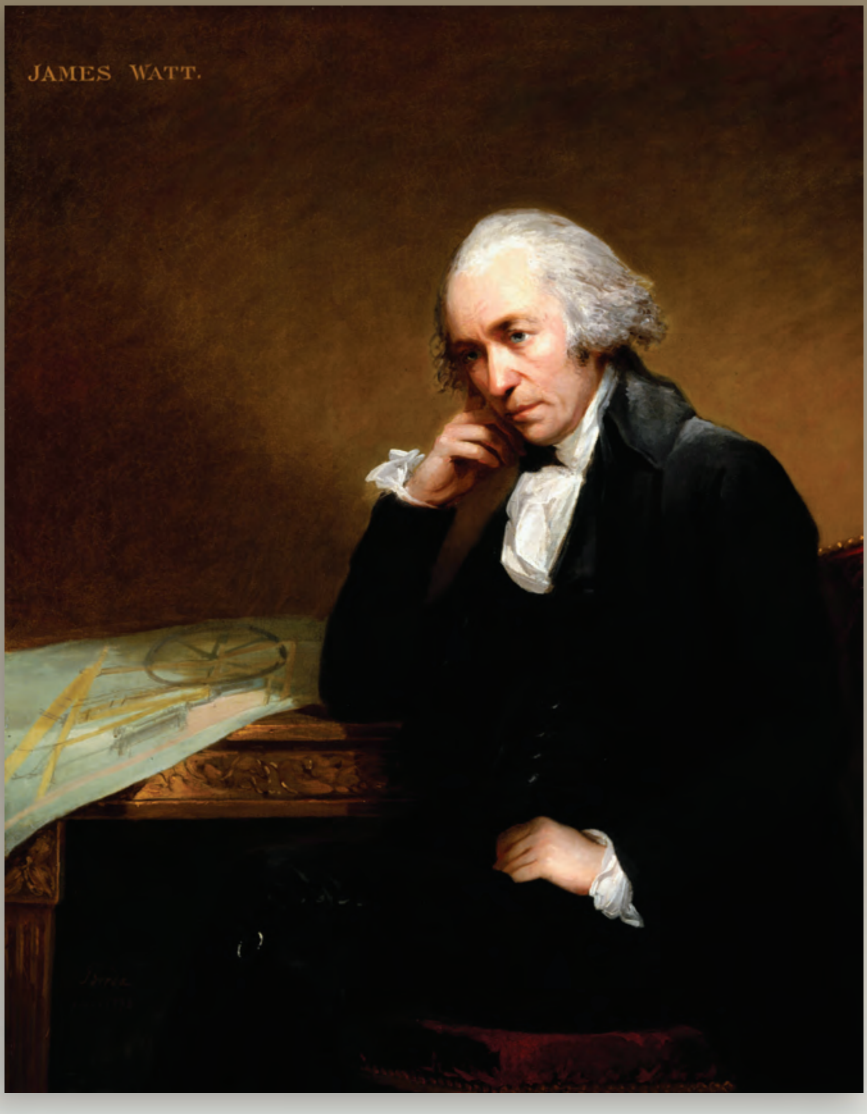
TOWARDS FACTORY POWER

WATT'S ROTATIVE STEAM ENGINE

Jim Andrew

Matthew Boulton intended that steam power should be applied to drive factory machines as well as pump water. James Watt's rotative steam engine first developed in the 1780s provided a solution.



James Watt sitting beside a drawing of a rotative beam engine, Carl Fredrik von Breda, 1792.

The early Newcomen engine design had been applied to power-rotating machinery, but its movement was not smooth enough for many industrial applications – although it had been used for raising coal out of mines where some irregular movement was not significant. Watt sought a smooth and controlled rotative engine as well as features, such as flywheels, which would smooth the force from the piston as it was moved by the varying pressures across it.

The Double-Acting Valve

The first task was to move from driving the piston in one direction to powering it each way. This was known as double acting and needed a design which would direct steam alternately to each end of the cylinder while the other end was connected to the condenser. A technically advanced valve gear, however, would also be needed to control the movement of steam through the engine. Watt developed his double-acting valve gear to control steam flow from the boiler to the condenser, above and below the piston in the cylinder.

