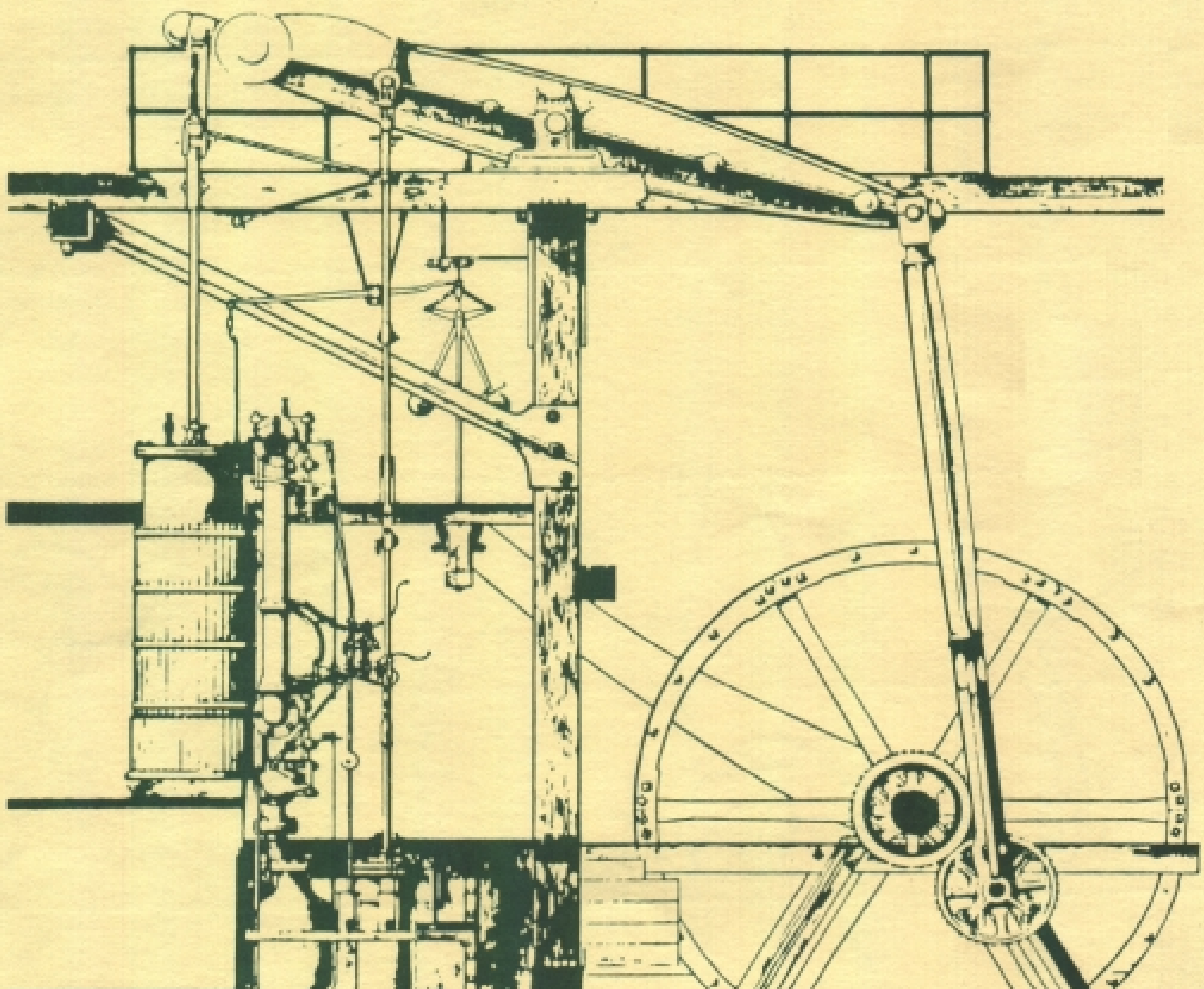
BOULTON ANDWATT ROTATIVE STEAM ENGINE

1785

Sydney, Australia

April 17, 1986

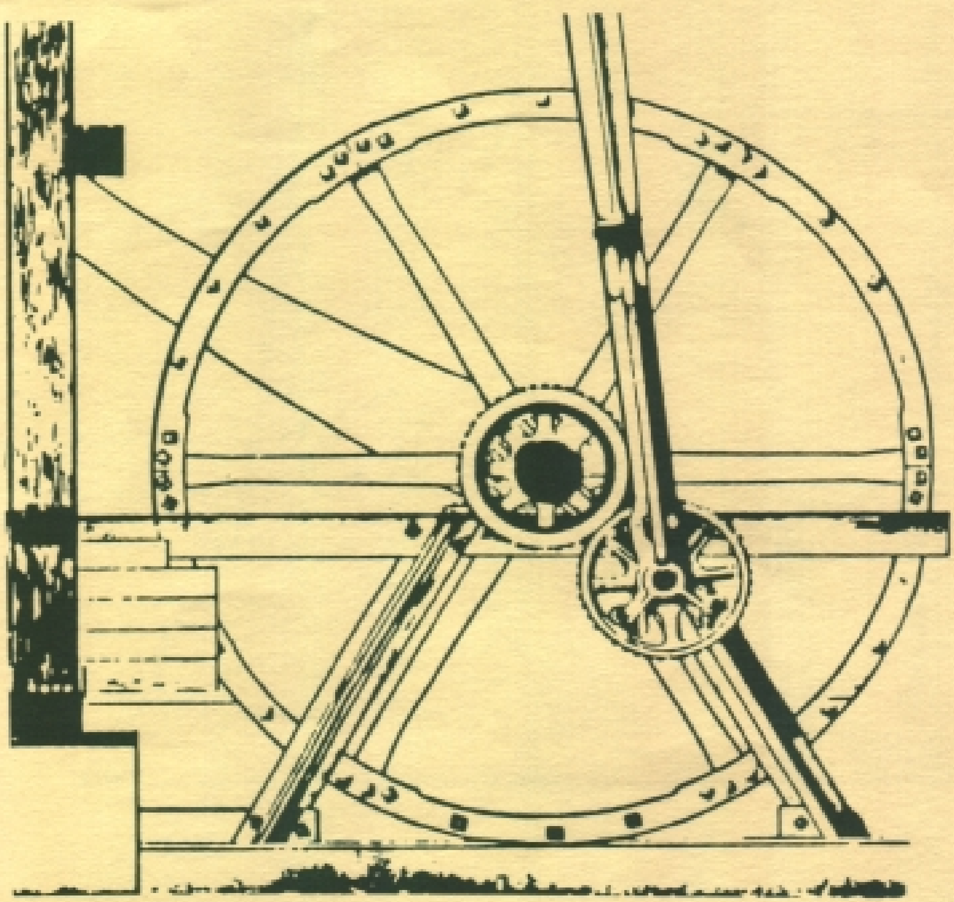
An International Historic Mechanical Engineering Landmark



The American Society of Mechanical Engineers

This engine of 1785 srands at the second beginning of steam power; it is the moment when the chain connection between the piston and beam of the 73-year-old steam pump was replaced by two links that formed a "parallel motion." The piston could now add an upward push to the former down-only pull permitted by the chain, giving an almost continuous flow of power from the two-fold or double action on the piston that allowed the engine to be rotative and so turn the shafts of manufacturing industry to achieve a long-sought goal.

The steam engine's transition from pumping duty to its second and more versatile form came slowly. Tracing the story of the rotative engine means returning to the early eighteenth century when it was known that: (1) given a vetical, open-topped cylinder with piston, atmospheric pressure would drive the piston down into a vacuum formed beneath it; (2) such a vacuum could be created by the condensation of steam under the piston. Thomas Newcomen (1663- 1729) of Devon, using these ideas and others, put together the first practical steam engine and pump for draining distressed mines or supplying water. This event of 1712 was immortalized by Thomas Barney's engraving dated 1719 relating to a coa1 mine in Staffordshire near Dudley Castle. Well-executed, the print includes a key to the parts of the "Steam Engine" and "A Scale of Feet & Inches" enabling the determination of principal dimensions.



