Chapter 1

What is hydraulic fluid power ?

POWER TRANSMISSION AND CONTROL

For many thousands of years, mankind relied on its own muscle power to perform its everyday tasks of building shelters, digging for minerals, felling trees etc. Then, as farming developed, animal power was harnessed to perform some of the heavier duty tasks such as ploughing fields or moving heavy objects. Next, wind and water power opened up more possibilities for activities such as milling flour or draining fields so the tasks that could be carried out now grew further in scale. Then along came the industrial revolution when steam power provided many new possibilities for powering machinery thus allowing human beings to concentrate more on the control of the machines. The steam engines of the Industrial Revolution however have now been superseded by today's more common sources of power namely the internal combustion engine and the electric motor. Traditionally, machinery which has to move around, such as earthmoving machinery or agricultural vehicles, have relied on the diesel engine to provide their motive power. The electric motor on the other hand has provided the main source of power for stationary machinery such as presses, plastics machinery, or machine tools. Some applications, fork-lift trucks for example, may use either power source depending upon their intended area of use and as hybrid technology advances, a combination of the internal combustion engine and electric motors will no doubt become increasingly commonplace. Humans now tend to be less directly involved in the control of machines also. As the requirements for fast, precise control have increased first analogue and then digital electronics have taken over the control responsibility from the human eye and hand for many machine functions.

However, connection of the power source (or prime mover as it is sometimes called) to the machine it is powering still requires some form of transmission mechanism since rarely will the output of a diesel engine or electric motor match the machine requirements exactly. In simple applications perhaps, such as a desk fan or power drill, an electric motor may be used to directly drive the machine but such situations are relatively few. Traditionally, electric motors have been single-speed, single-direction drives although variable speed electric drives are now becoming more common. Most diesel engines are also single direction drives but do have the capability to vary their drive speed although only over a fairly narrow speed range. The requirements of the machine however may be for a bi-directional drive over a wide range of infinitely variable speeds. It may also require a linear rather than rotary movement with the capability to limit the maximum torque or force output. The machine may also have idling periods when no movement is required but when frequent stopping and starting of the prime mover is not practical. It is often the case that several different functions all have to be powered from a single power source so some means of dividing the drive power is required. In some applications the available power has to be shared but with some functions having priority over others. For example the prime mover on vehicles may have to share the available power between the vehicle's transmission, which drives it along, and auxiliary functions such as a boom and bucket arrangement for handling a payload, while at the same time ensuring that the vehicle's brakes and steering have priority over all other functions.

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There are of course many ways in which power can be transmitted and converted by mechanical means. Most of us are familiar with gearboxes and clutches from driving our cars but also deep within the engine the linear, up and down movement of the pistons is converted to the rotary movement of the drive shaft by connecting rods and cranks. Lead screws can convert the rotary motion of an electric motor into the linear movement required by a machine tool for example and rack and pinions have been used for many years for converting linear to rotary motion or vice versa. The 'solid' gears, cams, clutches, lead screws and other components of mechanical or electro-mechanical transmissions of course have to be manufactured to close tolerances and assembled carefully to avoid excessive binding or backlash. Very often they also have to be lubricated in order to reduce wear between components which can limit their performance or service life.

Hydraulics and pneumatics, known together as 'fluid power', differ from mechanical power transmission by using a flexible medium for transmitting power namely liquids, (usually some form of oil) for hydraulic systems and air for pneumatic equipment. Strictly speaking, hydraulic technology can be further subdivided into hydrodynamic and hydrostatic systems. Hydrodynamic systems rely on the momentum of a fluid to transmit power smoothly through the vanes of a turbine, the most common application for which is in the torque converter of automatic transmissions used in vehicles. Contrary to what their name suggests, the fluid in hydrostatic systems can also be moving or flowing but the force or torque transmission in this case is carried out by virtue of the fluid's pressure rather than its momentum. It is the hydrostatic systems which will be covered in this book.

