1 Introduction, Applications, and Concepts

1.1 The Need for Fluid Power

In applications for which large forces, torques, or both are required, often with a fast response time, it is inevitable that oil-hydraulic control systems will be called on. They may be used in environmentally difficult applications because the drive part can be designed with no electrical components, and often they are the only feasible means of obtaining the forces required, particularly for linear actuation. A particularly important feature is that they almost always have a more competitive power–weight ratio when compared with electrically actuated systems, and they are the inherent choice for mobile machines and plants. Fluid power systems also have the capability of being able to control several parameters, such as pressure, speed, and position, to a high degree of accuracy and at high power levels. The latest developments are now achieving position control to an accuracy expressed in micrometers and with high-water-content fluids. In practice, there are many exciting challenges facing the fluid power engineer, who now must preferably have skills in several of the following topics:

- Materials selection, water-based fluids, higher working pressures
- Fluid mechanics and thermodynamics studies
- Wear and lubrication
- The use of alternative fluids, given the environmental aspects of mineral oil, together with the extremely important issue of future supplies of mineral oil
- Energy efficiency
- Vibration and noise analysis
- Condition monitoring and fault diagnosis
- Component design, steady-state and dynamic
- Circuit design, steady-state and dynamic
- Machine design and its integrated hydraulics
- Sensor technologies
- Electrical–electromagnetic design
- Computer control techniques
- Signal processing and associated algorithms
- Modern control theory and artificial intelligence

Hydraulic control applications cover a vast range of industries and power levels:

- Ore and mineral extraction, mining, and transportation
- Materials primary processing, steel mills, forging presses
- Product forming and shaping from metal and plastic stock
- Wood processing, paper production
- General production-line machines, injection molding
- General testing machines, test beds, four-poster rigs for vehicle testing
- Bridges, canal-barrage locks
- Transport, road vehicles, rail, shipping, aircraft
- Military vehicles, aerospace
- Mobile machines for construction
- Public services, road cleaning, health, maintenance, elevators
- Leisure, theme parks, wave generators, animation, theater stage control

Figure 1.1 shows a photograph of a hot steel strip finishing mill that forms the final stage of a series of operations involving hydraulic control systems and transforming iron ore to high-quality steel strips. The strip is then either passed on to customers – for example, for vehicle body pressing – or for further processing by means of cold rolling, tinning, or both. Work roll bending (WRB), automatic gauge control (AGC), and work roll shift (WRS) operations are dominated by hydraulic control on different stands. Each of the WRB cylinders and the AGC capsules is controlled by a servovalve–actuator unit, and most of the control systems are reproduced on all the mill stands.

Also shown in Fig. 1.1 is part of a condition monitoring and fault diagnostic system developed by members of the author's research group. Data acquisition is undertaken using National Instruments hardware and Labview software, and an *expert systems* approach significantly aids the fault diagnostic task. The fault diagnostic system developed automatically analyzes the performance of 28 servovalve systems, indicating when their condition is such that they need to be changed or repaired, thus avoiding mill downtime. The effect of this is to improve cost effectiveness, increase production, improve safety, and ensure customer supply on time.

Figure 1.2 shows a high-torque low-speed motor drive from just two of the many large-scale applications undertaken by Hagglunds, noted for its specialism in this area, among many others. These two applications indicate the need for hydraulic drives in bulk-materials handling and in the chemical-processing industry, and with a level of control sophistication. Other applications for this type of drive include pulp and paper, mining, rubber, recycling, sugar, conveyors, merchant, dryers, and evaporators, and many more.

Figure 1.3 illustrates some other fluid power applications – for example, rock drilling, underground tunneling, component or materials testing with cylinder drives used to create linear motion.

The mobile machine market relies on fluid power for cleaning, loading, lifting, excavating, quarrying, and so on, and with an impressive array of machines, many with multifunctional capabilities and advanced control technologies. For example, Fig. 1.4 shows a machine for cleaning city center buildings, repair work with machines similar to those used in fruit-picking and horticultural areas.

