Control under pressure

What is a Moog valve and why has it become an essential part of Formula 1 technology over the last quarter of a century?

BY CHARLES ARMSTRONG-WILSON

With this E050 cartridge valve, Moog has taken its valves from the rarified world of Formula 1 into the hostile environment of World Rallying

Most people in motorsport have heard of Moog valves, but very few outside Formula 1 and World Rallying know much about what they are and what they do. We therefore set out to find out why they have become so essential at the top end of our sport.

At their simplest, Moog valves are electrically operated servovalves that control hydraulic actuators. Their unique appeal, however, is the speed and accuracy with which they can regulate the flow using tiny electrical inputs. On a racecar this is an essential quality as a number of systems, such as gear selection and throttle operation, are driven by high-pressure hydraulics, and fast, precise control is essential. The fundamental reason for the adoption of hydraulic technology in F1 is its unparalleled 'power density' and, in the weight-conscious world of racecar engineering, hydraulic actuation systems are a fraction of the size and weight of the alternative electrical or pneumatic systems.

The valves themselves were invented by Bill Moog in 1950, for use in aircraft and missiles, but it was not until the early 1980s that they made their

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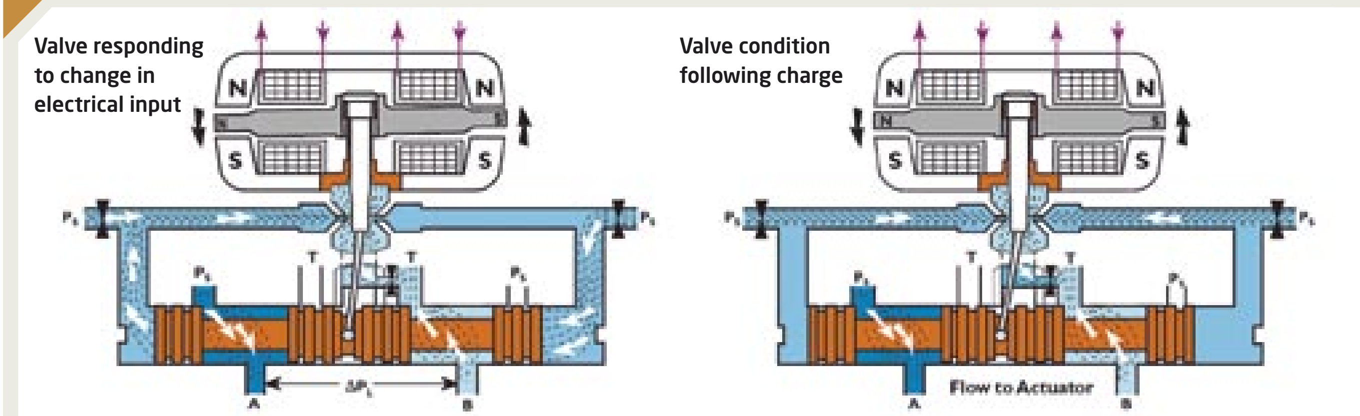
first appearance in motorsport. That was due to Team Lotus, which had been wrestling with the problems of ground-effect aerodynamics and the attendant ride height sensitivity. Its solution was active suspension – in essence, replacing the springs, dampers and anti-roll bars with hydraulic actuators controlled by a computer.

To get the precision, the company turned to the aerospace industry and used off-the-shelf Moog Series 30 hydraulic servovalves. By the early 1990s, while fully active suspension attracted few followers in F1, attitude control by hydraulics had become the state of the art, with

Moog's product range for motorsport has grown to include items like this power-assisted steering valve

The company's E024 series micro valve was developed specifically for motorsport and is now widely used on Formula 1 cars

HOW IT WORKS



When a current is applied the armature swings, blanking the flow from one jet and moving the spool. This, in turn, balances the force on the armature

When Bill Moog patented his fluid control valve in 1950, it comprised several hydraulic control principles developed over centuries. It was his packaging and refinement, however, that made the Moog fluid control valve such a powerful component. The clever part of a Moog valve is its ability to precisely control the flow of high-pressure fluids with very small control inputs. The way it achieves this is by using the pressure of the fluid it controls to power the valve.

A Moog valve continuously flows a small amount of fluid through two small jets facing each other. Between them is a flapper valve connected to the armature in a torque motor. The armature sits between permanent magnets and, as a current is fed to wire coils around the armature, it twists a small amount – a couple of degrees at most. This, in turn, moves the flapper valve, obstructing the flow from one of the two jets and increasing the pressure in that feed compared with the other, which is still venting pressure through its unrestricted jet.

Both these pressure feeds are connected via a side gallery to either end of a sliding valve, called a spool, in a cylindrical gallery with cut-out valve orifices. The difference in pressure between the two feed pipes causes the spool to slide along the cylinder, opening a supply of the main pressure feed in the direction required via the ports.