Newcomen's Influence

This was the first beam engine, a style that would carry on for long over a century. The overhead beam of wood with its arc ends was 24 ft (7.3 m) long and centrally pivoted on stout engine-house Wall 22 ft (6.7 m) above the floor. In reality the beam was a partial pulley, for the chains to the reciprocating piston rods, steam at one end, pump at the other, were always tangent to the ares of half-beam radius, thus providing rod guidance in the vertical (or perpendicular, as was said two centuries ago) as the beam oscillated. It can be read that the open-topped cylinder had a diameter of 21 in. (533 mm) with a length of 7 ft 10 in. (2338 mm).

The boiler-really an enormous tea kettle of 5.5-ft (1.67 m) diameter - was directly below the open-topped cylinder and would furnish steam at atmospheric pressure to the space under the piston, the piston having been hauled to the top of its cylinder by the weight of the pump rod and its gear. Injection of cold water into the steam under the piston caused condensation with the formation of a vacuum into which atmospheric pressure, acting down, shoved the piston. This was the power stroke with which the pump rod at the other end of the beam was hauled up.

If an incomplete (poor) vacuum of say 10 psia (68 kPa) is assumed, the force on the 21-in. (533 mm) piston would have been about 3400 lb (1542 kg), giving a pivot reaction on the wall of twice that. Someone's note on the engraving remarks that 10 gallons of water were raised 51 yards "perpendicular" when running at 12 strokes per minute. This works out at about 5.5 horsepower (4.1 kW) for the water end. A calculation for the cylinder (assuming a 6.5 - ft [1981 mm] stroke) yields an indicated horsepower of about 8.2 (6.1 kW). There are no real data on the thermal efficiency, but by any guess it was appalling, one-half percent has been suggested. In fact, these pumping engines that did a splendid job in saving the drowning coal mines could be afforded only there, being run on the coal that was so poor that it couldn't be sold. Mineral mines (non - coal regions) could hardly take advantage of the engine because of the cost of transporting coal.

Keep It Hot

James Watt (1736-1819) was born 24 years after that first Newcomen engine went to work at Tipton. As instrument maker at the College of Glasgow, he was brought into contact with the steam engine in 1763 by being asked to repair a model Newcomen engine used in the "Natural Philosophy" class. The problem was that the model, having large boiler and small cylinder, would make but a few strokes before stopping for want of steam. He recognized that the cylinder cooled between strokes, that several volumes of steam were therefore condensing idly before one remained to be deliberately condensed for the power stroke. This conclusion led to his first patent in 1769; it might be called the "Keep It Hot" patent, for central idea was to keep the cylinder hot, as close to 212° F as possible, to discourage that senseless steam - consuming initial condensation caused by a cool system. This "coolness" stemmed from having the piston top and the cylinder wall in constant contact with ambient air, and a cylinder bottom shockingly cooled everytime the condensing water was injected.

Patent No. 913, January 9, 1769, for "a new Method of Lessening the Consumption of Steam and Fuel in Fire Engines" featured a three-point program of direct concern: (1) reduce condensation at the piston by closing the top of the cylinder, letting the piston rod come through a gland, and use hot steam at atmospheric pressure instead of cool ambient air to force the piston down; (2) arrange for a steam jacket around the cylinder; (3) have a seperate vessel or "external condenser" connected to the cylinder bottom, and carry out the condensation in this remote vessel, thus keeping the cold condensing water and condensate away from the cylinder.

