General Survey of Power and Machines.

The development of rotary motion.

Reciprocating rotary motion was used for boring; hand-drills of various types, bow-drills (used in Egypt from 2500 B.C.), and pump-drills using something akin to the fretworker's drill with spiral drive and "flywheel" weights (used from Roman times onwards) all illustrate the development of non-continuous rotary motion. Lathes also used recip. rot. motion - such lathes continued in furniture making until quite recently.

Continuous rotary motion - all derived from the wheel. First requirement was to mark out a circle. This could be done with stick and string for large circles, or compasses (e.g. wishbone or forked stick) for small ones. The use of compasses can be inferred from circles precisely inscribed on bone and clay before 3000 B.C.

Discs revolving freely on a fixed axis, or on an axle free to turn in a bearing, were used both in pottery-making and in transport from around 3500 - 3000 B.C. Made of wood and .. not much surviving evidence. For pottery-making, the bearing was a pivot and the wheel driven by the potter's hand or foot.

Wheeled vehicles appear to have originated in Mesopotamia around 3500 B.C. Wheels made of wood, usually tripartite (i.e. 3 segments).

Around 2500 B.C. the felloe (wooden rim outside disc) was introduced.
Nails used to provide hard-wearing surface, but leather tyres also used, fastened with copper nails.

Typical diameters of early wheels were between 1/2 and 1 metre.
Uses of wheeled vehicles: earliest for war engines and royal hearses.

1200 B.C., migrating hordes from north carried families and chattels across Palestine to Egypt in ox-carts with solid wheels. Use of wheel diffused widely, as also use of yokes for draught oxen. (e.g. Egypt, Cyprus, Poland, Denmark).

Spoked Wheels introduced for lightness and therefore speed, about 2000 B.C. The wheel as then constructed (hub with axle hole and spoke holes, 4-8 spokes, felloe) varied little up to last century (see "The Wheelwright's Shop" by G. Sturt).

The next thing to consider is the use of power and then the development of machines.

Power Sources.

Man. Ancient states had supplies of slaves who worked water-lifting machines, cranes, treadmills, etc.

Animals. Ox was the ancient draught-animal. Very slow and ponderous. Used yoke to couple it's drawing power to vehicle or machine. Horses, donkeys, mules were available, but the ancients never realized the difference in their anatomy from that of the ox, and so used the yoke instead of the collar-harness which came in about eight-10th century A.D. They also did not have proper horse-shoes. Thus a horse could pull only as much as 4 men (instead of 15) and a donkey was equivalent to only 2 men. As a horse requires 4 times as much food as a man, there was no economic incentive to use animal power.

Water mills and turbines. First introduced 65 B.C. in Greece. Used for corn grinding. The Greek (or Norse!) mill had vertical shaft directly rotating the upper mill stone. A fast jet of water from a mountain stream was directed against the blades - see sketch.

Greek or Norse water mill originated in Greece and Near East. Spread, reaching Ireland and China by 3rd and 4th century A.D.; probably in Denmark by 0 A.D.; still used in France in 1588, and very recently in Shetland, Faroes, etc.

These were (at least in early times) very inefficient, about 1 man-power, needing fast stream with large head. (But there were efficient versions - see Lecture 2).

Overshot and undershot water-wheels developed later. They had horizontal shafts and used gearing. Romans were responsible for the main development - the Vitruvian mill. This could grind 150 Kg of corn/hr as compared with 7Kg/hr achieved by two slaves. (About 3h.p.).

In England, water mills first mentioned in 762 A.D.; but there were 5,624 of them by Domesday Survey in 1086. Mainly used to grind corn, but came into use for fueling in the cloth industry. Then for tanning 1217, Saw-mills 1376. Even at Domesday, some used for stamping or crushing ore and for hammers. Later for blowing forges.

Windmills.

Were unknown to the Greeks and Romans, May have originated in the prayer-wheel, rather like a modern anemometer - these were reported about 400 A.D. Windmills used for pumping water and grinding corn in Persia about 950. These had vertical shaft and were rather like Greek or Norse water mill (above). This invention spread, to Far East in 12th century, and to the west. But the way it got to the west is not known, and western windmills were quite different in principle, being post-mills with 4 vertical sails attached to horizontal shaft. This is aerodynamically much more efficient, as whole sail area is used by wind all the time. From 13th - 14th century the windmill became the dominant power source in the Low Countries, N. Germany and W. Russia. Systematic land drainage and reclamation of 14th century may have relied on windmills, but first documentary evidence of this use is 1430 and it was not very common until 1600. First wind-driven saw-mill was 1592 at Uitgeest, Holland.

Tower mill, occurs around 1390. Has advantage that only the top of mill has to be turned to face wind - much lighter and easier.

Post-mill

Tower-mill

Steam (Mention long "pre-natal" history: see Needham)

Thomas Savery: born about 1650, FRS 1705.

Patent granted 25th July 1698 for "raising water by the impellant force of fire".

Steam pressure pumped water from container up a pipe. Then steam condensed and vacuum sucked water from below into the container. Never really worked properly. Used a clack valve.