> At some point, the two opposing forces reach an equilibrium that stabilises the position of the spool

The Moog valve has an additional refinement that gives it its spectacular level of accuracy and control. On the end of the armature-mounted flapper valve is a feedback spring. Put simply, this is a flexible member with a ball end that locates in the spool. As the spool moves in response to the pressure difference, it moves the end of the feedback spring, opposing the movement of the flapper valve and armature. At some point, the two opposing forces reach an equilibrium that stabilises the position of the spool and, in turn, the amount of restriction to the main flow of fluid. In this way, it allows small changes to the current at the armature to produce precise changes to the flow of fluid. This principle allows the Moog valve to also work as a fluid pressure amplifier.

Although they differ in application, all Moog valves share the same basic principle of operation

A spool from one of Moog's linear power-assisted steering valves

A linear actuator, as used to drive position-sensitive systems like throttles and gear selector barrels

most teams running some kind of short-stroke actuator under the springs. But for the 1994 season, the FIA chose to ban it for a number of reasons, including development cost and safety.

F1 SYSTEMS

What is learned in F1, however, is rarely forgotten and the Moog valve had, by then, found its way into other areas of the car. As many as 10 systems on an F1 car were being controlled by Moog valves, including anti-lock braking, brake balance and braking power assistance. Moog had also recognised the sport as an ideal market for its products and started making valves specifically to meet the demands of F1.

Today, the most commonly used hydraulic servovalve in F1 is the Moog E024 series sub-miniature valve. Developed specifically for F1, it weighs just 92g, less than half the weight of the company's smallest aerospace valve. Typically, an F1 car would use five or six, operating the clutch, gearshift selector drums, throttle and differential.

In the interests of minimum size and weight, F1 hydraulic systems run at very high pressures (up to 230bar) and an E024 servovalve can control as much as 5bhp (3.5KW) with a command signal of just +_10mA. This allows the valves to be driven directly from the car's ECU. The valves are usually grouped onto a single hydraulics block, through which hydraulic pressure is distributed and controlled.

Essentially, all the valve does is accurately control the flow of hydraulic fluid and, to make this property useful in a racecar, it has to be incorporated into a feedback loop with a sensor. On the throttles and the gear selection barrels, where precise position is key, the valve operates in response to a position sensor. On the differential, however, it is responding to the signal from a pressure sensor. The clutch can be either, depending on the control strategy chosen. In these applications, very fast response is essential, the E024 for example reacting to an input in less than 1ms.

Two other applications for the Moog valve on an F1 car are the fuel flap and reverse gear. Both are simple on-off scenarios and do not use the closed-loop technology normally associated with Moog valves. A feature of the E024 valve, however, is that it can be modified to mimic the function of two independent, three-way solenoid valves, meaning a single E024 valve can be used either to open the fuel flap *or* to select reverse gear, saving the weight of a second valve and its associated wiring and mounting manifold. This relies on the premise that it's not necessary to re-fuel while travelling in reverse!

Over the years, the demands placed on Moog's products by F1 have intensified and there has been constant development to rise to the challenge. Response times, in particular, are critical and considerable effort has been put into reducing the inertia of the armature in the torque motor, increasing its field strength and reducing the air gaps. This has enabled Moog to reduce the response time of the electrics to less than 1ms, helping the valve achieve maximum control flow in less than 3ms.

Temperature also places great demands on hydraulic systems and their control valves. On an F1 car, the hydraulic fluid will typically operate at around 100-135degC and the high pressure and throttling action of the valve generates more heat. The hydraulic fluid reservoir of an F1 car typically holds less than 300cc, so there is very little mass of fluid to absorb heat and temperatures can rise very quickly. There is also reluctance on the part of teams to provide oil-to-air coolers for the fluid due to the extra weight and aerodynamic drag incurred. Instead, they sometimes use oil-to-water heat exchangers with the engine coolant that will already be running in excess of 110degC.

All this means the valves have to be designed to cope with the heat. All seals are of Viton high-temperature material and machining tolerances are kept very tight in pursuit of good sealing. At the high temperatures to which F1 subjects its hydraulic fluids, viscosity is considerably reduced, down to as low as 4-5CSt, compared with 20CSt in normal industrial applications. Such low viscosity makes retaining the fluid a challenge and the clearance between the spool and the valve housing needs to be just 1.25m.

