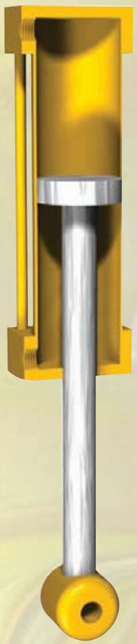
Since the beginning of time, long before written history, humankind has searched for ways to conveniently transmit energy from its source to where it is needed and then convert the energy into a useful form to do work. This chapter introduces the fluid power field as an approach that provides an effective means of transferring, controlling, and converting energy.



Objectives

After completing this chapter, you will be able to:

- Define the terms fluid power, hydraulic system, and pneumatic system.
- Explain the extent of fluid power use in current society and provide several specific examples.
- List the advantages and disadvantages of fluid power systems.
- Discuss scientific discoveries and applications important to the historical development of the fluid power industry.

Chapter 1

Introduction to Fluid Power

The Fluid Power Field

Selected Key Terms

The following names and terms will be used in this chapter. As you read the text, record the meaning and importance of each. Additionally, you may use other sources, such as manufacturer literature, an encyclopedia, or the Internet, to obtain more information.

actuator
Archimedes
Bernoulli, Daniel
Boyle, Robert
Bramah, Joseph
Charles, Jacques
compact hydraulic unit
cup seal
da Vinci, Leonardo
fluid compressibility
fluid power
Hero
hydraulic
hydraulic accumulator
laminar
Pascal, Blaise
pneumatic
pump
Reynolds, Osborne
Torricelli, Evangelista
von Guericke, Otto
water screw
waterwheel
Watt, James
windmill

Internet Resources

www.ideafinder.com/history/inventors/watt.htm
The Great Idea Finder
Provides information on James Watt and other inventors who made major contributions to industrial development during the Industrial Revolution.

www.island-of-freedom.com/pascal.htm
Island of Freedom
Provides details of the contributions of Blaise Pascal and others to science, mathematics, and philosophy.

www.nfpa.com
National Fluid Power Association
A good overall review of the basic aspects of fluid power systems. Go to the Our Industry section of the site.

http://library.thinkquest.org/3044
Oracle Education Foundation
Provides insight into Leonardo da Vinci as an artist and inventor.

www.en.wikipedia.org/wiki/hydraulic
www.en.wikipedia.org/wiki/pneumatic
Wikipedia: The Free Encyclopedia
Include information on history and operation of hydraulic and pneumatic power-transmission systems. Additional sites are listed that can provide information on specific fluid power system elements.

Definition of Fluid Power

The basis of ***fluid power*** is pressurized fluids. These fluids may be either liquids or gases. The fluids are incorporated into physical hardware systems that generate, transmit, and control power in a wide variety of consumer and industrial applications. Today, it would be difficult to identify a product that has not been affected by fluid power at some point along the route from raw material to final installation.

Fluid power systems are versatile contributors to industry. Applications range from brute force needed in heavy industry to the sensitive positioning of parts in precision machining operations, **Figure 1-1.** The systems are generally grouped under the two broad classifications of ***pneumatic*** and ***hydraulic.*** Pneumatic systems use gas, usually air, while hydraulic systems use liquids, usually oil. Other fluids are often used in special applications.

Fluid power is one of the three types of power transfer systems commonly used today. The other systems are mechanical and electrical. Each of the systems transfers power from a ***prime mover*** (source) to an ***actuator*** that completes the task (work) required of the system.

Fluid power systems use the prime mover to drive a ***pump*** that pressurizes a fluid, which is then transferred through pipes and hoses to an actuator, **Figure 1-2.** Mechanical systems transfer power from the prime mover to the point of use by means of shafts, belts, gears, or other devices. Electrical systems transfer power using electrical current flowing through conductors. Typical applications in business, industrial, and consumer products and systems use combinations of fluid, mechanical, and electrical power transfer methods.

Figure 1-1. Equipment used in construction and street maintenance is an example of a fluid power application commonly encountered in daily life. This backhoe is capable of producing the brute force needed to break and move concrete. (Deere & Company)

Fluid Power Industry

The fluid power industry is a complex entity. It includes education, design and manufacture of components, design and assembly of systems using those parts, and troubleshooting and maintenance needed to keep the systems performing efficiently, **Figure 1-3.** In addition, a complex sales and distribution system assures users access to replacement components and information concerning service, new and improved component designs, and new system applications.

Figure 1-2. Many consumer items make use of fluid power in their operation. This garden tractor has a hydrostatic transmission. (Used with permission of CNH America LLC)

Figure 1-3. The service of fluid power systems in business and industry provides employment for many highly trained individuals. (Photo: Atlas Copco)

Growth of the fluid power industry has required a parallel growth in the number of people who understand and can work effectively with fluid power systems. These people range from engineers responsible for designing the components to mechanics responsible for maintenance and repair of fluid power equipment. The type of education and training available to prepare these people varies considerably. Formally organized programs exist in two-year technical and community colleges, four-year universities, and in programs offered by component manufacturers. Many individuals seek fluid power training after exposure to the field through their jobs.