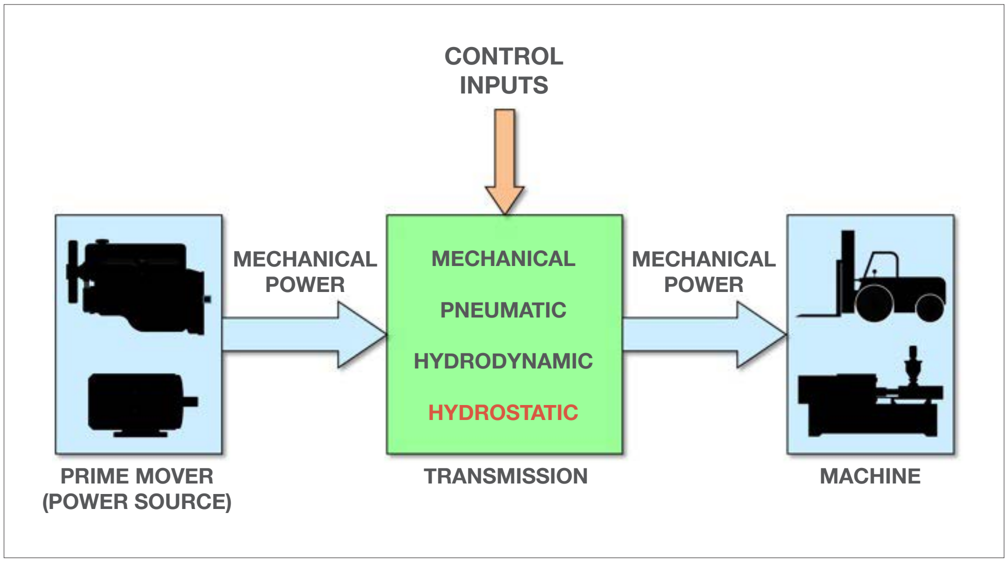

Fig. 1.1 The transmission and control of power

There are many similarities between the two sister technologies of hydraulics and pneumatics but also some important differences. The most obvious difference of course is in the properties of the fluid itself. The air employed in pneumatic systems is a gas and therefore easily compressed whereas the oil or other liquid used in hydraulic systems is virtually incompressible. Although it's not absolutely true to say that liquids are incompressible, the amount that they compress under pressure is very small and in many applications can be ignored. In other cases however the compressed volume of fluid can be significant (typically machinery which use large volumes of fluid at high pressure) and therefore has to be taken into account in the design of the hydraulic system in order to avoid unwanted shocks detracting from its performance.

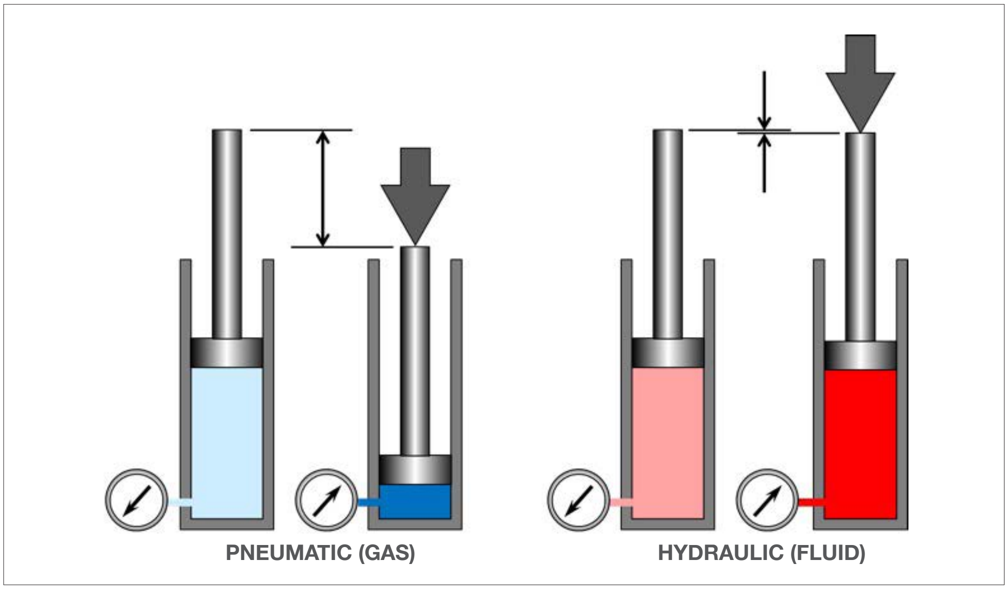

Fig. 1.2 Fluids are (virtually) incompressible

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The compressibility of air means that the pressure used in pneumatic systems is very low compared to that used in hydraulic systems so the amount of power that can be practically transmitted is also correspondingly less. So in general, pneumatic systems are confined to relatively light duty applications compared to the heavy duty tasks which can be performed by hydraulic systems. A pick-and-place robot used for assembling components onto an electronic circuit board would be an ideal application for pneumatics therefore, whereas a 10,000 tonne forging press would be a natural choice for hydraulics. The advantages and disadvantages of transmitting power hydraulically are summarised in fig. 1.3.

