in the current. The MR directional valve can be operated with variable flow rate Q by changing the value of the current. It is found that current is inversely proportional to the flow rate.

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