The fluid power industry is a broad field and a key contributor to the success of many businesses and industries. Fluid power is extensively used in manufacturing, construction, transportation, agriculture, mining, military operations, health, and even recreation. The list is almost endless. Applications vary and components have different appearances in the various applications. System sizes range from miniature to massive, but fluid power principles provide the needed power, force, and control.

Fluid power has been a key contributing factor in the development of current agricultural equipment. Modern farm equipment uses hydraulics extensively. These uses range from simple hydraulic cylinders that raise and lower implements to complex devices that maintain clearances, adjust torque, and provide easy control of speed and direction on tractors and a variety of specialized planting, harvesting, and processing equipment.

Fluid power is used in some form in all modern transportation systems designed to move people and products. These uses range from automobiles to complex, wide-body aircraft found on international flights. Specific examples of the application of fluid power principles include hydraulic and pneumatic braking systems, power-assisted steering found on most forms of wheeled vehicles, hydrostatic transmissions that provide almost unlimited speed and torque control, and suspension systems that use hydraulic and/or pneumatic dampening.

The construction industry is a very diverse industry. Construction activities include the building of residences and all types of commercial structures, roads and highways, irrigation systems, harbor facilities, and a wide variety of other construction-related activities. The industry makes use of many types of earth-moving equipment, material-handling equipment, and specialized fastening and finishing devices. Examples of typical applications that make use of fluid power include: backhoes for excavation; cranes for moving, lifting, and positioning materials; vibrators for consolidating concrete after it has been placed; and nail-driving apparatuses.

Manufacturing organizations extensively rely on fluid power. Applications range from huge presses in automobile body fabrication plants, which form body panels, to packaging equipment for miniature parts in electrical component manufacturing operations. These applications use hydraulics and pneumatics to make the equipment operate as needed. Required characteristics range from huge forces to draw metal into desired shapes, to a gentle nudge accurately positioning a part for machining, to the deliberate movement of sanders performing a final finish sanding. Fluid power can easily provide each of these characteristics. In many installations, the desired results can be obtained using off-the-shelf equipment. In many other situations, standard components may be used to assemble circuits and systems to produce the desired result, **Figure 1-4.**

Figure 1-4. Fluid power applications have been used during the manufacture or processing of most consumer products today. This carnival ride makes extensive use of fluid power. (©2007 Jupiterimages and its licensors. All rights reserved.)

Mining companies use fluid power both in open-pit and underground operations. Spectacular examples of an application in this industry are the huge shovels used in coal strip mining operations. These shovels remove the overburden from veins of coal that are near the surface. Some of these shovels are several stories high and they can remove multiple cubic yards of material during each pass of the scoop. The shovels use large numbers of fluid power systems and circuits for movement and control. Other open-pit mining operations use more standard front-end loader and truck designs for loading and moving ore. In addition, many fluid power applications, both pneumatic and hydraulic, can be found in mine drilling, crushing, and material-handling equipment. Fluid power applications are especially desirable in underground mining locations. Accumulations of gas may produce potentially explosive conditions, limiting or preventing the use of electrical devices.

Land, sea, and air defense forces use fluid power to assist in moving personnel, supplies, and equipment to support their operations. The military makes use of a full range of fluid power components and circuits. Many of these parallel civilian commercial applications, but others are highly specialized and are not directly duplicated in commercial applications. Hundreds of applications exist, ranging from power-assisted steering of land vehicles to the precision positioning of rocket launchers for air defense, **Figure 1-5.**

Fluid Power Systems

Fluid power is a highly versatile power transmission system, as illustrated by the range of applications discussed earlier in this chapter. No system, however, is entirely suitable for all applications. All power-transmission systems have characteristics that are desirable in one application, but turn into disadvantages in other situations. A system cannot have every desired advantage without disadvantages. Understanding system characteristics as well as what is needed for a particular result will help in producing an effective and efficient application.

The range of applications that use fluid power makes the development of a simple list of advantages and disadvantages difficult, since examples that do not "fit" can easily be found. This problem is further complicated by the inherent differences of the two major divisions of the fluid power field: hydraulics and pneumatics.

Figure 1-5. Complex defense systems make extensive use of fluid power. (©2007 Jupiterimages and its licensors. All rights reserved.)

System Characteristics

Although hydraulic and pneumatic systems share the characteristics of energy transfer by means of fluid pressure and flow, differences affect how and where they are applied. These differences include:

- Accuracy of actuator movement
- Operating pressure
- Actuator speed
- Component weight
- Cost

Accuracy of movement

Fluid compressibility is the inherent characteristic that produces the difference between hydraulic and pneumatic systems. A gas is compressible, while a liquid can be compressed only slightly. Hydraulic systems, therefore, can produce more accurate, easily controlled movement of cylinders and motors than pneumatic systems. Compressibility produces a more "spongy" operation in pneumatic systems that is not suitable where highly accurate movement is required.