ADVANTAGES

1. Power density (large amounts of power from small components)
2. Capability to provide linear or rotary output movement
3. Simple bi-directional output
4. Infinitely variable speed control
5. Force/torque, speed and power limiting easily achieved
6. Multiple outputs from single input power source
7. Manual, electrical or electronic control inputs
8. Self-lubricating
9. Ability to cope with difficult working environments
10. Relatively simple, well-understood technology

DIS-ADVANTAGES

1. Generally less efficient than mechanical transmission
2. Requirement for fluid cleanliness
3. Fluid leakage may create pollution, fire risk or health hazard

Fig. 1.3 Advantages & disadvantages of hydraulic power transmission

TRANSMITTING MOVEMENT

The fact that a liquid is (virtually) incompressible but at the same time able to take up the shape of its container is the principle upon which hydraulic fluid power is used to transmit movement. Consider the situation shown in fig. 1.4 where two cylinders are connected together by means of a pipe and each cylinder is fitted with a piston which is free to move up and down and is perfectly sealed against the walls of the cylinder. If the cylinders and the interconnecting pipe are filled with fluid then pushing down on one (input) piston will displace fluid along the pipe and cause the opposite (output) piston to rise. If both cylinders have the same dimensions then the distance moved by one will exactly correspond to the distance moved by the other.

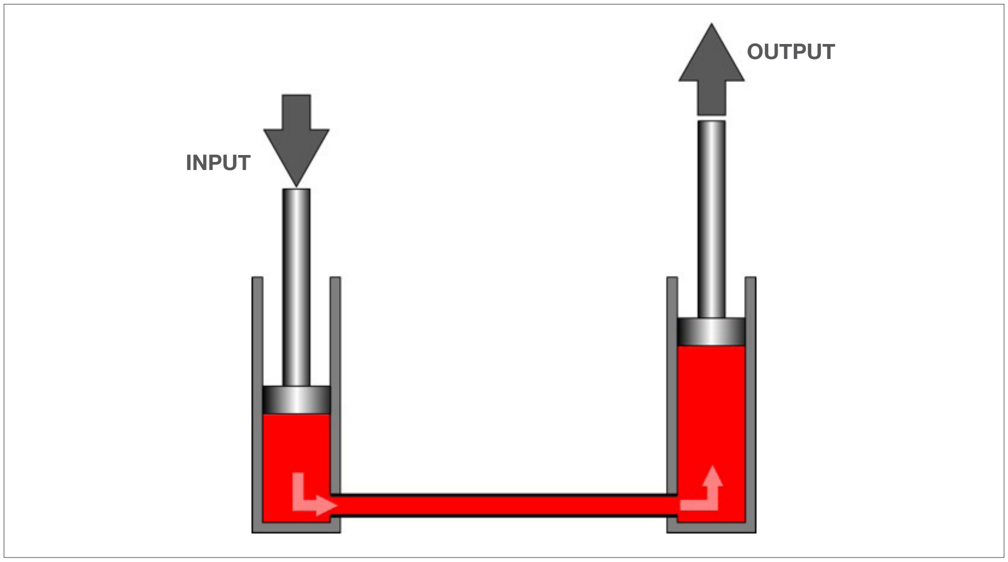

Fig. 1.4 Transmitting movement

An arrangement no more complicated than this is therefore capable of transmitting movement from one place to another and in theory there is no limit to how far apart the input and output cylinders can be. Furthermore, the output piston can be in a different orientation relative to the input so the movement can be converted from 'up and down' to 'side-to-side' for example. Not only is there no theoretical limit to the distance between the two cylinders but also the route taken by the interconnecting pipe can be as tortuous as it needs to be, that is to say it can follow walls and ceilings or be attached to convenient parts of the machinery as required. If the movement of the output cylinder means that it has to pivot as its piston extends and retracts then a flexible mounting can be used to attach the cylinder and a flexible connection can be incorporated into the pipe (normally in the form of a reinforced rubber hose). If the output movement needs to be a rotation rather than a linear up and down or side-to-side movement then a hydraulic motor could take the place of the output cylinder thus converting the input linear movement to an output rotary one. Finally, multiple outputs can all be connected to the input cylinder if necessary so that the input power can be shared between several output devices and distributed to wherever it is required.

