



The Pre-Industrial Sources of Power: Muscle Power

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The first of the series by J. Kenneth Major, on the harnessing of human and animal sources of energy.

Today industry and the machines that run it are thought of as synonymous with pollution and depletion of the world's natural resources. Before the Industrial Revolution, and indeed during its early stages, men employed machines which neither caused pollution nor depleted finite natural resources. Wind, water, tide and muscle - both animal and human - provided sources of energy that are still available to man and are still used to power simple machines in many parts of the world today. In this special feature, edited for History Today by Professor Walter Minchinton, Head of the Department of Economics at Exeter University, the history of the way man used these resources of energy is discussed in four articles, and the question is raised in the context of the present energy crisis: can these resources be harnessed anew?

The muscle-power of both men and animals has been used to drive machines since Pharaonic times. The ways in which their efforts have been harnessed to machines fall conveniently into two categories. The first is through the application of their power to the vertical machine, the second to the horizontal machine. A typical example of the former is the notorious prison treadmill in which men worked in the inside rim of a large diameter wheel whose shaft then acted either as a windlass or as the crank to drive a simple machine that required reciprocating motion. A similar result was obtained by men or animals treading the outside rim of the wheel.

The horizontal machine driven by muscle-power was not only much more efficient than the vertical machine, but came in a greater variety of forms. It was more efficient because effort could be applied with a greater mechanical movement or was more useful since it could incorporate gearing that increased speed or accepted a greater load. Of the various principal types of horizontal machine, the first was the one in which the animal was coupled directly to the moving parts: the apple-crusher in a cider mill is the best-known example in Britain. Here a heavy stone roller was rotated by an animal pulling it around a circular trough in which the apples to be pulped were placed. The second type used the animal to turn a drum mounted on a central shaft to wind up a rope and so bring water out of a deep well or minerals out of a mine. The third type was the one that had the greatest application for our agricultural and industrial growth: here the machine was geared to create a mechanical advantage in the use of animal-power. These geared machines fell into two types: the first was that whereby the animal was harnessed to a shaft so that it passed round outside the machine but had to step over the drive shaft between it and the machinery it was powering; the second was that whereby the animal was harnessed under a large diameter

gear wheel and the drive to the other machinery was carried at high level. There were, of course, variants on these such as the paddle wheel and the oblique treadwheel. In the case of the paddle wheel the animal stood harnessed on an inclined plane which was in effect a belt which moved under the animal, thereby transmitting power by means of gears or belting to the machinery. The oblique treadwheel was a circular tread plate on which the animal was tethered. The plate was then mounted with its shaft at an angle to the vertical, and, as the circular tread plate moved away from under the animal, a gear on the underside of the plate transmitted power to the machinery by means of the shaft.

Animal-powered machines, looking remarkably like their historical ancestors, still carry out work in many parts of the world. The ancient Egyptians used animal-power to raise water from the Nile to fill their irrigation channels, as do Egyptians today. The saqiya is a machine which transmits the drive of an ox or camel through primitive gears to lift water through a chain of pots to a higher level. Whilst this was originally created out of timber, giving the minimum of efficiency, iron examples are still in use in Portugal side by side with crude wooden examples. The most significant machine driven by animals in the Roman period was the 'hourglass' mill which can be seen in Pompeii, Ostia, Capernaum and, indeed, in London. In this machine the rotating upper stone acted as the hopper and the grain was ground between it and the conical fixed lower stone. Whilst the direct drive corn mill was reaching this level of efficiency, the method of crushing olives in Rome changed from the hard labour of beating the fruit in a mortar with a pestle to employing a roller crushing mill. Here a pair of hemispherical stones rotated over the olives as a beast pulled the whole around the sunken trough in which they lay.

Known to the Romans, the treadwheel is the machine that has lasted longest in its original form. The use of the tread-wheel in which men, and later donkeys, trod the inside rim of a large diameter wheel to raise water and building materials is illustrated on several Roman carvings, and there are many examples dating from the Middle Ages in existence in Europe today. The great vaults and towers of the Gothic cathedrals of Europe were built with materials which were raised by a treadwheel. These could be permanent fixtures, as in Canterbury Cathedral, Beverley Minster and the Grotekerk in Haarlem, or could be temporary structures which were moved with the scaffolding as the vaults were built.