Operating pressure

Hydraulic systems can operate at much higher pressures than pneumatic systems. Hydraulic system operating pressure ranges from a few hundred pounds per square inch (psi) to several thousand psi. Pressures of more than 10,000 psi are used in special situations. Pneumatic systems, in contrast, normally operate between 80 to 120 psi. Extremely high–pressure pneumatic systems normally are not used.

Actuator speed

Pneumatic systems are commonly used when high-speed movement is required in an application. Rotation speeds of over 20,000 revolutions per minute (rpm) are possible. Rapid-response cylinder operation is also possible with pneumatic systems. These designs are generally found in situations involving lighter loads and lower accuracy requirements.

Component weight

System operating pressure affects the structure of components. Hydraulic systems operate at higher pressures, requiring the use of stronger materials and more-massive designs to withstand the pressure. Pneumatic systems operate at much lower pressures and, therefore, can be manufactured using lightweight materials and designs that minimize the amount of material.

Hydraulic applications tend to involve equipment that handles heavier weights, requiring both higher system operating pressure and physical strength of machine parts. **Figure 1-6** shows a front-end loader. The cylinders used to operate the bucket must be of a construction that can withstand high system pressure and the heavy load of the bucket and its contents.

Pneumatic systems tend to involve applications where ease of handling and lightweight are critical for effective operation of the tool or system. **Figure 1-7** shows a pneumatic grinder being used on a large metal casting. The grinder is lightweight and very portable. The tool is easily manipulated by an individual and constructed to provide a long service life.

Figure 1-6. Hydraulic systems are commonly used in applications where high system pressures are needed to complete the required work. (Deere & Company)

Figure 1-7. Pneumatics are commonly used where high speeds and lightweight tools are needed. (Photo: Atlas Copco)

Cost

The cost of fluid power systems ranges widely. A variety of situations exist and a number of solutions are available for each one. The solution selected to solve the problem directly affects the cost. Understanding system advancements, basic characteristics of hydraulic and pneumatic systems, and knowing which standard components are available are necessary to produce a system that does the best job at the lowest cost.

The cost of system operation is a factor that must be considered. Generally, pneumatic systems are more expensive to operate than hydraulic systems. This cost can be directly associated with the compression, conditioning, and distribution of air. Careful maintenance to eliminate leakage can greatly reduce operating cost.

Advantages and Disadvantages of Fluid Power Systems

Fluid power systems have several advantages and disadvantages when compared with mechanical and electrical power transfer systems. Several of the important advantages and disadvantages of fluid power systems are presented in the next two sections.

Advantages

The following list of advantages applies to both hydraulic and pneumatic systems, except as noted.

- An easy means of multiplying and controlling force and torque.
- Infinitely variable speed control for both linear and rotary motion.
- Overloading the system simply stalls the actuator without damage to the components.
- Provides an easy means of accurately controlling the speed of machines and/or machine parts.
- Provides the ability to instantly stop and reverse linear and rotary actuators with minimal shock to the system.
- Systems easily adapt to accommodate a range of machine sizes and designs.
- Systems readily adapt to external control methods, including mechanical, pneumatic, electrical, and electronic systems, **Figure 1-8.**
- Systems can easily provide component lubrication.

Figure 1-8. Both hydraulic and pneumatic systems can be readily adapted to external control systems, including state-of-the-art electronic designs. (Photo: Atlas Copco)

- Large volumes of compressed air may be easily stored in pneumatic systems to provide energy for intermittent, heavy system demand, **Figure 1-9.**
- Pneumatic systems provide clean operation with minimal fire hazard.

Disadvantages

The following list of disadvantages applies to both hydraulic and pneumatic systems, except as noted.

- Higher safety factors associated with high-pressure oil and compressed air.
- Susceptibility to dirty environments, which can cause extreme component wear without careful filtration.
- Fluid leakage and spills cause a slippery, messy work environment around hydraulic equipment.
- Fire hazard with hydraulic systems using combustible oils.

Figure 1-9. Pneumatic systems can easily store large volumes of compressed air to meet the intermittent high demand of some systems. The vertical tank on the right serves as a storage area for compressed air. (Photo: Atlas Copco)

- Special handling and disposal procedures for hydraulic oil required by environmental regulations.
- High cost of compressing and conditioning air for use in pneumatic systems.
- Reduced accuracy in actuator speed control in pneumatic systems caused by compressibility of air.
- Noise level of pneumatic systems when air is directly exhausted to the atmosphere from components.

Historical Perspective of Fluid Power

Awareness of the historical background of our civilization, our particular culture, and our nation are generally considered an important part of the preparation to be a responsible citizen. This awareness provides an appreciation of our current situation by providing information about the origin and development of cultural, religious, and political ideas, principles, and systems. Likewise, an awareness of the historical development of a technical field of work should provide an appreciation of what we have, some idea of how it was achieved, and an appreciation of the cultural changes associated with the technical field.