Next, the piston rod needed to push and pull the beam up and down without any deviation sideways – the earlier design just pulled on a chain. Any alternative to the beam engine required the machining of components beyond that available at the time, so an improved design was necessary.

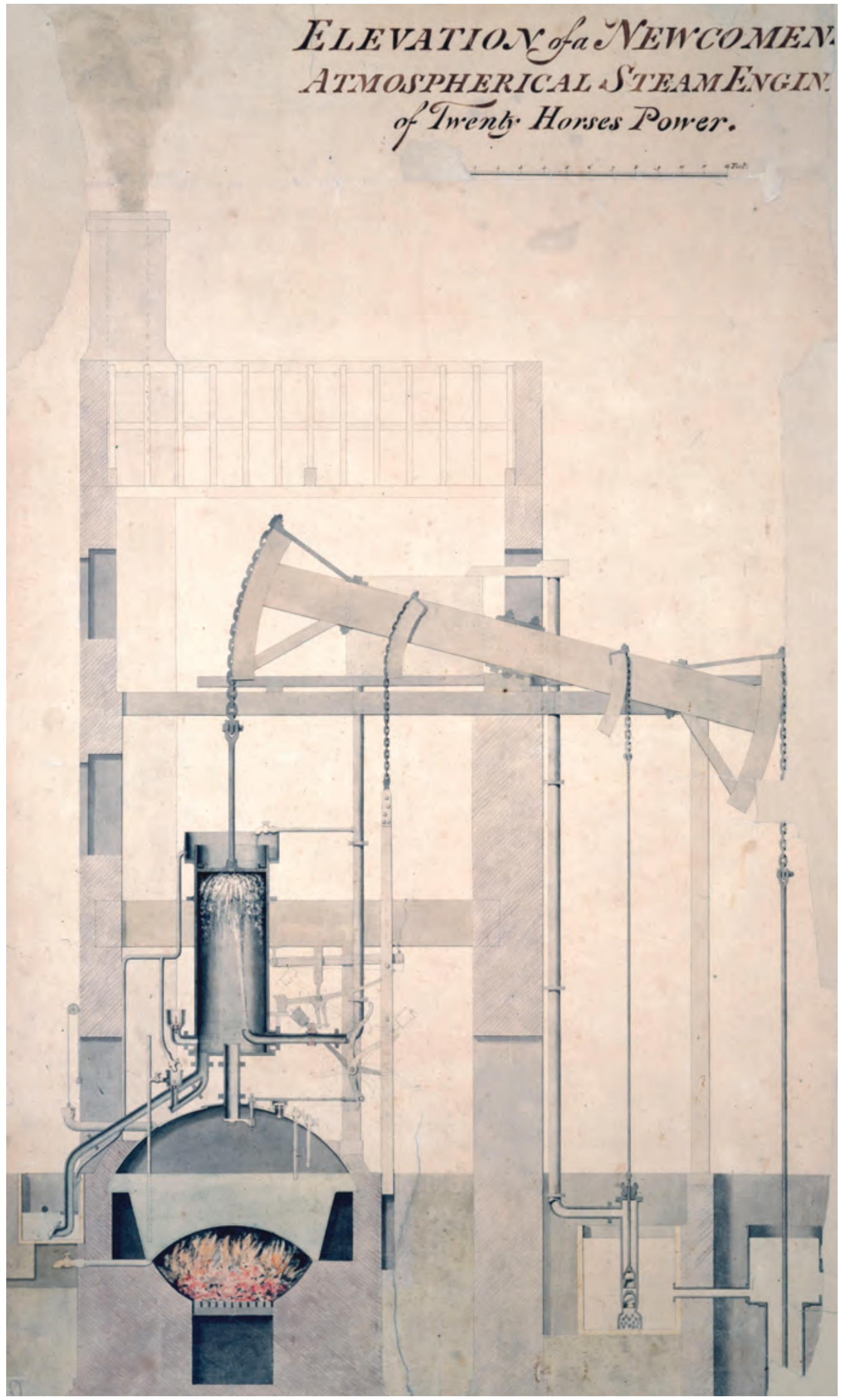
Watt worked on various ideas. Some were successful, including a rack and sector, but the reversal at each end of the stroke induced wear and unevenness of motion. This had to be avoided in powering looms and similar machines. Several designs similar to the slide motion developed for later steam engines were considered, but machine tools were not capable of the accuracy sought by Watt.

