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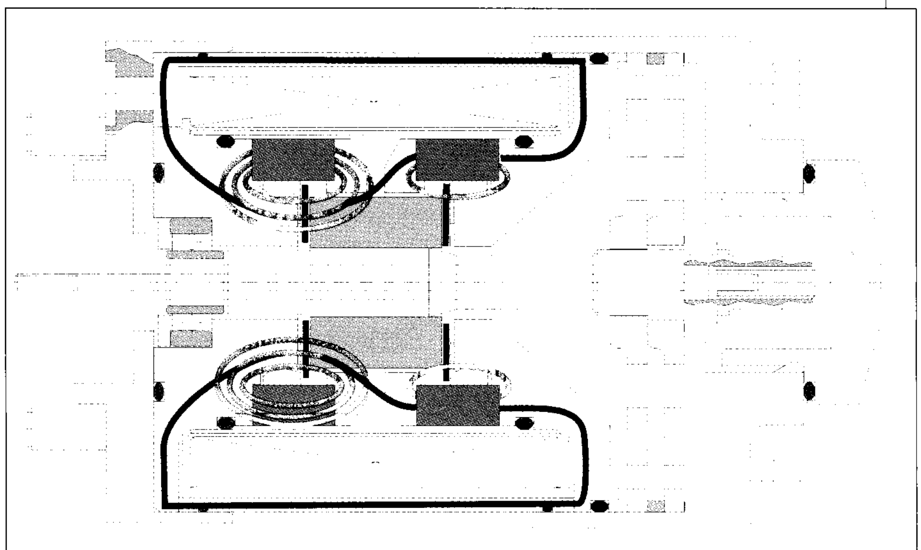
Linear-force motors enhance proportional valves

Solenoids have been a part of direct- drive valves since electrical control systems for fluid power came into being. While solenoid-actuated valves have served fluid-power technology well, a problem with nearly all conventional solenoids is that they pull in one direction only. As a result, a direct-drive valve with a single solenoid is a uni-directional device. During loss of electrical power, such a valve can create undesirable load movements as it transitions to its fail-safe position.



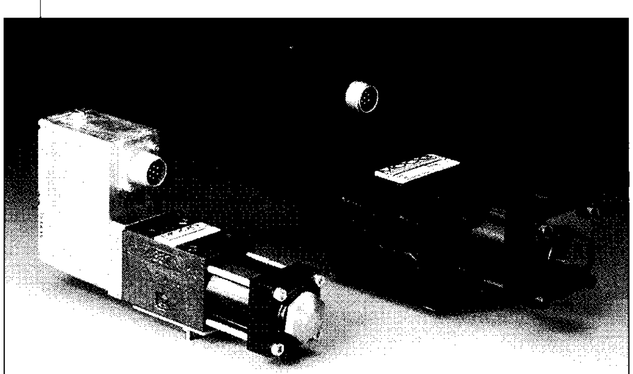
In cross-sectional view of linear-force motor, dark gray blocks represent rare-earth magnets, blue lines represent their flux fields, and red line represents flux field generated by current in the coil. Interaction of the three flux fields as depicted here drives valve armature to the right.

In conventional solenoids, current is applied to the coil to create a magnetic flux. The polarity of the magnetic flux cannot be changed, but its strength can be altered by changing the current in the coil. The solenoid can only pull its armature, but the pulling force can be increased by applying additional current to the coil. For proportional systems, the solenoid works against a spring. A major drawback of this design is its increased susceptibility to uncontrolled load movements if the electrical signal is lost.

To achieve bi-directional operation for proportional systems, two conventional solenoids can be used. However, this increases cost and the mass of a second solenoid's armature negatively impacts dynamic response.

Another design possibility is one of the recently developed bi-directional solenoids. In conjunction with centering springs, these solenoids create a push-and-pull effect to reduce uncontrolled load movements during the fail-safe condition; but they generate lower driving forces, consume more power, and cost more.

At Moog Inc., we believe that linear-force motors in direct-drive servo-proportional valves provide numerous benefits over traditional solenoids. These include: higher frequency response, greater spool-driving force, and lower power consumption. Because linear-force motors inherently function as bi-directional devices, they can push and pull in both directions. Thus, linear-force motors generate higher driving forces with lower power consumption — and they naturally achieve a center fail-safe position. These characteristics not only enhance efficiency and safety, but also can reduce operating costs.



Moog's D633 (left) and D634 Series proportional valves — both directly driven by linear-force motors — are built in ISO 4401 size 3 and 5 configurations with 1- through 26-gpm flow rates.

The linear-force motor is a permanent-magnetic differential motor used in direct-drive valves with electric closed-loop spool-position control. The motor consists of a coil and a pair of high-energy, rare-earth magnets. While de-energized, the combination of electromagnetic and mechanical stiffness maintains the spool in its center position. When direct current with one polarity is applied to the coil, the flux in one of the air gaps surrounding the magnets increases, canceling out the flux in the other. This imbalance forces the armature to move in the direction of the stronger magnetic flux. By changing the polarity of the current applied to the coil, the armature will be moved in the opposite direction.

Because of the magnets, linear-force motors need less current and their magnetic flux patterns are more efficient — producing greater force. Also, because they are bi-directional, the center fail-safe position is easy to design, and the valve consumes power only when called upon to flow oil. (Uni-directional solenoids consume power continuously because they must hold the valve spool in place even when it is at null.) Considering that a valve typically spends 70 to 80% of its time at null, the savings in power consumption can be significant.

Because the linear-force motor has a neutral mid-position from which it generates force and stroke in both directions, the force and stroke are proportional to the current signal. High spring stiffness and resulting centering force — combined with external forces such as friction forces and flow forces — must be overcome during outstroking. But during backstroking to the center position, the spring force adds to the motor force, providing higher total force to drive the spool.

The bi-directional function of the linear-force motor allows for the design of a valve with a true center fail-safe position, which results in no consumption of power at null. When compared to the solenoid system, the linear-force motor will have at least twice the driving forces, the result of the total flux created by the coil and magnets being much stronger than that of a coil alone. Power consumption is much less because the magnets require less current to obtain greater force.

Although conventional solenoids have long had their place in direct-drive valves, linear-force motors have successfully met the challenges of more-demanding applications. We believe that they will be the next wave in servo-proportional valve technology.

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