This section provides a brief discussion of some aspects of technical development and innovation as viewed by Western culture. Volumes of information are available on developments throughout history involving Islamic and Eastern contributions as well as those reflecting Western thought. Fluid power, as the term is currently used in our society, describes a relatively new field. However, the roots of this field extend far back into history.

Historical Awareness

The use of fluid power has developed along with civilization. The natural movements of air and water were probably the first sources of power used by early humans. It is speculated that the use of crude sails to reduce the effort to move boats was the first attempt to harness this natural power, **Figure 1-10.** These early applications were followed by the development of more sophisticated systems, which eventually lead to the development of the windmill.

Figure 1-10. People have used the natural movement of both air and water throughout history to reduce work and aid in transportation. Using sails on ships is an example of using fluid power (wind). (©2007 Jupiterimages and its licensors. All rights reserved.)

Flowing water in rivers and streams was also used to assist in transporting boats and materials. The Egyptians, Persians, and Chinese built dams, ditches, and gates to form elaborate water-control and irrigation systems. These various applications eventually led to the development of variations of the waterwheel to lift water for irrigation purposes and turn simple mills. These early uses of fluid power were dependent on vast quantities of low-pressure air and water supplied by nature. They also were subject to variations in the weather, which made them somewhat unpredictable and only partially under the control of the operators.

The windmill and waterwheel were extensively used as power generating devices before and through the early years of the Industrial Revolution. Their power-generating capabilities were very limited, however, usually in the 5–10 horsepower range with a maximum of 30 horsepower. The development of large industrial complexes needed a larger and more-controllable power generating system, such as the steam engine developed by James Watt. This steam engine was not constructed until 1775.

It is doubtful whether the physical principles associated with modern hydraulics and pneumatics were fully understood in early history or even at the beginning of the Industrial Revolution. The physical principles and design features that we consider basic to the operation of fluid power systems were developed over several centuries. Many of these developments were the products of tinkerers more than due to an understanding of advanced scientific principles. Application of the scientific method played an ever-increasing role in the development of both fluid power theory and machinery design. The ***scientific method*** dictates accurate measurement, controlled testing, reproducibility of results, and systematic demonstration and reporting of results.

Individuals in History

The identity of individuals involved in the original development of the significant fluid power scientific principles has been lost to time. One of the factors that makes the identification of individuals difficult is that many of the practical solutions were considered below the dignity of "pure" science and, therefore, never recorded. Several individuals, however, need to be recognized as having made important discoveries. Other individuals contributed by bringing together a group of known elements to form a principle that has become basic to the fluid power field.

Archimedes is credited with the discovery of the principle of buoyancy in the third century BC. Folklore relates that discovery to the need to establish the amount of gold in the king's crown. Archimedes did extensive work with mathematics and other scientific principles. Two volumes of his known manuscripts deal with hydrostatics and floatation. He is also credited with the invention of the water screw, **Figure 1-11.** This device has been used to lift and move water for centuries. It has also greatly influenced the development of pumping devices in the fluid power field.

Hero is another individual who is recognized as contributing basic knowledge to the area of fluid mechanics. His work appears to have been done in the second century BC, although no specific dates have been established. Historians often considered him to be a recorder of information, rather than an originator. Nevertheless, Hero is popularly identified with a rotating, steam-jet device. At the time,

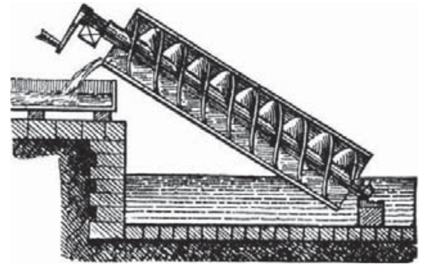


Figure 1-11. Archimedes is credited with the design of the water screw, which has been used to move and lift water since the third century BC. The basic principles found in this device are still used in modern fluid power components. (©2007 Jupiterimages and its licensors. All rights reserved.)

the device was considered to be an interesting toy, rather than a practical machine. His more practical and enduring contributions relate to basic concepts of fluid flow and the study of the principles of the siphon.

Leonardo da Vinci is a name commonly associated with the fine arts, but he also must be considered an equal genius in many other fields. During the latter part of the fifteenth and early part of the sixteenth centuries, he worked extensively in the engineering and architectural fields in Italy and France. He made many contributions in the fields of mechanical design and fluid mechanics that involved the flow of water, hydraulic machinery, and principles that closely match the later work of Pascal. As with many other early scientists, his work was recorded as private notes, many of which have been discovered only in recent years.

Blaise Pascal is usually credited with the basic principle that is the foundation of the fluid power industry, **Figure 1-12.** During his relatively short life (1623–1662), he experimented extensively with liquids and mechanical devices, including siphons, syringes, and tubes. This work produced the proof that many previous mathematicians and scientists had sought:

> In a fluid at rest, pressure
> is equally transmitted in all
> directions.

