Watt and the Steam-Engine

by Rupert Holland

It was no pressing need that drove John Gutenberg to the invention of his printing press, nor was it necessity that led to Galileo's discovery of the telescope, but it was a very urgent demand that led to the building of a steam-engine by James Watt. England and Scotland found that men and women, even with the aid of horses, could not work the coal mines as they must be worked if the countries were to be kept supplied with fuel. The small mines were used up, the larger ones must be deepened, and in that event it would be too long and arduous a task for men and women to raise the coal in small baskets, or for horses to draw it out by the windlass. A machine must be constructed that would do the work more quickly, more easily, and more cheaply.

A Frenchman named Denys Papin had built the first steam-engine with a piston. He had seen certain experiments that showed him how much strength there was in compressed air. He had noticed that air pressure could lift several men off their feet. His problem therefore was how best to compress the air, or, as it appeared to him, how to secure a vacuum. His experiments proved that he could do this by the use of steam. He took a simple cylinder and fitted a piston into it. Water was put in the cylinder under the piston, a fire was lighted beneath it, and as the water came to the boiling point the piston was forced upward by the steam. Then the fire was taken away, and as the steam in the cylinder condensed, the piston was forced down by the air pressure above. He fastened the upper end of the piston to a rope, which passed over two pulleys. If a weight were hung to the other end of the rope it would be raised as the piston was forced down. In that way the air pressure did the work of lifting the weight, and the necessary vacuum was obtained by forming steam and then condensing it in the cylinder. This was a very primitive device, requiring several minutes for the engine to make one stroke, but it was the beginning of the practical use of steam as a motive power.

Thomas Newcomen, an English blacksmith by trade, first put Papin's idea to use. Instead of the rope and pulleys Newcomen fastened a walking-beam to the end of the piston, and attached a pump-rod to the other end of the walking-beam. He used the steam in the cylinder only to balance the pressure of the air on the piston, and let the pump-rod descend by its own weight. As the steam condensed the piston fell, and the pump-rod rose again. By this means he could pump water from a mine, or lift coal. His first engine was able to lift fifty gallons of water fifty yards at each stroke, and could make twelve strokes a minute. At first he condensed his steam by throwing cold water on the outside of the cylinder, but one day he discovered that the engine suddenly increased its speed, and he found that a hole had been worn in the cylinder, and that the water with which he had covered the top of the piston was entering through this hole. This condensed the steam more rapidly, and he adopted it as an improvement in his next engine. A little later a boy named Humphrey Potter, who had charge of turning the cocks that let the water and steam into the cylinder, found a way of tying strings to the cocks so that the engine would turn them itself, and so originated what came to be known as valve-gear.

Newcomen's engine was a great help to the coal mines of England and Scotland, but it was very expensive to run, a large engine consuming no less than twenty-eight pounds of coal per hour per horse-power. Then it happened that in 1764 a small Newcomen engine that belonged to the University of Glasgow was given to James Watt, an instrument-maker at the university, to be repaired. To do this properly he made a study of all that had been discovered in regard to engines, and then set about to construct one for himself.

There are many stories told of the boyhood of James Watt. He lived at Greenock on the River Clyde in Scotland, and was of a quiet, almost shy disposition, and delicate in health. He was fond of drawing and of studying mechanical problems, but rarely had much to say about his studies. The story goes that as he sat one evening at the tea-table with his aunt, Mrs. Muirhead, she said reprovingly to him, “James Watt, I never saw such an idle boy: take a book or employ yourself usefully; for the last hour you haven’t spoken a word, but taken off the lid of that kettle and put it on again, holding a cup or a silver spoon over the steam, watching it rise from the spout, and catching the drops it falls into. Aren’t you ashamed of spending your time in this way?” And history goes on to presume that as the boy watched the bubbling kettle he was studying the laws of steam and making ready to put them to good use some day.

He picked out the trade of a maker of mathematical instruments, and went to London to fit himself for it. He was apprenticed to a good master and made rapid progress, but the climate of London was bad for his health, and as soon as his term of instruction was finished he went back to Scotland. There he found it difficult to get employment, but at last he obtained permission to open a small shop in the grounds of the University of Glasgow, and to call himself “Mathematical-instrument-maker to the University.”