Thomas Newcomen: born 1663, died 1729, established as ironmonger in Dartmouth about 1685. Frequently visited tin mines and knew their pumping problem. Realised he couldn't use pressure as a basis of practical engine, as technology not good enough; so relied entirely on atmospheric pressure. First record of his engine 1712, but he was experimenting 14 years before this.

Newcomen engines were a great success and were used in large numbers in coal mines and tin and lead mines (e.g. throughout Cornwall) and sometimes in very large sizes. But they had low efficiency and used enormous quantities of fuel (coal as a rule). Many mines therefore retained water wheels where possible.

James Watt: born 1736, died 1819 invented the separate condenser in 1765 and thus raised thermal efficiency. Partnership with Matthew Boulton (born 1728) entered upon in 1775 and numerous Watt engines made. Rotative motion obtained 1780, crankshaft and conn rod invention necessitating Watt's sun-and-planet motion. Governor fitted in 1787.

Richard Trevithick: born 1771, developed high-pressure steam engine around 1809 for winding duties at a Cornish mine. Steam road carriage 1801. Pumping engine at Coalbrookdale 1802 ahd 145 lb/in^2 pressure. Steam locomotive 1804, for Pen-y-daren Wonworks, hauled 25 tons at 4 m.p.h.

Internal Combustion.

First practical engine was a gas engine in 1859, but it had no compression stroke. The 4-stroke cycle invented by Beau do Rochas (French) in 1862.

N. A. Otto, born 1832, developed 4-stroke gas engine in 1878. Very successful, 35,000 manufactured by his firm.

Oil engines, 1873 onwards.

Rudolf Diesel, born 1858, patented diesel engine in 1892.

Gottlieb Daimler, born 1834, devised petrol engine with carburettor in 1885, successful V-engine in 1889. Used 4-stroke cycle.

Electricity.

Alessandro Volta, born 1745, announced his invention of the battery 1800.

Michael Faraday; born 1791, announced electromagnetic induction 1831.

Thereafter generation of electric power proceeded rapidly.

E.W. von Siemens born 1816
Henry Wilde, born 1933
S. A. Varley
Charles Wheatstone

} were all important in making advances in the 1860's.

Z. T. Gramme, born 1826, made first really practical dynamo 1870.

First power station 1882.

Electric railways at turn of century.

The development of machines.

We can start with the Greeks and Romans, but machines are much older. The Greeks recognized 6 "simple" machines: lever, wedge, screw, pulley, winch and inclined plane. "Complex" machines were combinations of these.

The lever has its origins lost in antiquity. Pincers are a development. Often used in association with a spring (usually a natural one, e.g. bough of tree, skin, etc.).

The introduction of the wheel and of rotary motion had a great influence on the development of machines.

The real development of machines may be said to have started around 600-400 B.C. with the Greeks. Their concern with navigation and the theatre necessitated pulleys and winches.

The wood-turning lathe was known by 500 B.C.

The screw was certainly known before Archimedes (287-212 B.C.)

Precision screw-cutting mechanisms were developed by Hero of Alexandria in the 1st century A.D.

The Greek mathematicians applied themselves to the theory of machines - e.g. Pythagoras and Archimedes.

The Alexandrian school of mechanics flourished between 300 B.C. and 400 A.D.: mainly theoreticians, but some practical men. For example, Philo (around 0 B.C. - early A.D.) used pistons and cylinders. Simple steam devices also appeared, but only as toys. Hero developed the crank, cam-shaft, and rotation using counter-weights. A later member of the school, Pappus (c A.D. 300), studied the principles of gearing.

The Romans displayed little inventive genius, but perfected some machines they had inherited from the Greeks. Their work has been described as a mechanical revolution. The basis of it was the widespread use of rotary motion, e.g. water-mills and treadmills. The Romans could raise water from deep mines by windlasses driven by treadmill, and they used water-raising devices to develop irrigation on a large scale, especially in N. Africa and Spain. They applied power sources to machines.

The Dark Ages lost a lot of this progress. Industrial urban centres gave way to rural family units and a reversion to hand power. Recovery set in 10th - 12th century A.D., and old ideas were re-introduced. Woodworking tools improved, the wheelbarrow was developed (although it had long been known in China). By the use of cam-shafts, hammers and crushers could be operated by water-power. Later, bellows were thus operated. Saws could be driven by using cam for one stroke, spring return for the other (e.g. by using springy pole).

Gearing of various kinds came into use during the later middle ages (c 13th century), including the screw jack (and also the ratchet).

Leonardo da Vinci (1452-1519) thought out many mechanisms and their efficiency. He applied science to technology.

The crank and connecting rod (as a mechanism - the simple crank was known in antiquity) emerged in the 15th century. It was used for generating rotary motion from reciprocating motion, e.g. from a treadle; but it could also give reciprocating motion from rotary motion as generated by e.g. a water wheel - e.g. for force and suction pumps.

Cranes are an important class of machine. The Romans knew about them (although the Greeks also did, in effect, because they understood pulleys), and Vitruvius the inventor of the water mill (horizontal) (1st cent. B.C.) wrote a treatise on them. Medieval cranes could swivel and were used in ports especially.

Machines have come a long way since medieval times, but we shall not pursue their development further at present.