He is also credited with demonstrating and clearly defining the principles involved in the hydraulic press: multiplication of force, and piston movement relationships.

Figure 1-12. Blaise Pascal developed during the 1600s what is now called Pascal's law. He is one of a number of individuals who worked during the fifteenth through the eighteenth century identifying and proving basic principles by using the scientific method. (©2007 Jupiterimages and its licensors. All rights reserved.)

The English scientist ***Robert Boyle*** (1627–1691) was one of the first to work with the characteristics of gases. He referred to this as the "springiness of air." By direct measurement, he was able to establish:

> If the temperature of a dry gas is
> held constant, its volume inversely
> varies with its pressure.

Today, this principle is referred to as ***Boyle's law.***

As in most other situations where new laws or principles are under development, Boyle was not the only person to do fundamental work in the area of gases. ***Otto von Guericke*** (1602–1686) from Germany was also involved in experimentation with gases. He developed a vacuum pump in 1650. He used this pump to demonstrate the pressure of the atmosphere by pumping the air from a sphere constructed of two equal parts. Once the air had been removed, the pieces could not be pulled apart by horses.

An Italian, ***Evangelista Torricelli*** (1608–1647), is recognized as having identified the principles that affect fluid flow. He also did extensive work in the field of mechanics and had an influence on the development of many scientific principles. Today, he is generally associated with the development of the barometer. However, close analysis of historical data indicates the basic principles were tested by others with Torricelli properly interpreting the results.

The French scientist ***Jacques Charles*** (1746–1823) provided another key element to understanding fluid power principles. He developed a law relating to the effect of temperature on the volume of a gas:

> All gases expand or contract in direct proportion to the change in absolute temperature.

Charles' law combined with Boyle's law form the ***general gas laws,*** which are fundamental to any calculations done for gases today.

Daniel Bernoulli (1700–1782) is credited with laying the foundation of hydrodynamics. Although his name is applied to the Bernoulli theorem, some historians contend that his 1738 publication *Hydrodynamics* does not include specific formulas. He extensively studied both static and dynamic fluid phenomena. His contemporaries and successors considered his work to be the first specific principles on fluid movement.

James Watt (1736–1819) was a productive inventor who is usually thought of with respect to the steam engine, **Figure 1-13.** His inventive genius went well beyond this device, however. He impressed his contemporaries as the individual who provided mankind with devices that had the potential of producing unlimited power. As new designs were developed to meet the power demands of the Industrial Revolution, Watt developed, or caused to be developed, new manufacturing techniques that greatly influenced the Industrial Revolution.

English engineer ***Joseph Bramah*** (1748–1814), with his assistant ***Henry Maudslay*** (1771–1831), invented the cup seal. This seal greatly contributed to the practical application of fluid power devices. The cup seal enabled the development of devices requiring pressurized liquids and gases to operate with little leakage. Bramah went on to build the first functional hydraulic press, which had extensive application in the fluid power industry.

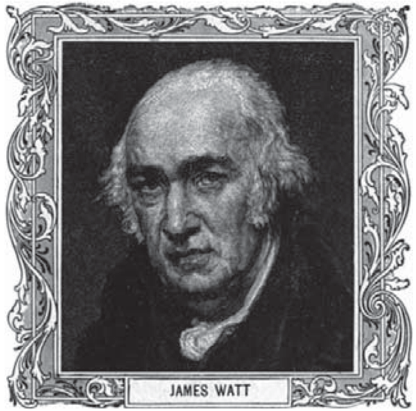


Figure 1-13. James Watt perfected the steam engine and greatly influenced the development of the Industrial Revolution. Many of his ideas were used in the development of pumping devices. (©2007 Jupiterimages and its licensors. All rights reserved.)

Maudslay went on to develop numerous devices and is generally considered to be the father of the machine-tool industry.

Lord William Armstrong (1810–1900) developed a hydraulic accumulator that made a major contribution to the development of the early fluid power industry. An ***accumulator*** stores excessive pressurized fluid from the pump until needed during peak system operation. The Armstrong accumulator was basically a large, vertically positioned cylinder with a weighted ram. These devices were extensively used during the late nineteenth century in large, centralized, pressurized-fluid systems found in major cities throughout Great Britain.

Osborne Reynolds (1842–1912) established by direct observation that two types of fluid flow exist: ***laminar*** (smooth and steady) and ***turbulent*** (chaotic and rough). The observations he made in 1883 eventually led to the development of a formula that produces a dimensionless number today called the Reynolds number. The ***Reynolds number*** is considered one of the basic parameters of fluid mechanics.

Applications of Fluid Power through History

Fluid power as it is know today has been under development for thousands of years. It has experienced rapid growth since the onset of the Industrial Revolution. The previous section introduced some of the many individuals credited with identifying the basic concepts that resulted in continued industrial growth. This section presents some of the concepts and applications of fluid power from a historical perspective.