Such precision components being used in a hostile environment inevitably have

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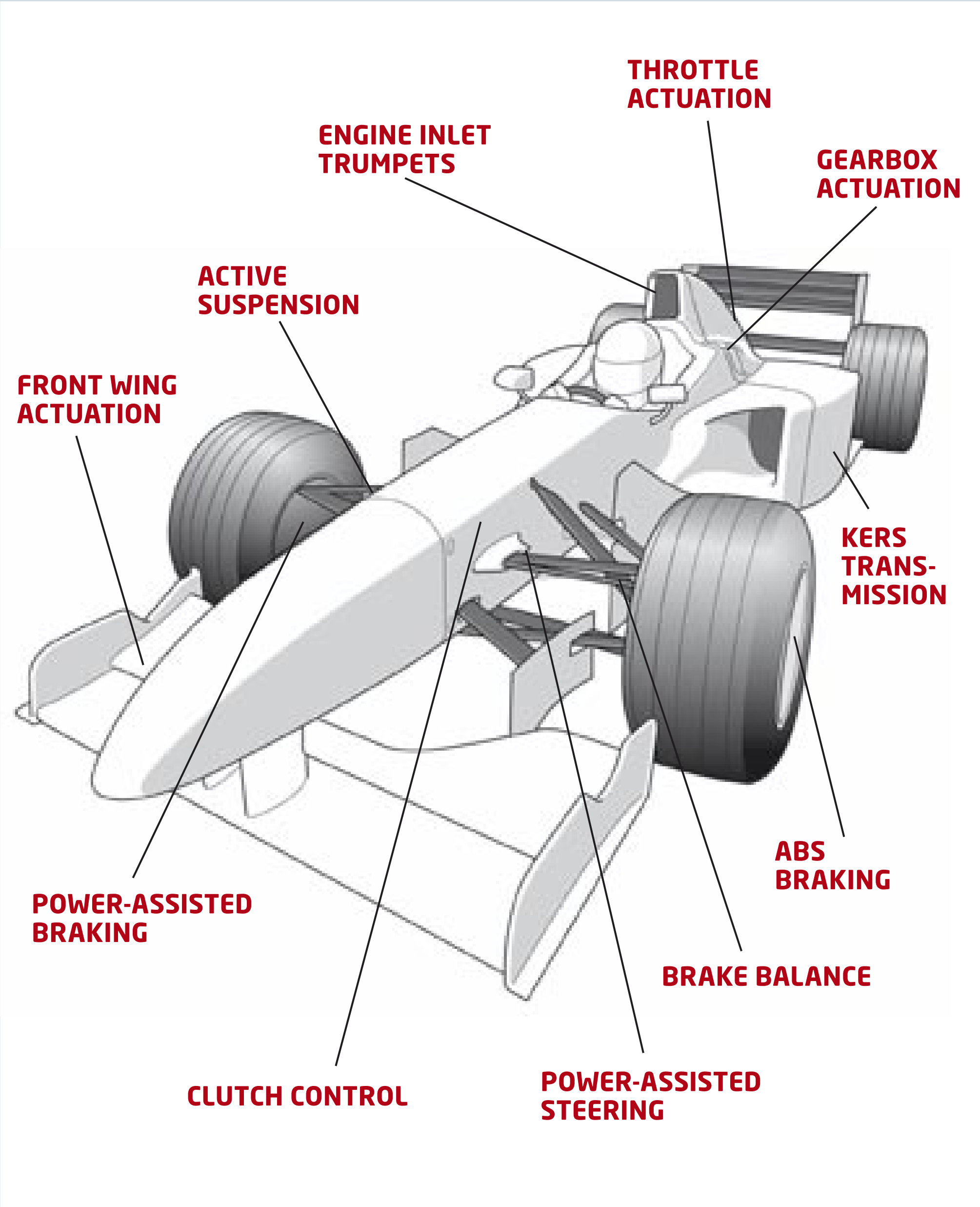
FORMULA 1 APPLICATIONS



Mick Hill at freelanceillustration.com

Diagrammatic showing the multiple and varied roles of Moog control valves on the current breed of Formula 1 cars

a limited service life and in F1 Moog valves are usually replaced after 12,000km. They also need to be serviced either every 4000km, or after 20 hours of use. This entails the valve being dismantled and inspected and key parts replaced, including the seals, a tiny, 15m filter that strains out particles and a thin-wall stainless steel tube in the pilot stage.

For a long time, rallying resisted the use of Moog valves due to their need for scrupulously clean hydraulic fluid being perceived as incompatible with the nature of servicing on events. Ever more complex transmissions with active differentials requiring precise hydraulic control, however, forced the manufacturers to consider Moog valves. The company responded with its E050 Proportional Cartridge DDV, which uses a linear electric motor to activate the spool valve. By removing the pilot stage and its very fine jets, the valve is much less susceptible to fluid contamination and the hydraulic system can be serviced in the field.

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Despite approaching its 60th birthday then, the Moog valve is still very much part of the cutting-edge technology on which motorsport's highest echelons rely and, unless hydraulics fall from favour, looks likely to remain so.

POWER STEERING

Over the years, Formula 1 steering has become increasingly heavy, as steering geometry has sought to extract aerodynamic benefits. Now all F1 cars have power steering and would be undriveable without. A few years ago, however, during one of its sweeping rule changes aimed at attempting to put control of the cars back in the hands of the drivers, the FIA banned electromechanical power steering. This removed any ability to map the steering assistance the driver was given in response to the conditions. Some form of power steering was still needed, however, and because Moog valves had been used in the now banned electromechanical systems, it was an obvious move for the company to look at developing a passive, hydro-mechanical, power-assisted steering system.

HYDRO-MECHANICAL

What the company came up with is in essence very similar to the principles of a conventional road car system, but smaller, lighter, more accurate and able to work at constant pressures of 200Bar. Essentially, the regulating valve is very similar to one of the company's electro-hydraulic servo valves but, instead of the signal coming from a torque motor, it is fed from a torsion bar or linear springs in the load path of the steering. As the steering load increases it creates a displacement in the torsion bar that is linked directly to the spool that, just as in the normal valve, provides a pressure differential to the ends of the steering rack, giving power assistance.