Some seven years would elapse before the merits of the patent could be demonstrated, for development costs posed a problem. Watt had his living to earn, doing so as civil engineer and surveyor; his patent sponsor, an industrialist with two-thirds interest in whatever profits might be made, went bankrupt. Great good fortune brought Watt the engineer into partnership with Matthew Boulton (1728-1809) the astute industrialist. It was 1776 before the propositions of the 1769 patent were reduced to successful practice.

Public achievement came with a mine pumping engine having a 50-in. (1270 mm) diameter cylinder and a blowing engine (for an iron works) with 38-in. (965 mm) cylinder. Their most satisfactory performance was in part due to the accurate steam cylinders finished on ironmaster Wilkinson's newly contrived boring mill. Fuel consumption of these engines was third of that normal for the time. Word got around, and enquiries from the long-suffering metal mines of Cornwall were followed by orders from there and other places as well.

The Industrial Push

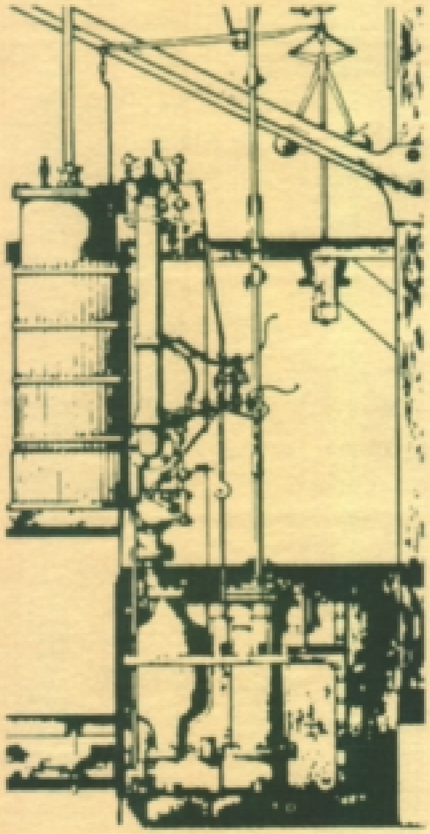
With the ever-increasing industrial activity of the burgeoning eighteenth century, especially in England, rotational power beyond that derived from animals, water, or wind was desperately needed. Animal power was bulky and troublesome what with feeding and stabling; wind power was uncertain except in favored areas and hardly suited to the regularity of industry; and water power could only be exploited further by going farther away from the cities to tap the remoter portions of already well-populated streams. Mine drainage and water supply to municipalities and canal feeders (canals constituted the main transportation system, the roads being wretched) were handled by Newcomen (atmospheric) pumping engines, but here the heavy cost of fuel for the primitive engine set limits. More and more millwork and machinery, dependent upon shaft power, was in the making but faltering for lack of adequate drives. The need was met, in small part, by the awkward arrangement of having an engine pump water over a waterwheel from a reservoir to which the water returned to be again pumped over the wheel.

That a rotative engine would have unlimited industrial application was very clear to Boulton who began to urge Watt to take the matter in hand, as by letter in 1781, June 21: "The people in London, Manchester, and Birmingham are steam mill mad. I don't mean to hurry you but we should determine to take out a patent for certain methods of producing rotative motion from the fire engine."

The basic problem at this stage was to convert the beam's oscillation into rotation, readily done with a connecting rod to a crank, an idea unfortunately patented by someone else. However, the crank arrangement and the single-acting engine weren't the best of partners, for it may be imagined that the rotational motion was non-uniform despite flywheel and often ill-suited if not unacceptable to machine operations of sensitivity, as in textile mills.

Watt devised substitutes for the crank, in Patent No. 1306, October 25, 1781, "circular motion round an axis." Of the several schemes the sun- and- planet gear (epicyclic) was chosen and would be used until 1802, even though the crank patent expired in 1794. With a large flywheel, this arrangement worked well-enough for some purposes in the manner of the crank. After all, the engine was single-acting—power on only the downstroke, the piston being returned to the top of the cylinder by inertia from the wheelwork. Double action, or power from the upstroke too, a notion Watt had been toying with since 1775, came into view again.