Antiquity

The origins of fluid power are difficult to identify. Recorded evidence does not exist and the relationships that eventually produced important developments are not evident in most cases. Archeology gives us many hints, but speculation still plays a major role in our current thinking about how existing scientific principles and mechanical devices were developed.

Three items that are very essential to the existence and comfort of humankind are associated with fluid power developments:

- Transportation.
- Movement of water.
- Generation and transmission of power.

These elements have had far-reaching effects on the development of our industrial society.

Artwork from Egyptian tombs that date to 2500 BC shows reed boats with bipod masts and sails designed for the special problems associated with river sailing. ***Sails*** for the propulsion of ships continued to be refined through the ages. Many sailing principles were applied to the development of windmills and, eventually, pneumatic components.

Movement and control of water for irrigation, flood control, and municipal water systems also produced ideas that eventually were used in fluid power systems. Controlling the annual flood of the Nile River and moving water for irrigation purposes during the remainder of the year produced a better understanding of water flow in channels. Archimedes is credited with inventing pumping devices that were used in the Nile Delta for irrigation purposes. Applications for moving and pumping water were also developed in the Islamic world, especially in Persia. The most common design, the ***water screw,*** is still used in parts of Egypt and other areas of the world for moving or lifting small volumes of water. The Roman Empire constructed great aqueducts for the movement of water. Ruins of these systems can still be found throughout the territories the Romans controlled, **Figure 1-14.**

It is generally believed that the energy of running water was first effectively harnessed during the first century BC. Early ***waterwheels*** used a horizontal wheel rotated by a running stream. These designs typically developed one-half horsepower or less. Roman engineers developed vertical wheels that produced up to three horsepower. These wheels used both undershot and overshot designs. Undershot wheels were placed directly in a stream. Overshot wheels used water directed on the top of the wheel through sluice channels from dams or natural waterfalls. Waterwheels revolutionized the grinding of grain and were gradually adapted to other purposes.

The use of ***windmills*** for doing work did not appear until after the decline of the Roman Empire. The earliest record of a windmill-like device is from central Asia. These wind-driven devices were used to turn prayer wheels. Historians believe that the first "real" windmills were developed and used in central Asia about 400 AD.

Figure 1-14. An understanding of basic scientific principles has developed slowly throughout civilization. Ruins of the aqueduct system of the Roman Empire illustrate an early need for a practical understanding of fluid flow. (©2007 Jupiterimages and its licensors. All rights reserved.)

Middle Ages

During the Middle Ages following the fall of the Roman Empire, the development of new technology was extremely slow in Western civilization. In the Western countries of Europe, existing Roman structures were allowed to gradually deteriorate as major emphasis was placed on defense, conquest, development of monastic (religious) orders, and support of the Crusades. The Islamic world, however, continued to make progress on public water supply systems, public baths, and power-driven mills. Many of these ideas were introduced in Europe during the twelfth and thirteenth centuries by returning Crusaders.

At first, waterwheels were just a means of turning millstones for grinding grain for local consumption. Waterwheels began to be recognized as an important source of power for other uses during the fourth and fifth centuries. They were slowly adapted for use in sawmills, paper mills, iron mills, and mining operations. An example of the slow, but pervasive, growth of water power as a prime mover is that the earliest recorded use in England was in the eighth century with over 5000 in use by the eleventh century, **Figure 1-15.** Water mills were profitable operations and found in every community that had a suitable stream.

Windmills continued to be developed in several forms in the Near East, where easy access to water was limited. Records indicate that windmills were extensively used in Afghanistan and Persia, with a number of designs developed to control speed. Speed control was required because of strong winds in the area. Use of wind power spread throughout the Islamic world during the period.

The first recorded use of windmills in Western Europe was during the twelfth century, **Figure 1-16.** These mills were initially used for grinding grain, but were gradually modified for use in other applications, such as sawing lumber, pumping water, and manufacturing. Holland and the other "low countries" of Europe were prime users of these mills because of their flat terrain and consistent winds.

Windmills gradually developed with improvements in design and increases in size. Power output ranged from 4 to 5 horsepower for the average mill to over 15 horsepower for larger mills. At the peak of windmill use, Holland had over 8000 mills, with many of them having sail spans as large as 100 feet.

Figure 1-15. Thousands of watermills have been used throughout history as prime movers for grinding grain and powering early machines. Modern water turbines for electric generation and fluid power motors have evolved from these early designs. (©2007 Jupiterimages and its licensors. All rights reserved.)

Figure 1-16. Windmills have played an important part in the development of civilization. Their use was limited to areas with consistent winds, such as coastal and plains areas. (©2007 Jupiterimages and its licensors. All rights reserved.)