In England the use of the treadwheel for raising water lasted from medieval times up until the nineteenth century. Many examples still exist, mainly on the chalk uplands of the South, though they are also found on the chalk in Yorkshire. Their survival is largely due to the fact that they were used on large country estates. That at Greys Court, near Henley in Oxfordshire, the largest extant example, typifies the principles of these machines. A donkey, or man, trod the inside of the wheel and the windlass raised a bucket from a deep well. Because of the depth (200 ft), two buckets were used so that the weight of bucket and rope was counterbalanced and only the weight of the water remained to be raised. A natural development from the treadwheel in the large church used for raising materials, or from that used for raising water, was the tread-wheel crane for lifting materials into or out of a boat. Several examples of such cranes exist in Europe and, fortunately, two examples remain in England. The first, the dockyard crane at Harwich, though now preserved away from its original site, was built in 1660 and comes close to the pattern which was then common in Europe. Here two wheels, 16 ft in diameter, were mounted on a common shaft which was its windlass. The interest of this crane lies in the fact that it dates from the period when the Navy and its administration were being reformed after the return of Charles II and his Court from exile in Holland. In dimension and principle this crane derived from Dutch models. However, the crane arm at Harwich was all that rotated, although in many of the examples still existing in Germany, the crane arm and the treadwheels all rotate about a central vertical post. For example, the crane at Andernach on the Rhine, built in 1534, loaded millstones from nearby Mayen into the Rhine barges until 1911 when it ceased to work. The second English example at Guildford, on the Wey Navigation, had a single tread-wheel and was in reality no different from the Greys Court wheel except for the rotatable crane arm which could operate over a canal barge or over a cart on the bank.

The rope winding engine, used both for water raising or for raising men and minerals out of mines, was a horizontal machine with a direct drive. Several examples exist in Kent of the type of water raising drum mounted on a vertical shaft turned by a horse harnessed to an arm underneath. The best example of the winding drum used in mining is the machine now preserved at Wolaton Hall Museum, Nottingham. Here a horse walked in a circle of 26 ft diameter turning a winding drum 9ft 6in in diameter. It was an efficient, if somewhat primitive, method of raising men and coal out of a mine. The diamond mines at Kimberley in South Africa had dozens of such drums set up around the edge of the diggings to raise the spoil from the individual claims. The Stora Kopparburg mines in Sweden also had several 'one-up-one-down' versions of the horizontal winding drum around the edge of the great mine pit.

The direct-drive roller crusher had many uses. Almost every farm from Herefordshire to Devonshire appears to have had one for the making of cider. The crushing roller was usually mounted on the shaft to which the horse was harnessed. As the horse went round outside the stone trough containing the apples, the stone edge-runner rotated as it rolled in the trough. Roller crushers similar to those in the cider mills were used to crush minerals at mines or to work the clay in a clay pit attached to a brick and tile works. The example at Broxbourne in Hertfordshire is typical of those used in the clay mills that existed in England to serve the brick and tile industry. The production of blasting powder and gunpowder required a process of careful rolling and crushing between non-sparking stones, and although this was usually powered by water, examples exist in which the stones were drawn round by horses, as in the preserved machine in the gunpowder works at Ouderkerk outside Amsterdam. Roller crusher engines powered by horses were used in the oil-seed crushing industry. Whilst no examples of these machines remain in England, several do in Holland, of which those in the Open Air Museum at Arnhem and at Erve Kots in Gelderland are the best. In both, the horse rotated the stones, while further gears driven off the main shaft powered the stamps and turned the oil seeds on the roasting plate.

In Britain there was intensive use of men and their families on the land up until the middle of the eighteenth century, when agricultural labour became scarce in the North and in Scotland because of the growth of industry in the coal-rich areas. In Scotland the scarcity of labour led to the use of the thrashing machine, which Andrew Meikle patented in 1778, powering it with horses. In the North hand-thrashing had always taken place in the barn, so when the horse engine was installed to drive the thrashing machine it was housed in an additional building next to the thrashing barn. These buildings were usually some 20 ft in diameter and varied in shape according to the tradition of the area and the building materials available. They were frequently semi-circular with solid walls or polygonal with pillared corners. In Northumberland there were at least 575 such horse-wheel houses, or gin-gangs to give them their local name, although only one survives with its gearing and machinery intact. The horse wheel was mounted at high level so that the horses were harnessed to horns fixed to the spokes. Whilst these were designed specifically to deal with the process of thrashing so as to reduce the requirement for intensive seasonal labour, they quickly became the source of power for other farm activities. The example at Sawley Hall near Ripon was powered by up to six horses. The original thrashing machine stood in the barn, and in the rear of the horse-wheel house there was a pulley system from which a circular saw and turnip chopper were driven. At one stage an old blind mare was harnessed to the wheel, and she powered a small two-cylinder water pump which pumped rainwater back into cisterns on the roof of the Hall.