Watt addressed the problem with his next patent, No. 1321, March 12, 1782, in which he presented a number of "new improvements": the expansive principle; double action to double the power and get a more regular motion; a compound engine in which steam used in a first cylinder would act expansively in a second; a rack-and-sector relating piston rod to beam to permit "push" as well as "pull" for double action; and a steam wheel or rotative engine. Pertinent is the rack piston-rod engaging a gear sector on the beam end. The obvious solution of constraining the piston rod with a crosshead in a vertical guide was impractical then for manufacturing reasons: straight guides several feet in length would have had to be worked out by chipping and filing, prohibitively expensive for anticipated production engines.



With the rack-and-sector hookup, a rigid rack replaced the flexible chain as an extension of the piston rod. When kept in engagement with the gear sector that replaced the arch head around which the chain had wrapped, the rack held the piston rod to the same vertical as the chain would, with the advantage of being able to transmit not only the pull of the conventional single-acting piston, but also the push from a double-acting piston. Although a kinematically sound idea, workmanship and materials of the day weren't up to it, the cast teeth of sector and rack being troubled by the shock loading on reversal of the piston's motion. Furthermore, the headroom for the rack added perhaps five feet to the height of the engine house. Some other mechanism was needed.

Perpendicular Motion

Watt puzzled mightily over the problem, and in a letter of June 30, 1784, reports to Boulton that he "got a glimpse of a method of causing a piston rod to move up and down perpendicularly by only fixing to it a piece of iron upon the beam, without chains or perpendicular guides or on. towardly frictions, arch heads or other pieces of clumsiness."

About a week later (July 11th) he reports that he is pleased with tests on a "very large model of the new substitute for racks and sectors. . . It is a perpendicular motion derived from a combination of motions about centres."

Early kinematicians would call this the "three-bar motion," recognizing the three connected bars or links that were in play. (For "motion," one may at times read "mechanism" and even "bar," depending upon the circumstances). Retaining the basic beam as one of the "motions about centres," Watt added an outboard radius rod of half-beam length (another "motion about centres") and joined the two by a link to whose midpoint the piston rod attached. This special point described a practically straight line in the vertical or perpendicular. Because of this, the whole linkage—the three-bar motion or mechasnism — was also called a "perpendicular motion." This mechanism is the mechanical invention of which Watt would say that he was proudest. It and two other linkages doing similar jobs were protected by Patent No. 1432 dated August 24, 1784.

This three-bar motion was a bit awkward, for the radius rod lengthened the engine by half again, thus calling for an enlargement of the engine house. After building two engines with the three-bar motion, Watt held the length of subsequent engines down to beam length by halving the three-bar motion (the radius bar was tucked under the outer half of the beam), and adding two links to form a pantograph, the farthest joint of which had a motion that was an enlargement of the perpendicular motion's unique straight-line point: it would take the piston rod. In summary, there were two points, the first located on the small three-bar motion, with the second or parallel point being the far joint of the pantograph: the motion of this second point was parallel to that of the first, hence the quite proper name "parallel motion" for the pantograph configuration.

It is now that "our" engine enters history somewhat cautiously. Samuel Whitbread, a London brewer had ordered an engine with a 24-in. (610 mm) cylinder, 6-ft (1829 mm) stroke, in 1784. Although single-acting, it was to be rotative, and a drawing (in the Boulton & Watt Collection in Birmingham) dated November 1784 shows a parallel motion, almost certainly the first application of that mechanism. This parallel motion had followed hard on the three-bar motion of the Coates and Jarrett oil mill engine ordered in 1783. A drawing of June 1784 shows that engine laid out with rack and sector — but a three-bar motion sketched over it and actually supplied. The Whitbread drawing of a few months later shows the more elegant parallel motion.