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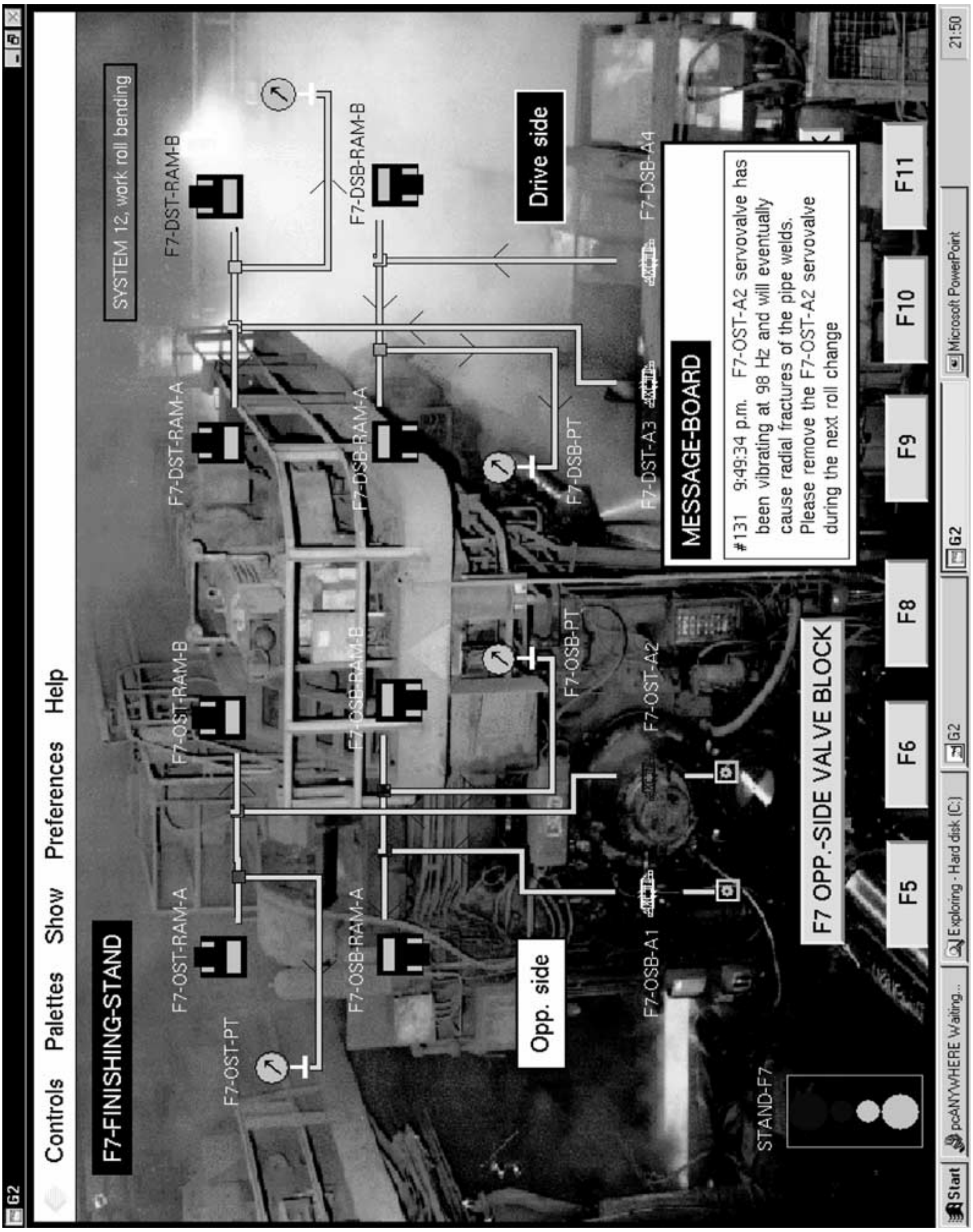
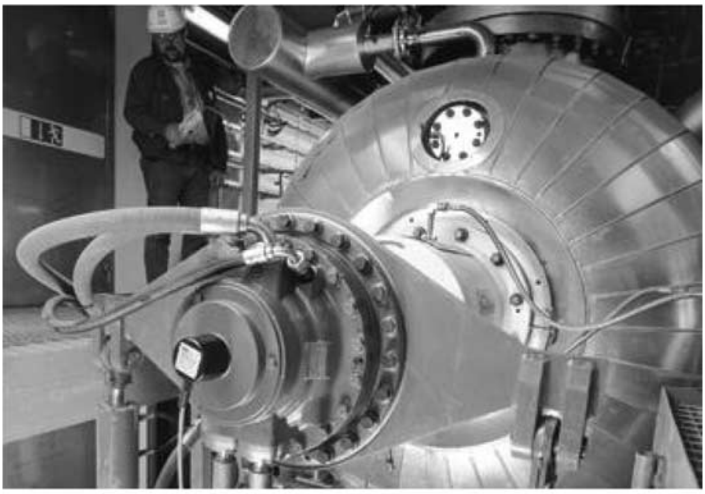