These engines are all known to have been basically wooden machines to which wooden or cast-iron gear teeth were added. With the growth of cast-iron products it was natural that this material should be used increasingly in agricultural machinery. The horse wheel became one of the first machines to be re-designed to make use of cast-iron. Cast-iron horse wheels were small and frequently mobile, consisting of a central shaft carrying the horse arm at low level so that the horse was harnessed with a trace from its collar to the horse arm. The main shaft carried a primary bevel gear engaging with a smaller bevel gear which powered the drive shaft going to the barn or other machinery. Such wheels were in use until the Second

World War and could be seen powering the endless belting elevator which lifted sheaves of corn on to a rick. They reached their ultimate in design in the horse engines employed on the American prairies. Large numbers of horses were used to drive these enormous reaping machines and the same teams were then used to cart the sheaves. In some cases twenty-four horses were harnessed to an engine, although twelve was the usual number. Whilst none of these American examples was British made, there was a considerable export of such machines from Britain to the rest of Europe, South Africa and Australia. For example, Reading Ironworks had agents in Berlin and Budapest, selling horse engines and thrashing machines. Wilders of Reading exported to South Africa and Hunts of Earls Colne to the Indian subcontinent.

The horse engine was used widely in industry in the eighteenth century. Research carried out by Dr. Tann of Aston University on the Boulton and Watt papers has shown that their steam engines were sometimes introduced into factories that had previously been powered by horse wheels. Arkwright drove his cotton-spinning machines by horse power before developing his water-powered cotton empire in the valley of the Derbyshire Derwent.

Many breweries had horse engines to provide power for the pumps and for the malt mills. Often the horse wheel was the drive wheel between the steam engine and the brewery. In the case of Morrell's brewery in Oxford, the horse wheel was the wheel between the waterwheel and the brewery. In this way, if the water was too low or the steam engine out of action, the brewery horses could be pressed into service so that it could continue production.

One of the less obvious uses of the horse engine was for grinding grain. Whilst this was rare in England, it was common in Holland, Belgium and Germany. There is a fine example at Woolley Park in Berkshire where there are two pairs of millstones driven by an 18 ft diameter horse wheel to which two horses were harnessed. The other conventional dressing machines of a corn mill were also driven by the same horse wheel. This survival is interesting because the situation is in a sheltered dry chalk valley. Whilst grain grew well in the area, there was no possibility of using a water-mill for the grinding of the grain and it seems that it was too sheltered from the prevailing winds to make a windmill worthwhile. In Holland, horse-driven corn mills in the towns ground buckwheat as a special service for the townspeople. Whilst the ordinary wheat would have been ground in windmills around the town, these horse mills were situated in the town centre at the back of a range of buildings. In the front would be a bakehouse and shop where poffertjes (fritters) and pancakes were sold for consumption on the premises.

Most of the foregoing examples of animal-powered engines were driven by horses, and sometimes by donkeys and oxen. Man-power was only used in the treadwheel for raising water or building materials, in the treadmill, where punishment was more important than power, for the turning of a well windlass or in low-powered querns and corn mills turned by hand. Examples of the latter are still to be found on some farms and in some museums. In these machines ingenuity has been used to extend the mechanical efficiency of human muscles by increasing the speed of the millstones so that the labour of grinding meal was not such a back-breaking task.

The use of horse-power to define the capacity of steam or other types of modern engine serves as a reminder of the significant part muscle-power had in our development. Much research, however, still needs to be undertaken before we can appreciate fully the scale on which animals were or still are used in many parts of the world as a source of power for machines.

Further Reading:

Hugo Brunner and J. Kenneth Major, *Water Raising by Animal Power* (Reading, 1972) (reprint of a paper in *Industrial Archaeology*, IX, ii, 1972); Frank Atkinson, 'The Horse as a Source of Rotary Power', *Trans. Newcomen Society*, XXXIII, 1960-61; J. Kenneth Major, *Animal-Powered Engines*, Batsford (London, 1978).

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