It has been said that when first installed, the single-acting engine did the work of 24 horses. This probably meant the total number of animals required during a day, not the number in use at one time, for a conservative calculation leads to about 17 indicated horsepower, (12.7 kW), assuming a mean effective pressure of 10 psia (69 kPa) and a speed of 20 to 21 strokes per minute. When the engine was made double-acting in 1795, the power developed by its cylinder was of course doubled, to an IHP of perhaps 35 (26 kW) for the rest of its working life that extended to 1887: 102 years of service. The re- build in 1795 did not replace the original wood beam nor add a centrifugal governor, for these items are not shown on the official drawing of the time. The present cast iron beam with proper counterweights appears to have been fitted about 1805.

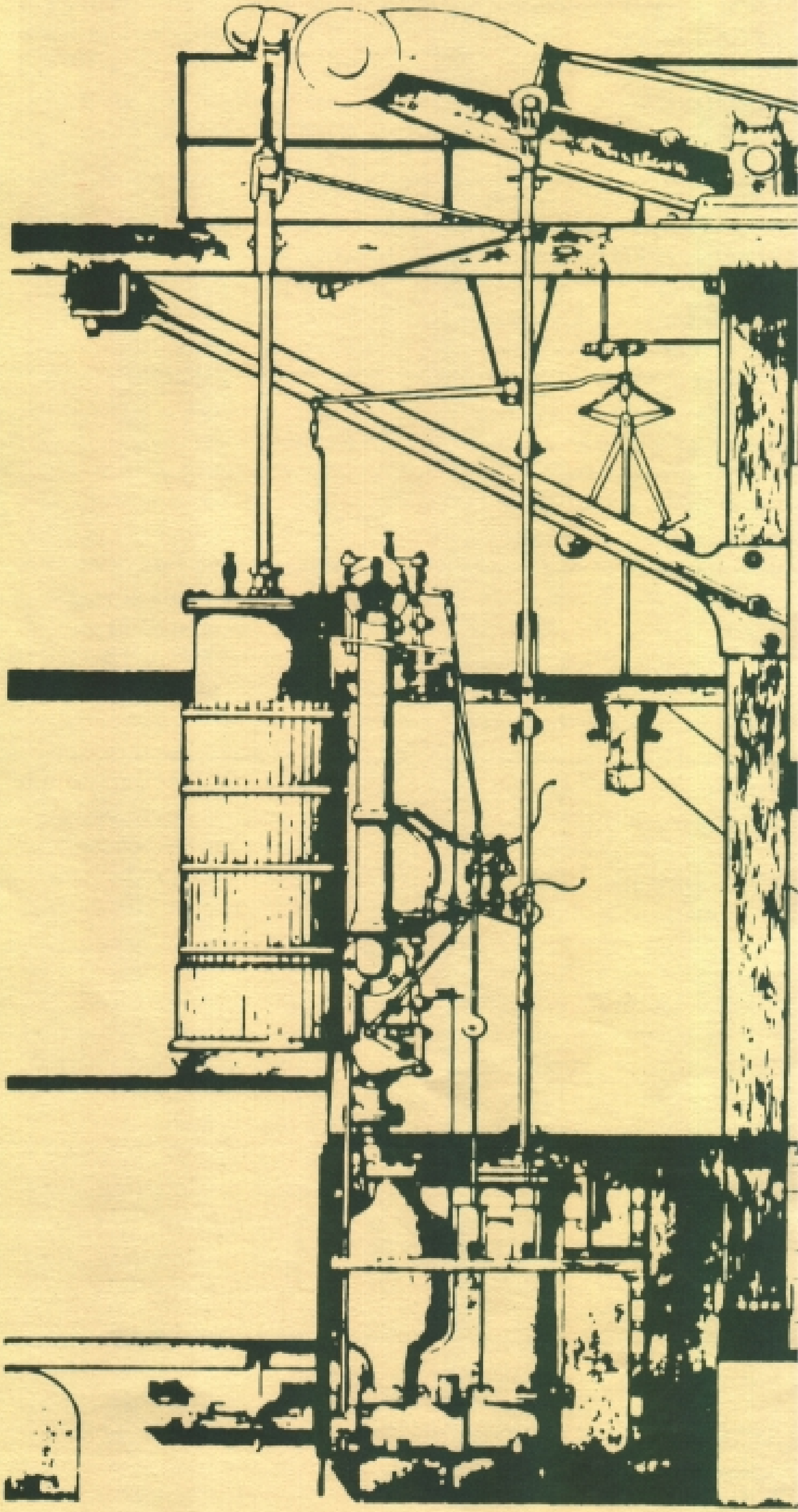
Early High - Tech

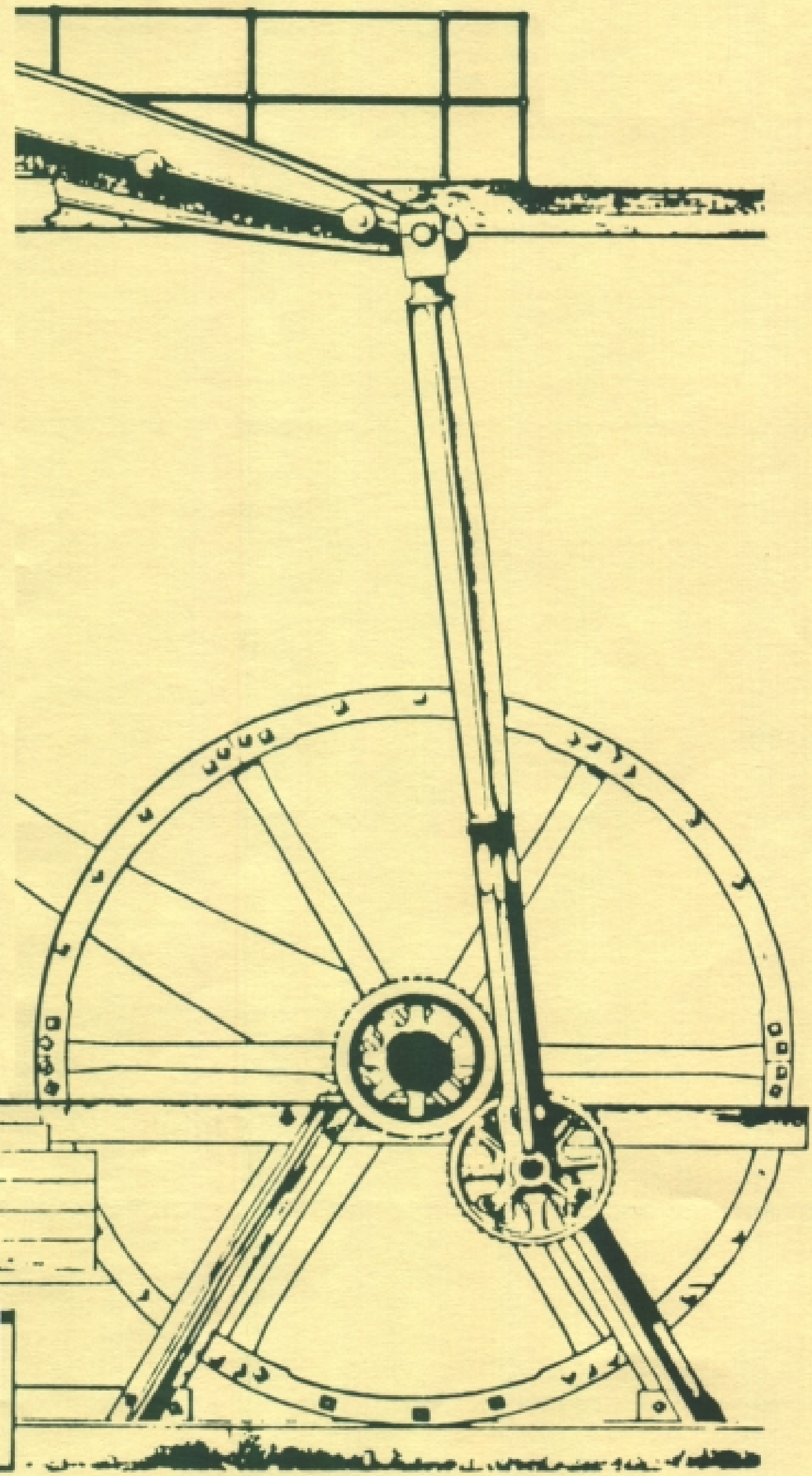
The engine was high technology for its day, much more commanding than the other mechanical marvels of the time, the windmill and clock. King George III, a man of plain and practical tastes and amusements, partial to hunting and mechanical contrivances, brought Queen Charlotte and their four children to the brewery in May of 1797 to inspect the "wondrous works to be seen there," the moving and exciting engine being a key attraction. Although of modest capacity, it had set a good example, for by 1796, eleven other Boulton and Watt engines were amiably at work in London. A second engine came to Whitbread's in 1841.