Although several engines were probably built with these early unsatisfactory devices, Watt moved to developing a series of linkages which showed more promise and eventually arrived at the parallel motion. The linkage did not move the descending rod in a straight line but in a very elongated 'S', though the deviation, by only using the centre of that movement, is too small to cause problems. This mechanism is satisfying to watch in action, giving the smooth motion which Watt demanded. This linkage, in final form, was patented in 1784 – the sun-and-planet gear.

The connecting rod at the other end of the beam had to be linked to the engine's output shaft. The simplest answer was to use a crank, as a cyclist's leg drives the pedals round. A minor problem was that James Pickard took out a patent for the crank as applied to steam engines in 1780, but because the device had already existed, Watt could probably have successfully challenged it.

Watt knew that his separate condenser patent, in some people's eyes, claimed too much. One possibility was that he did not want to start a process which might rebound on him. Another possibility is that he was very aware of the need to smooth the motion of his engine to drive sensitive machinery.

Watt drew up many devices to smooth the uneven force from the pistons of his engines, while also being aware that flywheels could perform a similar function. The sun-and-planet gear, with a gear wheel on the output shaft and an identical gear wheel fastened to the connecting rod, not only gave the necessary rotary motion but also doubled the speed of rotation of the shaft compared to designs using a crank.



Drawing of a 20 hp Newcomen Atmospheric Steam Engine, *c* 1780.

The smoothing effect he sought was related to the square of the speed of rotation and thus the sun-and-planet gear gave four times the smoothing effect of any flywheel on the output shaft. This also reduced the weight and hence the cost of the engine flywheel. Often the flywheels of many sun-and-planet engines were slimmed down to not much more than an output gear wheel.

The sun-and-planet gear was patented in 1782, but Watt was uncertain at this stage how to hold the two gear wheels together, known in engineering as keeping them in the correct mesh. After experimentation, Watt was able to adapt the sun-and-planet gear for his rotative engines.