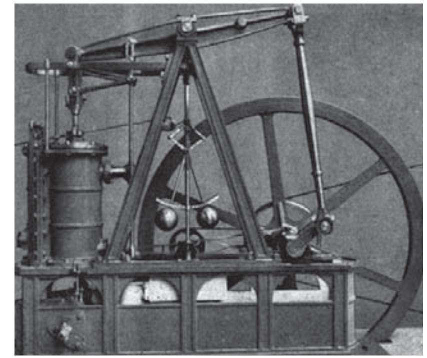


Figure 1-17. The steam engine provided a reliable, portable source of power. Its development is considered one of the key factors in the development of the Industrial Revolution. (©2007 Jupiterimages and its licensors. All rights reserved.)

Many mechanical improvements were made as water and windmills became prime sources of power. These improvements included methods of power transmission through shafts, cogged wheels, crude gears, and cams. These devices were needed to transmit the power and transform it into the type of motion needed to do the desired work. Many ingenious devices were developed that have contributed to the body of knowledge as the world moved toward the Industrial Revolution.

Industrial Revolution

The eighteenth and nineteenth centuries are often designated as the period in which an "industrial revolution" occurred. That period of history produced tremendous changes in world society, particularly in Great Britain. Great Britain had established extensive world trade, a strong financial base, large local reserves of iron ore and coal, and key individuals interested in the practical development of scientific principles. These factors combined to lead to the ***Industrial Revolution.***

Changes during the Industrial Revolution occurred much more quickly than those during the Middle Ages. However, identification of specific dates or events that started the "revolution" is not possible. It must also be emphasized that the industrial change was not just tied to mechanical devices, but involved changes as diverse as world trade and application of scientific methods. Nevertheless, development of new prime movers must be considered to be the key to the Industrial Revolution, **Figure 1-17.** The ***steam engine,*** internal combustion engine, and gas turbine all were developed during the period. Unlike water and windmills, these devices were mobile and not dependent on local weather or terrain conditions. Even with those new power development devices, water and windmills continued to play important roles in industrial power generation throughout the middle 1800s and much later in smaller, local and rural applications.

The use of machines instead of hand tools was another key to the changes of the period. These machines exceeded the capabilities of skilled craftsmen to develop products. They allowed production rates that met demands resulting from expanded trade areas.

The development of manufacturing increased the need for methods and devices to move water and transmit power. The procedures and devices developed to satisfy these needs are where fluid power, as we think of it today, began to emerge. Many of the early fluid power elements involved pumping water from mines or for manufacturing uses. James Watt designed steam-driven, reciprocating pumps that were used in the late 1700s and early 1800s. By the mid-1800s, these pumps were widely used. The East London Water Company operated a unit with a 100″ diameter cylinder and a stroke of 11 feet. By the 1870s, patents were issued for variable-stroke, piston pumps. The centrifugal pump was invented in the late 1600s, but was not generally used until the mid-1800s. The jet pump was also produced during this same period.

A key factor that allowed the development of many practical fluid power components was the ***cup seal.*** This type of seal uses the pressure within the system to force a sealing collar against a shaft or ram to prevent fluid loss, **Figure 1-18.** Invented in 1795, the cup seal allowed hydraulic presses to be built that both did not leak and could be continuously used.

Two other devices that were especially important to the development of fluid power during the 1800s were the ***hydraulic accumulator*** and the hydraulic intensifier. Large, weighted accumulators were used to store pressurized fluid from

Figure 1-18. Modern sealing devices are often taken for granted. However, their development in the late 1700s by Bramah and Maudslay was instrumental to the practical application of fluid power principles. (Photo courtesy of Apple Rubber Products, Inc.)

a pump during the idle time of a press or other machine. During peak operating time the charged accumulator assisted the pump by supplying high volumes of fluid needed for operation.

The ***hydraulic intensifier*** was used to more easily obtain high system pressures for use in bailing, metal forming, forging, or other applications. The intensifier, which usually consisted of some combination of large and small diameter rams, used the area differences of the rams to boost system pressure above the capability of the pump. This principle allowed the use of higher pressure even when the technology of the time did not allow pumps to operate at extremely high pressure.

Pressurized water was extensively used to distribute power to businesses and manufacturers in several cities in Great Britain. By 1900, it was considered economical to transmit power up to 15 miles from a centralized pumping station. These systems provided water under several hundred pounds per square inch of pressure that could be directly used for the operation of presses, hoists, and water motors. These systems continued in use until electrical generating and distribution systems were perfected.

Fluid power development and use during the nineteenth century was very extensive. This use involved the generation of power through the design of effective water turbines; the transmission of power using central power stations and elaborate distribution lines; and the use of fluid power in construction, manufacturing, and material distribution systems.

Recent history

The emphasis on the development of fluid power applications decreased as the use of electricity grew in the late 1800s and early 1900s. Development concentrated more in the heavy industrial and mobile areas where fluid power applications appeared to be most practical. Generally, these factors have promoted progress in fluid power applications in recent years:

- Development of new materials.
- Miniaturization of components.
- Effective electrical/electronic control.