Figure 1.1. Part of a hot steel strip rolling mill (Gale and Watton, 1999).

(a) A bulk-handling application



(b) A chemical-processing application

Figure 1.2. Bulk-material handling and chemical-processing use of Hagglunds high-torque low-speed motor drives (www.hagglunds.com).

Figure 1.5 shows machines for quite different market requirements, one a three-wheeled machine for third-world operations, the other two from a major manufacturer and used for excavation and construction applications.

A feature of the low-cost three-wheeled loader is that both the loading boom and the two front wheel drives are hydraulically operated using load-sensing proportional control-valve technology. The two drive wheels are independently controlled, allowing the machine to turn a tight circle, almost about its own axis, by virtue of the free-wheeling pivoted wheel at the rear.

Considering the specifications of the JCB Ltd. range of mobile machines reveals the innovations in vehicle suspension, power transmission, and fluid power control necessary to ensure continual improvements in machine efficiency, performance, safety, and reliability (www.jcb.com).

Rock-drilling and tunneling applications

Materials–components testing machines

Figure 1.3. Some further examples of hydraulically controlled machines.

The leisure and entertainment industries are increasingly calling on hydraulic control systems such as the three-axis motion ride, a simplification of vehicle testing systems and flight simulators, and the modern interpretation of the fairground Ferris wheel, shown in Fig. 1.6.

The London Eye has four separate drive units, two on each side of the rim, each with four drive wheels operating in pairs that grip beams fixed along each side of the rim's outer frame. In normal operation, all 16 wheels will run in unison, but the system has been designed with sufficient capacity to allow individual pairs of wheels to be retracted, should a problem occur, with no effect on the running speed. The Eye can be run normally with only 12 wheels in operation and can be safely evacuated with as few as 8, though turning at a slightly lower speed. The running

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Figure 1.4. A multiaxis mobile machine being used for city center building cleaning.

(a) A low-cost loader co-designed by the author, HR Wright, and Compact Loaders Ltd., the UK manufacturer

(b) A JCB UK Ltd. Fastrac tractor (www.jcb.com)

(c) A JCB UK Ltd. tracked excavator (www.jcb.com)

Figure 1.5. Further examples of mobile machines.

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(a) Motion control simulator (b) The London Eye

Figure 1.6. Examples of fluid power for entertainment and leisure purposes.

beam has a high-grip coating, and each pair of wheels is fitted with sensors that increase the drive pressure automatically should any slippage be detected. It is a fairly standard system and is considered very reliable. A high level of redundancy has been built in that should guarantee near-permanent operation. There are two separate hydraulic supply lines, for example, and each drive unit can be isolated and run independently. Should all hydraulic pressure be lost, mechanical brakes have been installed within the hub of each wheel; safety for the passengers and the operating staff is paramount (www.londoneye.com).

Figure 1.7 shows just one of many applications of cylinder drives in the general navigation–maritime–marine area. It illustrates bridge-lifting and the integral lock-gate parallel actuation by means of computer control.

Aerospace also relies on fluid power, not only for testing systems but also for flight controls, as shown in Fig. 1.8. Moog Inc. is a worldwide designer, manufacturer, and integrator of precision-control components and systems. In general, electrohydraulic servovalves are used for primary flight controls, such as aileron, elevator, and rudder actuation. Secondary flight controls include spoilers and air-brake actuation. High-lift devices such as leading- and trailing-edge slats use power supplies with hydraulic motor rotary actuation. In addition, hydraulic auxiliary power units and hydraulic motor control of emergency generators illustrate the crucial importance of fluid power control in aircraft. The advantageous power–weight ratio, relatively benign failure modes, and the pedigree of flight reliability experience may explain why a change to purely electrical power control is many years away, as far as the author can deduce.