In 1887 a compound engine by Messrs. Simpson & Co. fitted with Cowper's intermediate steam reservoir replaced "our" engine. The new machine, with high and low pressure cylinders, would have operated on steam pressure a good deaal higher than the perhaps 3 psig (21 kPa) of the Boulton and Watt engine it superseded. And it would have been compact-one thinks of the old engine standing 30 ft (9.1 m) tall and swinging a 14-ft (4.2 m) flywheel, all for an IHP of maybe 35 (26 kW). At any rate, the engine was dismantled.

Archibald Liversidge, Professor of Engineering at Sydney University and trustee of the Sydney Technological Museum (founded 1880), happened to be in London at this time visiting his friend the engineer of the Brewery. Samuel Whitbread kindly donated the engine to the Museum where it arrived in 1889. In course it was housed in a special building behind the Museum in Harris Street and given an electric turning motor in 1930.

In 1983 the engine was removed to the Castle Hill site





and with loving care was brought to steaming condition to celebrate its bicentenary in July of 1985.

As mentioned earlier, the engine is 30 ft (9.14 m) tall, and has about the same length, with an overall weight of 33 tonnes. The cast iron beam, 18 ft 4 in. (5.6 m) center to center weighs about 9.2 tonnes; the wood beam of the 1795 drawing might have weighed about 1.5 tonnes if of oak. Built of sections of cast iron, the 14-ft (4.26 m) flywheel weighs, together with its shaft, some 8 tonnes. Finally, the connecting rod is 18 ft (5.5 m) center to center.

Mention must be made of the next-in-age survivor, the "Lap" engine of 1788 now in the Science Museum, London, of which faithful copies have been made for museums in Munich, West Germany, and Dearborn, Michigan, U.S.A. This engine drove the laps or polishing buffs for steel ornaments in Boulton's Soho Manufactory, delivering 70 years of service. It was the first engine to be fitted with centrifugal governor. Smaller than the Whitbread engine, its bore and stroke are 18.75 in. (476 mm) and 4 ft (1219 mm). Watt rated it at 10 horsepower (7.5 kW), but put on test when the museum acquired it in 1858, some 13.75 horsepower (10.3 kW) could be noted. Power was taken off the flywheel rim that carried 296 inserted gear teeth.

June 1986

R.S. Hartenberg
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The American Society of Mechanical Engineers is most grateful to the officers and staff at the Power House Museum and the Institution of Engineers, Australia, for their assistance and support of this designation, and to Professor Richard S. Hartenberg, who wrote the text for this brochure.

The Boulton and Watt Rotative Steam engine is the twentieth International Historic Mechanical Engineering landmark to be designated by ASME, and the fifth to be designated outside of the United States. The others are in Puerto Rico, Great Britain and France. For a complete list and information on the Society's History and Heritage Program write:

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345 East 47th St.
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