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Formula One racers go with ultralight hydraulics

Hydraulics packs a lot of power into compact packages, and today's Formula One race cars take advantage of this feature with great success. Over the past two decades, Formula One cars have incorporated sophisticated hydraulic systems to handle multiple applications, including ABS and power-assisted braking; clutch, gearbox, and throttle actuation; and controlling engine air inlets and active suspensions.

Moog Inc.'s facility in the United Kingdom first supplied the Formula One industry with custom versions of miniature servovalves used on aircraft, missiles, and spacecraft. But these were soon replaced by products tailored to the rigors of Formula One.

Car designers are weight watchers

One key demand of motorsport engineering is designing for absolutely minimum weight, according to Martin Jones, the company's motorsport market manager. "The weight-watching culture is particularly prevalent in Formula One, where much effort is expended to shave a few grams from even the smallest components," offered Jones. Curiously, all current Formula One cars carry ballast to achieve the minimum allowed weight of 600 kg. However, teams can gain considerable competitive advantage by maximizing the ballast and placing it low in the vehicle, which aids handling, explains Jones. It also facilitates on-track setup procedures, as moving the mass fore or aft alters the vehicle center of gravity.

Jones continued, "Hydraulics is absolutely unique in terms of power density, and the little valves we supply to Formula One can control 5 hp of power at a fraction of the size and weight of equivalent electric motors."

Moog's E024 subminiature servovalves, for instance, weigh only 92 g, less than half the mass of the company's smallest aerospace servovalve. In today's Formula One cars they're typically used on the clutch, gearshift, throttle, and differential.

The valves' small size — the E024's spool has a 4-mm diameter — and steel construction permits thin walls without excessive internal stresses, even at 280 bar. This lets designers build in a significant safety factor with minimum impact on weight.

Valve drivers in the car's ECU (electronic control unit) supply a ±10-mA signal that is varied to produce a proportional valve response. An electric torque motor that rotates ±2° drives the pilot stage. Considerable design effort on details such as the inertia of moving parts, magnetic field strength, and air gaps results in a response time of less than 1 msec for the electromagnetic stage, explained Jones. It controls the tiny second-stage spool, giving total step response of only 2.8 msec.

Taking the heat

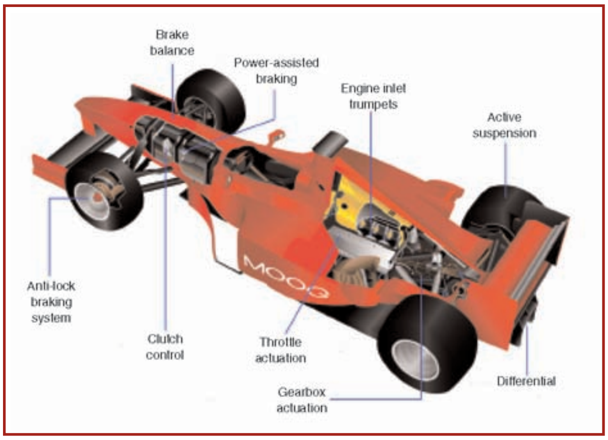
Heat is another issue. Formula One hydraulics generally operate at temperatures to 135°C, versus about 60°C on typical industrial systems. In any hydraulic circuit, throttling flow generates heat. But most industrial systems include large reservoirs or heat exchangers to keep fluid temperature within operating limits. In contrast, Formula One hydraulic reservoirs hold only 20 to 30 cc. With no significant oil mass in the system, temperature rises quickly.

Air coolers could be used to keep hydraulic temperatures down, but they would add weight and create aerodynamic drag. Instead, valves are built to handle the heat. High-temperature Viton seals are the norm, and components are held to extremely tight tolerances.

One consequence of high temperatures is low oil viscosity. Compared with industrial hydraulic fluid that runs in the 20-cSt range, Formula One hydraulics have a viscosity of 3 to 4 cSt at 135° C. As a result, any large clearances in the valve will generate internal fluid leakage, energy losses, and heat. To counteract these effects, radial clearance between the valve spool and body is only 1.25 mm.