(a) One of three Bascule bridges

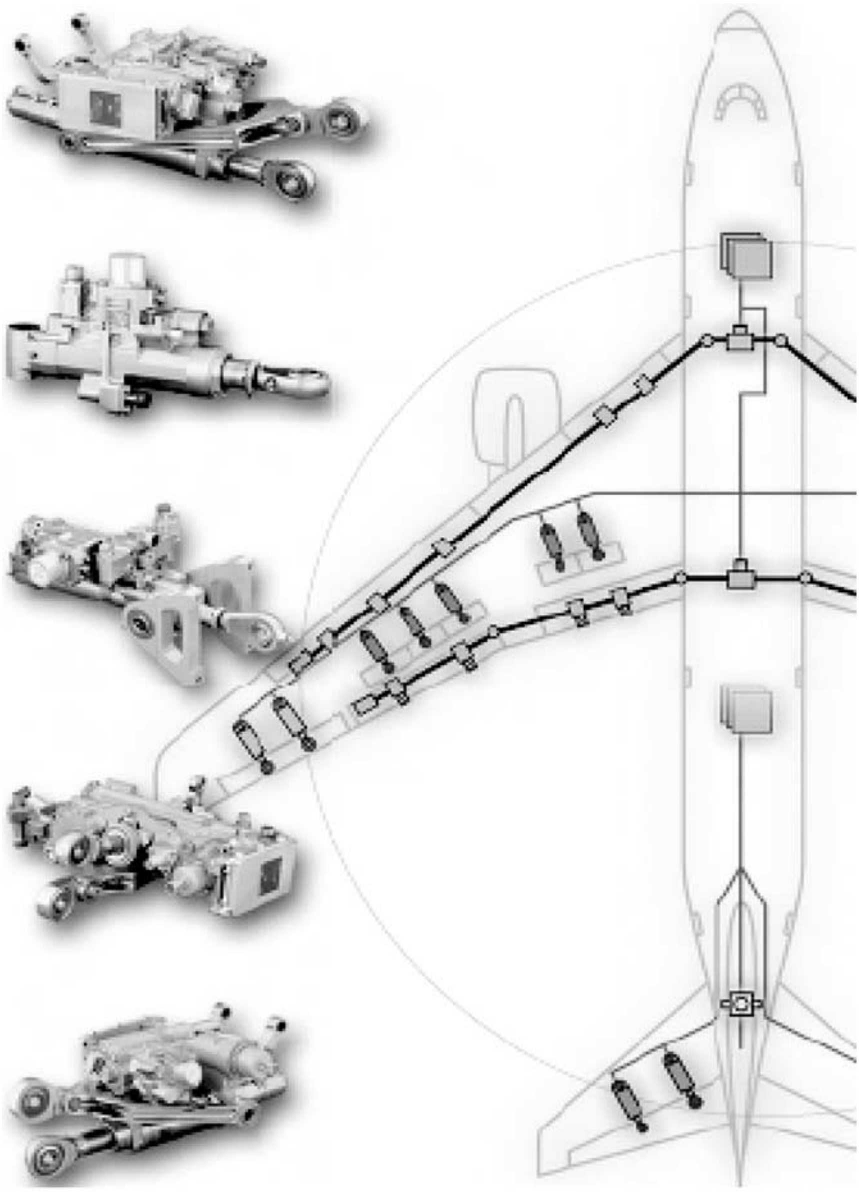
(b) Control of a pair of lock gates

Figure 1.7. The bridge-lifting system and lock-gate control at the Cardiff Bay Barrage, UK.

1.2 Circuits and Symbols

It is clear from just the few examples shown that fluid power systems can vary significantly in both circuit complexity and operating strategy. However, some basic functional requirements common to all systems are as follows:

- A hydraulic power source – pumps
- A means of distributing the power – steel pipes and flexible hose



Aircraft wing surface position control

Figure 1.8. Applications in the aerospace industry. Supplied by Moog Inc. (www.moog.com).