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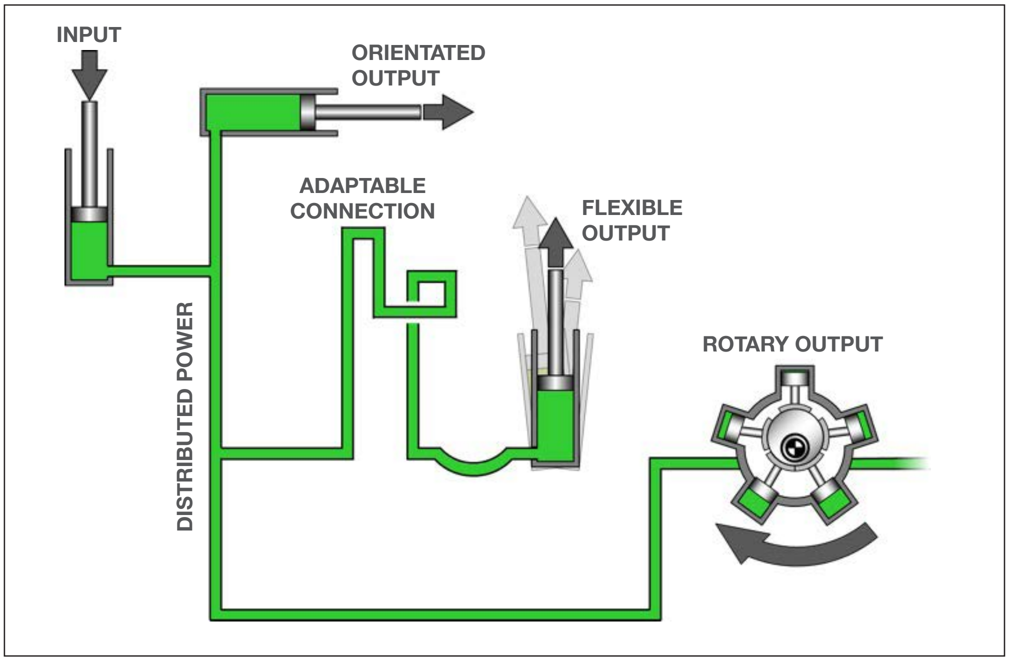

Fig. 1.5 Transmission, conversion and distribution of input power

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Closing off the opposite side of a cylinder, sealing the rod and adding an extra connection means that the piston can now be pushed hydraulically in both directions (double acting) and does not have to rely on gravity or any other means to retract it. The same also applies to hydraulic motors of course which can normally be driven in either direction.

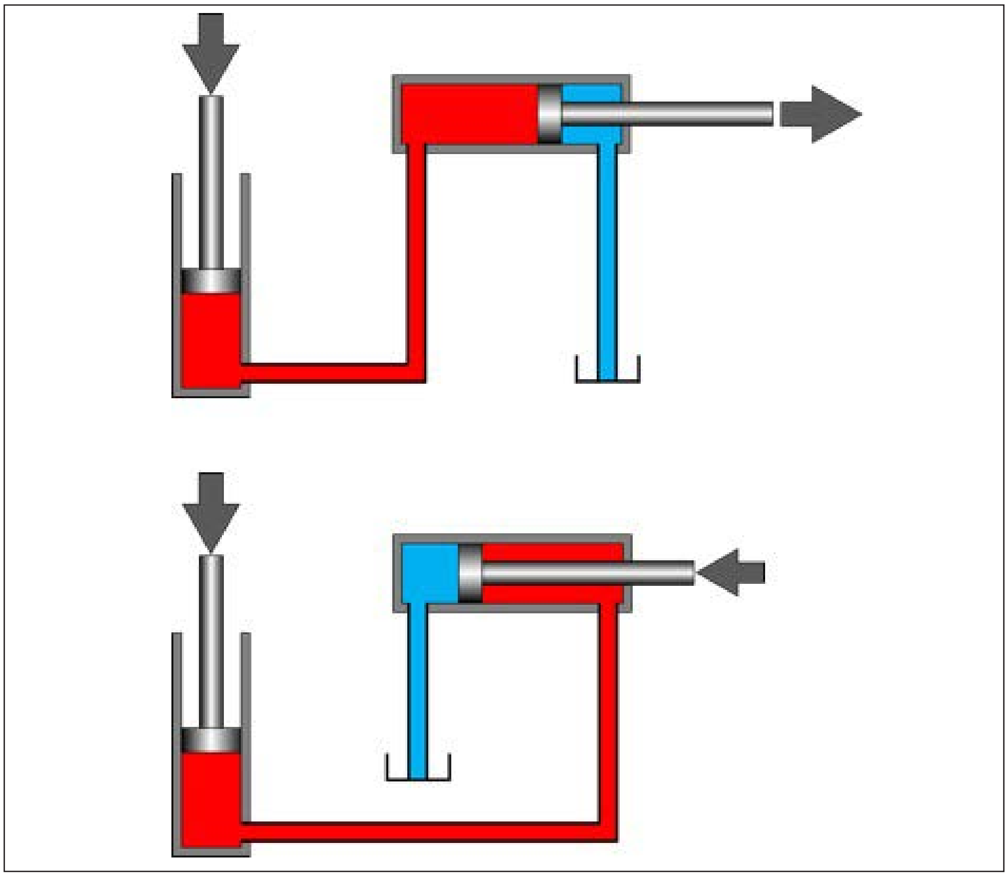

Fig. 1.6 Double acting cylinder