When the Newcomen engine was given to Watt to repair he studied it closely, and soon reached an important conclusion. A great amount of heat was lost whenever the cold water was let into the cylinder to condense the steam, and this loss vastly increased the expense of running the engine, and cut down its power. He saw that to prevent this loss the cylinder must be kept as hot as the steam that entered it. This led him to study the nature of steam, and he had soon made some remarkable discoveries in regard to it. He found that water had a high capacity for storing up heat, without a corresponding effect on the thermometer. This hidden heat became known as latent heat.

It was of course a matter of common knowledge that heat could be obtained by the combustion of coal or wood. Watt found that heat lay also in water, to be drawn out and used in what is called steam. If you change the temperature of water you find that it exists in three different states, that of a liquid, or water, that of a solid, or ice, and that of a gas, or steam. If water were turned into steam, and two pounds of this steam passed into ten pounds of water at the freezing point the steam would become liquid, or water, again, at 212° of temperature, but at the same time the ten pounds of freezing water into which the steam had been passed would also have been raised to 212° by the process. This shows that the latent heat of the two pounds of steam was sufficient to convert the ten pounds of freezing water into boiling water. That is the latent heat which is set free to work when the steam coming in contact with the cold changes the vapor from its gaseous to a liquid state. The heat, however, is only latent, or in other words of no use, until the temperature of the water is raised to 212°, and the vapor rises.

Mr. Lauder, a pupil of Lord Kelvin, writing of Watt’s “Discoveries of the Properties of Steam,” describes his results in this way: “Suppose you take a flask, such as olive oil is often sold in, and fill it with cold water. Set it over a lighted lamp, put a thermometer in the water, and the temperature will be observed to rise steadily till it reaches 212°, where it remains, the water boils, and steam is produced freely. Now draw the thermometer out of the water, but leaving it still in the steam. It remains steady at the same point—212°. Now it requires quite a long time and a large amount of heat to convert all the water into steam. As the steam goes off at the same temperature as the water, it is evident a quantity of heat has escaped in the steam, of which the thermometer gives us no account. This is latent heat.

“Now, if you blow the steam into cold water instead of allowing it to pass into the air, you will find that it heats the water six times more than what is due to its indicated temperature. To fix your idea: suppose you take 100 lbs. of water at 60°, and blow one pound of steam into it, making 101 lbs., its temperature will now be about 72°, a rise of 12°. Return to your 100 lbs. of water at 60° and add one pound of water at 212° the same temperature as the steam you added, and the temperature will only be raised about 2°. The one pound of steam heats six times more than the one pound of water, both being at the same temperature. This is the quantity of latent heat, which means simply hidden heat, in steam.

"Proceeding further with the experiment, if, instead of allowing the steam to blow into the water, you confine it until it gets to some pressure, then blow it into the water, it takes the same weight to raise the temperature to the same degree. This means that the total heat remains practically the same, no matter at what pressure.

"This is James Watt's discovery, and it led him to the use of high-pressure steam, used expansively."

Newcomen, in making his steam-engine, had simply made additions to Papin's model. Watt had already done much more, for in trying to find how the engine might be made of greater service he had discovered at the outset the principle of the latent heat of steam. He knew that in Newcomen's engine four-fifths of all the steam used was lost in heating the cold cylinder, and that only one-fifth was actually used in moving the piston. It was easy to see how this loss occurred. The cylinder was cooled at the top because it was open to the air, and was cooled at the bottom in condensing the steam that had driven the piston up so as to create a vacuum which would lower the piston for another stroke. Watt knew that what he wanted was a plan by which the cylinder could always be kept as hot as the steam that went into it. How was he to obtain this? He solved it by the invention of the "separate condenser." This is how he tells of his discovery. "I had gone to take a walk on a fine Sabbath afternoon, early in 1765. I had entered the green by the gate at the foot of Charlotte Street and had passed the old washing-house, when the idea came into my mind that as steam was an elastic body it would rush into a vacuum, and if a communication were made between the cylinder and an exhausted vessel it would rush into it, and might be there condensed without cooling the cylinder. I then saw that I must get rid of the condensed steam and injection-water if I used a jet as in Newcomen's engine. Two ways of doing this occurred to me. First, the water might be run off by a descending pipe, if an offlet could be got at the depth of thirty-five or thirty-six feet, and any air might be extracted by a small pump. The second was to make the pump large enough to extract both water and air.... I had not walked farther than the golf-house when the whole thing was arranged in my mind."