The Centrifugal Governor

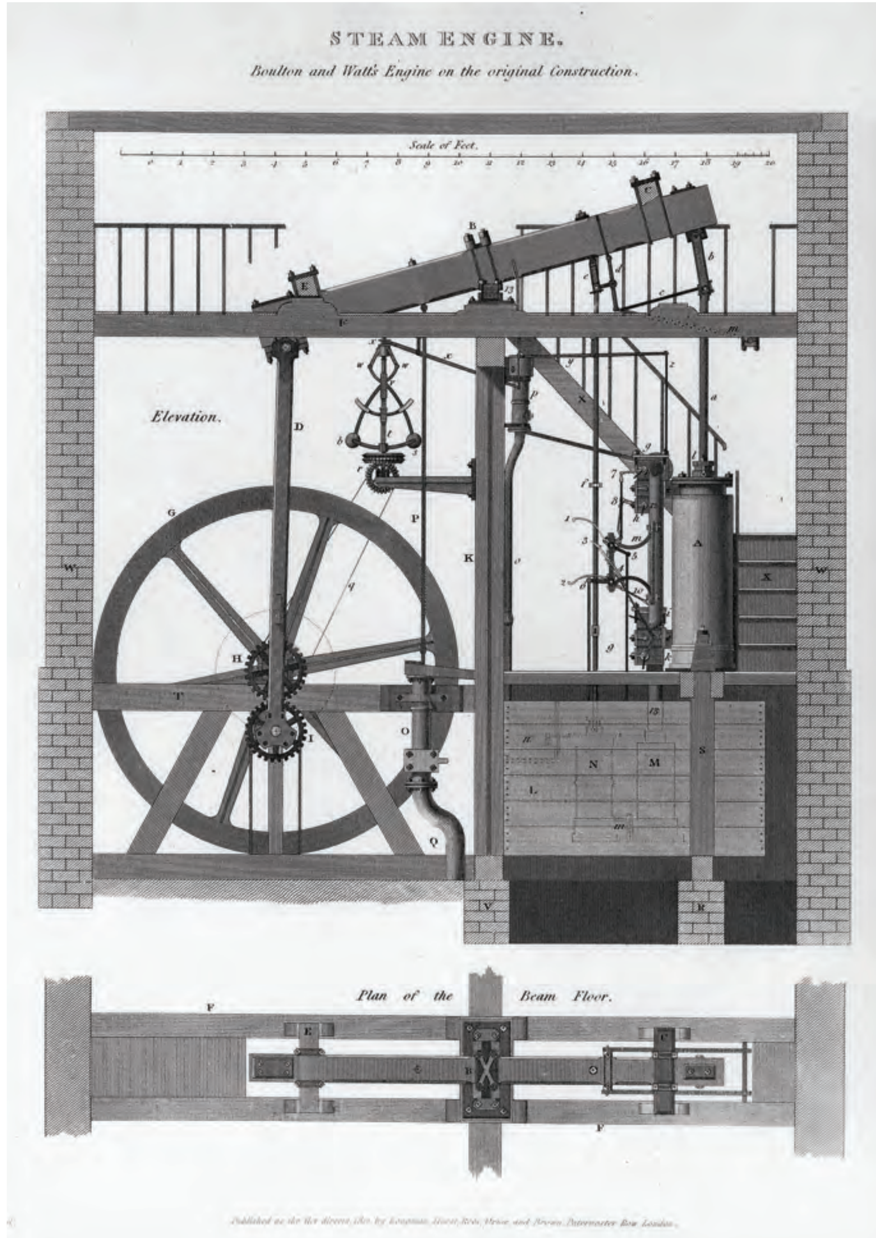
The engine's fluctuation in speed with changing load had to be reduced to improve the application of steam power to drive machinery. Watt adopted the centrifugal ball governor which had been used to adjust the gap between millstones to suit changes in the speed of rotation. The balls would fly outwards as the speed increased or drop lower as the speed fell. This movement could close or open a throttle valve in the pipe from the boiler to the steam engine and would significantly reduce the speed variation with changing load. This Watt governor could not maintain a constant speed but damped any variation. In the nineteenth century, the feedback governor was developed, where the link to the throttle valve was automatically adjusted to return to the required speed of rotation.

Application and Development

It took from just after 1780 to about 1788 for Watt to evolve his rotative engines which were, initially, of relatively small power because they had to replace earlier low-power waterwheels and animal-driven machines.

Once the rotative engine was established, customers wanted more power so that they could drive more machines. Textile mills were built with many more spindles or looms, but owners only wanted one factory power unit. While pistons, cylinders, valve gear and parallel motion could accommodate the greater forces involved in having a higher-power output, the sun-and-planet gears experienced some serious problems.

The sun-and-planet's limitation was that its geometry became distorted if the gears needed to be wider to carry the loads imposed by higher-power output. This distortion led to gears and pivot bearings wearing badly, or failing. The crank patent expired in the 1790s and in later designs by Boulton and Watt the crank was adopted in place of the sun-and-planet gears. Economics had also changed as the price of castings fell and a heavy flywheel imposed a lower cost penalty.



Boulton and Watt Steam engine, circa late eighteenth century, plate from *Rees' Cyclopaedia volume IV.*

Unlike the Newcomen engine, the Watt engine could accept and profit from the higher boiler pressures which were obtained from better boiler design during the nineteenth century. The Watt engine, which was built into the 1880s, continued to power industry with more powerful and efficient engines into the twentieth century. ●

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Further Reading

H.W.Dickinson & R.Jenkins, *James Watt and the Steam Engine* (First published before 1927; Moreland, 1981).

R.L.Hills, *James Watt*, Vol. 2 (Landmark, 2005).

Ben Marsden, *Watt's Perfect Engine: Steam and the Age of Invention* (Icon Books, 2002).