Improvements were made in sealing devices and machining techniques that reduced both internal and external leaks. This, in turn, improved system efficiency. Reducing external leaks also allowed use in applications where cleanliness was an important factor. Water was replaced in hydraulic systems by petroleum-based fluids, which improved lubrication and eliminated the danger of freezing in cold climates.

Military applications contributed to the development of fluid power. A milestone occurred in 1906 when hydraulic systems first appeared on a warship, the battleship USS Virginia. These hydraulic systems replaced many mechanical and electrical systems. Since that time, all branches of the military have incorporated fluid power on numerous devices to solve problems in gunnery, materials handling, navigation, and support services.

The development and refinement of the concept of ***compact hydraulic units*** in the 1920s had a far-reaching effect, extending to today's fluid power applications, **Figure 1-19.** These self-contained systems include the power source, pump, and reservoir. The units have been applied to a full range of industrial and consumer applications. Central hydraulic and pneumatic power systems have remained in large industrial applications, but the more-compact direct system adds flexibility.

Figure 1-19. Compact power sources such as these hydraulic units have added flexibility to the application of fluid power. (Continental Hydraulics)

It has been the key to the development of today's large mobile hydraulics field.

The development of new materials and manufacturing techniques has promoted the design of new fluid power concepts and allowed practical application of old ideas, **Figure 1-20.** The miniaturization of components has produced new applications, while the combining of electrical/electronic control and fluid power systems has produced more effective machines. Two components that illustrate these factors are hydrostatic transmissions and servo systems. These units are heavily used in both industrial and consumer applications, **Figure 1-21.** Neither could exist in their present form without the sophistication of the present manufacturing community.

Today's automobile can be used as an example of the use of fluid power. The body of the vehicle is formed by huge hydraulic-powered presses. Hydraulically-controlled resistance welding equipment assembles those parts, while untold numbers of other hydraulic and pneumatic tools are used in the production of the additional parts and during the final assembly process. Intricate fluid power systems are also used in the steering, braking, and ride control systems of the vehicle, which promote safety and comfort of the driver and passengers.

Figure 1-20. Central power systems are often used in large manufacturing facilities to produce compressed air for pneumatic applications. (Photo: Atlas Copco)

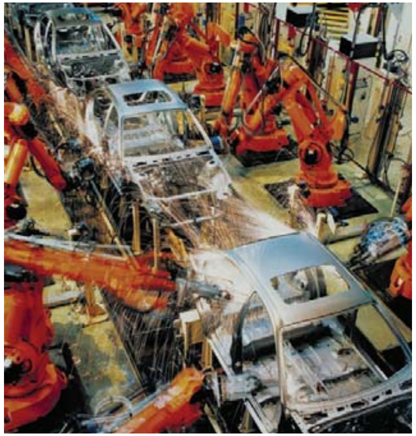


Figure 1-21. An automobile assembly line illustrates the diverse use of fluid power in industry today. A full range of both pneumatic and hydraulic applications can be found in such operations. (Photo: Atlas Copco)

Figure 1-22. Windmills have experienced a resurgence as prime movers in the windmill farms currently used for electrical generation. As energy costs rise, so does interest in harvesting this "free" energy. (©2007 Jupiterimages and its licensors. All rights reserved.)

To say the least, fluid power has grown tremendously during the 1900s and into the 2000s. Current space technology, manufacturing industry demand, and consumer interest indicate that this growth will continue into the twenty-first century, **Figure 1-22.**

Chapter Test

Answer the following questions. Write your answers on a separate sheet of paper.

1. Fluid power systems use ______ fluids to transmit power.
2. The physical components in a fluid power system are used to ______, ______, and ______ power to produce the desired results in an application.
3. The three power transfer systems commonly used today are ______, ______, and ______.
4. Name six industries in which fluid power applications contribute to daily operations and long term business success.
5. The ______ fluid power system can usually provide the best solution where lightweight and easily handled tools are a requirement.
6. The pneumatic fluid power system is generally considered to be the most expensive to operate because of the cost of ______, ______, and ______ the air.
7. Clean operation with minimum fire hazards are characteristics of which fluid power system(s)?
8. The earliest records indicating the use of natural air and water movement to reduce effort comes from archaeological discoveries in ______.
   A. Egypt
   B. Germany
   C. Holland
   D. Great Britain
9. It is generally believed by historians that much of the early development of fluid power was based on ______, rather than on an understanding of scientific principles.

10. James Watt, who perfected the steam engine, is credited with greatly influencing the Industrial Revolution through his development of new and innovative ______ techniques.
11. ______ and ______ are credited with the invention of the cup seal, which led to the development of the first functional hydraulics press.
12. Artwork from Egyptian tombs indicates that sails were used to assist in the propulsion of boats as early as ______ BC.
13. In early times, the movement and control of water for ______, ______, and ______ also produced ideas that eventually were used in fluid power systems.
14. The invention of new ______ is usually considered to be the key that allowed the development of the Industrial Revolution.
15. List three factors that have promoted progress in fluid power applications in recent years.