- A means of controlling the fluid power – pressure and flow control valves
- A means to provide load actuation – cylinders and motors

Consider a simple circuit, for example, Fig. 1.9, which shows a cylinder and a motor drive circuit illustrating basic system components. The circuit requires a tank with its fluid, a pump, a pressure-relief valve (PRV), a directional control valve, and a cylinder to provide the force to move the load.

Pump (1) draws oil from tank (2), and the pump output line will contain high-pressure filter (3) to prevent dangerous particles from passing into the system and causing damage. PRV (4) is required to set the working pressure and also to

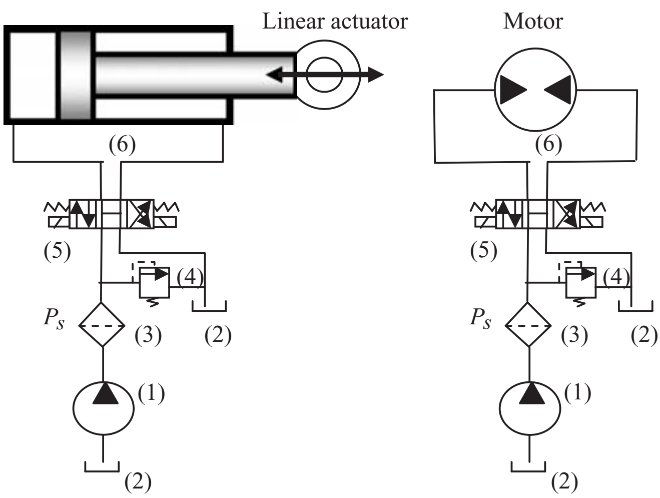


Figure 1.9. Two simple circuits.

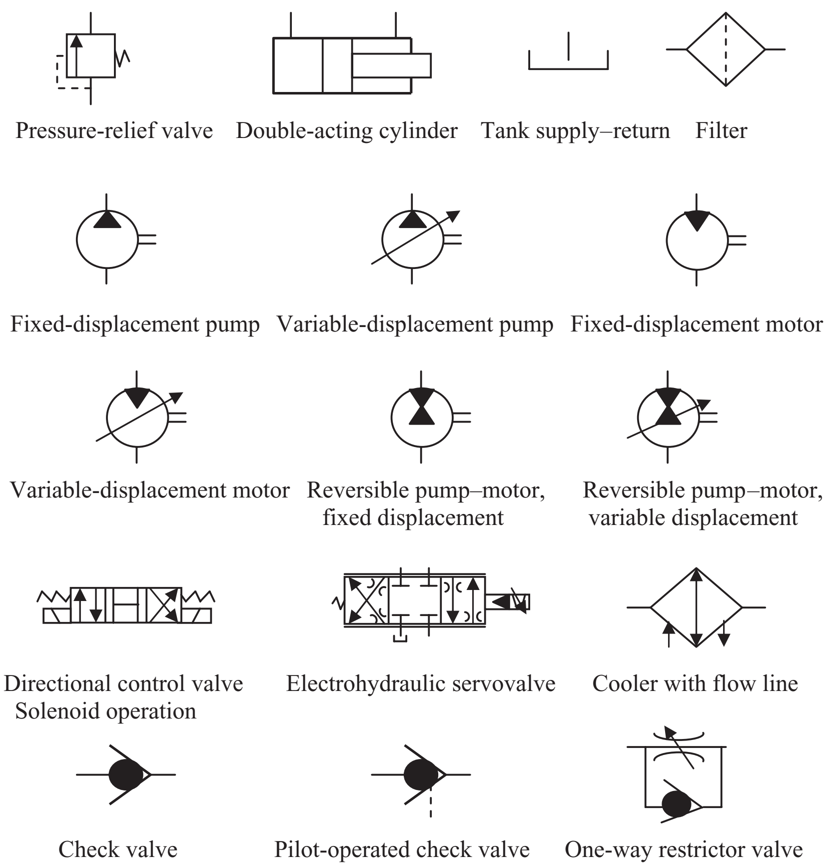


Figure 1.10. Some common fluid power component symbols.