This was the discovery that gave us practically the modern steam-engine, with its countless uses in unnumbered fields. Newcomen's engine was limited to the pressure of the atmosphere, Watt's could use the tremendous force of steam under higher and higher pressure. He led the steam out of the cylinder and condensed it in a separate vessel, thereby leaving the cylinder hot. He closed the cylinder top, and prevented the loss of steam. The invention may seem simple enough as we study it, but as a matter of fact it was the attainment of this result of keeping the cylinder as hot as the steam that enters it that has given us our steam-engine.

The morning following that Sunday afternoon on which the idea of the condenser had occurred to Watt he borrowed a brass syringe from a college friend, and using this as a cylinder and a tin can as a condenser tried his experiment. The scheme worked, albeit in a primitive way, and Watt saw that he was on the track of an engine that would revolutionize the labor of men. But he saw also that it would take both time and money to bring his invention to its most efficient form.

His instrument-making business had prospered, he had taken in a partner, and the firm now employed sixteen workmen. About the same time he married, and rented a house outside the university grounds.

Soon he was busily at work building a working model of his steam-engine.

A working model was very hard to make. Watt himself was a skilful mechanician, but the men who helped him were not. The making of the cylinder and the piston gave him the chief trouble. The cylinder would leak. It took him months to devise the tools that would enable him to make a perfect-fitting cylinder, and when he had accomplished that he still found that in one way or another a certain amount of steam would escape. Yet, although imperfect, his model was already many times more powerful than the Newcomen engine he had started with.

But before very long Watt found that this work was leading him into debt. He told his good friend Professor Black, who had discovered the latent heat of steam before Watt had, that he needed a partner to help him in his business of building engines. Black suggested Dr. Roebuck, who had opened the well-known Carron Iron Works near Glasgow. The two men met, and, after some negotiations, formed a partnership. Roebuck agreed to pay Watt's debts to the sum of a thousand pounds, to provide the money for further experiments, and to obtain a patent for the steam-engine. In return for this he was to become the owner of a two-third interest in the invention.

It was more difficult to secure a patent in those days than in later times, for both the courts and the public considered that the right to make use of any new invention should belong to the whole world, and not alone to one man or to a few men. Watt's models had to be very carefully made, and his designs very accurately drawn if he was to secure any real protection, and the preparation of these took a vast amount of time. But Roebuck continued to encourage him, and on January 5, 1769, he was granted his first patent, the very same day on which another great English inventor, Arkwright, obtained a patent for his spinning-frame. This first patent covered Watt's invention of the condenser, but not his next invention, which was the double-acting engine, or in other words, a method by which the steam should do work on the downward as well as on the upward stroke.

With his patent secured Watt spent six months building a huge new engine, which he had ready for use in September, 1769. In spite of all his painstaking it was only a partial success. The cylinder had been badly cast, the pipe-condenser did not work properly, and there was still the old leakage of steam at the piston. Men began to doubt whether the new engine could ever be made to accomplish what Watt claimed for it, but although he realized the difficulties the inventor would not allow himself to doubt. Unfortunately his way was no longer clear. Dr. Roebuck met with reverses and had to end the partnership agreement, and Watt had to borrow money from his old friend Professor Black to secure his patent. To add to his distress his wife, who had been his best counselor, died.

Dr. Roebuck had owed money to a celebrated merchant of Birmingham named Matthew Boulton. Boulton had heard a great deal about Watt's engine, and now consented to take Roebuck's interest in Watt's invention in payment of the debt. At the same time the firm of Boulton and Watt was formed, and in May, 1774, Watt shipped his trial engine south, and set out himself for Birmingham.