Systems normally rely on high-temperature, flame-resistant aircraft hydraulic fluids. Engine coolant at 110° C is often used to cool the hydraulics via a liquid-to-liquid heat exchanger.

Servovalves are typically serviced every 4000 km — or about 20 hr of operation — and retired after 12,000 km. Maintenance involves dismantling and visually inspecting



Hydraulic components are situated throughout a vehicle, so their compact size and light weight give them a tremendous advantage over other technologies.

all components. Technicians replace all O-rings, a tiny 10-mm filter inside the valve (that protects against hard-over failure from stray contamination), and a thin-wall, stainless-steel tube in the pilot stage, which has a finite fatigue life.

Some car functions require only discrete (on-off) hydraulic control. These include engaging reverse gear and opening the "cat-flap," an access door to the fuel filler. Formula One cars also include a special safety feature, the clutch-disengagement system, which is used after accidents or breakdowns. Pressing a red button on the dashboard routes oil stored in an accumulator into a clutch slave cylinder, which opens the clutch and permits race marshals to push the car off the circuit.

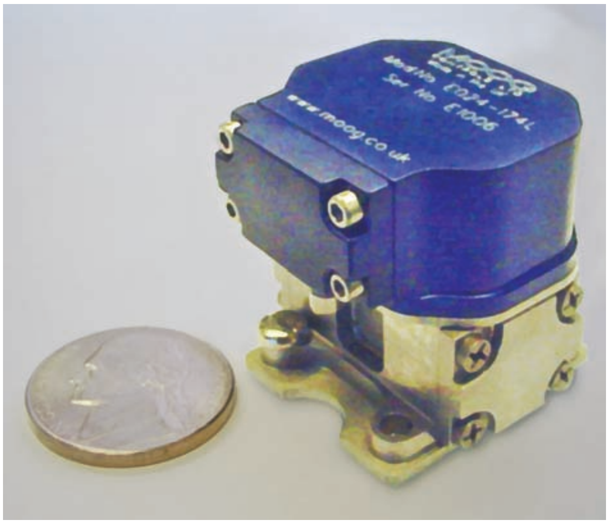
For these applications, Moog developed the E050-747 microsolenoid valve. The three-way, normally closed, two-position valve weighs less than 40 g, making it one of the smallest direct-acting hydraulic solenoid valves available, according to Jones.

Another application of note, explained Jones, is power steering. Although Formula One cars are light, they experience nearly 3 G of down force at high speeds. They also have extreme steering geometries with large caster angles, which lifts or lowers the front end as the steering wheel turns. This makes the cars essentially undriveable without power steering.

A rules change several years ago banned electrohydraulic power steering (in what was reported as an economizing move). This forced teams to revert to hydromechanical control, for which Moog developed a precision rotary power-steering valve. It features two concentric sleeves connected by a torsion bar in the load path of the steering column. Torque applied in either direction rotates the inner and outer sleeves relative to each other. This, in turn, opens flow-metering ports that direct high-pressure oil to one side of the assist actuator. Closed-center operation minimizes energy consumption and offers high accuracy and repeatability. The valve generates high flow with small angular inputs, giving high steering stiffness and virtually instant response.

"Effectively, we've made a miniaturized version of a road-car power-steering system, but it runs at 200 bar and is much more energy efficient. It's a passive hydromechanical device, with no electronic-control inputs," said Jones.

In addition to Formula One, other racing circuits have also embraced hydraulics. For example, rally cars use servovalves for transmission control and on suspensions to improve traction and handling on a variety of road surfaces. In these instances, high-response miniature servovalves survive extreme environmental conditions. The tiny E024 valves have also made hydraulic control possible on motorcycles, and are expected to soon appear on Moto GP bikes. Future motorsport developments will likely include more energy-efficient hydraulics and even lighter actuators.



The E024 servovalve weighs 92 g, is rated for 7.5-lpm flow at 70 bar, with maximum pressure of 210 bar. On Formula One cars, it handles high-power applications such as shifting gears and actuating clutches.

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