Boulton was a business genius, and Watt now found that he could leave financial matters entirely to his care, and busy himself solely with his engine. He had better workmen, better appliances, and better material in Birmingham than he had had in Glasgow, and the engine was soon beginning to justify his hopes. But the original patent had only been granted for fourteen years, and six of these had already passed. Boulton was not willing to put money into the building of a great factory until he was sure that the engines would be secured to the firm. Therefore more time had to be spent in obtaining an extension of the patent. This was finally done, and Watt was granted a term of twenty-four years. At once Boulton set to work, the first engine factory rose, and hundreds of men in England turned to

Birmingham to see how much truth there was in the wonderful stories that had been spread abroad of the new invention.

Men soon learned that the stories were true. Orders began to flow in, and Watt had his hands full in traveling about the country superintending the erection of his steam-engines. The mines of Cornwall had become unworkable, and as a great deal depended on the success of the engine in such work, he traveled to Cornwall to make sure that there should be no faults. The miners, the engineers, and the owners had gathered to see the new engine. It stood the test splendidly, making eleven eight-foot strokes per minute, which broke the record. After that the other mines of Great Britain discarded the old expensive Newcomen engine, and sent in orders for Watt's. The firm prospered, and the inventor began to feel some of the material comforts of success. He had married a second time, and made a home for his wife and children in Birmingham. Now, when he could spare the time from superintending the workmen and traveling over the country, he gave his thoughts to further inventive schemes.

Watt had not only invented the condenser and the double-acting engine, he had produced an indicator for measuring the pressure of steam in the cylinder, and also what was called the fly-ball governor, which took the place of the throttle-valve he had first used to regulate the speed of his engines. These improvements had so increased the uses of the engine that scores of rival inventors were abroad, and therefore he decided to secure a second patent. This he did in 1781, the patent being issued "for certain new methods of producing a continued rotative motion around an axis or centre, and thereby to give motion to the wheels of mills or other machines." The next year he secured still another patent, and now he had so perfected his double-acting engine that it had a regular and easily controlled motion, in consequence of which, as he said in his specifications, "in most of our great manufactories these engines now supply the place of water, wind and horse mills, and instead of carrying the work to the power, the prime agent is placed wherever it is most convenient to the manufacturer." This meant that the steam-engine had now reached the point where it could be made to serve for almost any purpose and placed in almost any position that might be required.

There was one further step for Watt to take in the development of his invention. He wished a more powerful engine than his double-acting one, and so he produced the "compound" engine. This was really two engines, the cylinders and condensers of which were so connected that the steam which had been used to press on the piston of the first could then be used to act expansively upon the piston of the second, and in this way the second engine be made to work either alternately or simultaneously with the first. And this compound engine is practically the very engine that we have to-day. Improvements have been made, but they have been made in details. The piston-rings invented by Cartwright have prevented the escape of steam, and so permitted the use of a higher pressure than Watt could achieve, and the cross-head invented by Haswell has provided the piston with a better bed on which to rest and freed it from a certain friction.

The firm of Boulton and Watt had a successful career, and in time the sons of the two partners took the latters' places. Watt had occasion to protect his patents by a suit at law, but he was victorious in this, and by the time the patent rights had expired the firm had built up such a large business that it was safe from rivals. Confident of his son's ability to carry on the business Watt at length retired, to busy himself in studying other inventions, to cultivate his garden, and to revisit familiar scenes in his beloved Scotland.

The steam-engine had come to take its place in the great onward march of progress. Men were already at work planning to make it move cars across the land and ships upon the sea. It was to revolutionize the manufacture of almost everything; what men and women had done before by hand it was now to do, and, devised at first because of the great need of a new way to work the coal mines, it was to provide a motive power to accomplish all kinds of labor.

Such is the story of how James Watt took Newcomen's simple piston and cylinder and so harnessed steam that he could make it do the work he wanted.

Source:

Holland, Rupert. "Watt and the Steam-Engine." *Historic Inventions*. Philadelphia: George W. Jacobs & Company Publishers, 1911. 70 – 83. Electonic.