The Engineer and Modern Civilisation*

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THE PRIME MOVER

IN examining the picture of the prime mover I shall look at it through the spectacles of the scientist, and endeavour to find out why the industrial revolution came when it did and not thousands of years before, and why Hero's steam engine of two thousand years ago was never more than a toy. The reason was not that the brains of Hero were not as good as those of James Watt or Trevithick, for whatever the claims may be of the engineer, he does not claim to have markedly improved the thinking power of the human race.

For thousands of years the engineer's prime mover consisted of nothing more than the water-wheel and the windmill. How came it that the steam engine was ever invented?

Hero's steam engine was the forerunner of Barker's water mill, and some might even say of the steam turbine. Why did Hero's engine remain undeveloped? The reason is, I think, that knowledge of the physics of gases and liquids and of pressure was almost non-existent in those days, and without such knowledge progress was impossible. For 2,000 years philosophers spoke of the horror that Nature had for empty space. Nature, they said, abhors a vacuum. Even Galileo, when told that a suction pump would not raise water higher than about 33 ft., appeared to think that it was due to Nature's resistance to a vacuum being limited.

It was Pascal, the mathematical physicist, who showed that a pressure exerted upon a fluid is transmitted in all directions, and it was Torricelli who discovered that the atmosphere exerted a pressure. It was almost inconceivable at the time that the air in which people moved and which appeared to impede their progress so little exerted a force the aggregate pressure of which on the human body was of the order of 15 tons. It was one of the great discoveries of the seventeenth century. To-day this discovery of Torricelli's may appear to be of slight importance, but one of the first committees which the Royal Society appointed for a scientific purpose considered Torricelli's results. Christopher Wren was a member of the committee; Boyle was another. Boyle made a distinct contribution to the knowledge required for steam engine practice, for he proved the relationship between the pressure and volume of a constant mass of gas, in fact, he demonstrated the elastic properties of air.

In the days of Boyle the coal industry was in a bad way, as it is to-day, but the cause was different. The mines were becoming flooded with water, and man and horse-power were insufficient to cope with the trouble. The knowledge obtained by Torricelli and Boyle was used by Papin (1690)

who observed that a small quantity of water made a large volume of steam, and this steam appeared to have all the elastic properties of air. I can but surmise that Papin concluded that if he condensed the steam a vacuum would be produced, and that water might thus be caused to rise to a higher level by the pressure of the air. In such a way atmospheric engines arose. Worcester's, Savery's and Newcomen's engines were all atmospheric engines. If the air had not exerted a pressure on the earth's surface, these early steam engines would not have worked. Watt's first engine was an atmospheric engine. It was only when steam was used at high pressure and allowed to do work by virtue of its elastic properties, that is by expansion, that there was departure from a simple atmospheric engine. Trevithick's engine was a high-pressure engine, and it was Trevithick, you will remember, who applied it to propel carriages on roads. To Trevithick also belongs the honour of being the first to use a steam carriage on a rail.

With such scant knowledge of the internal mechanism of gases the nineteenth century began. The scientist looking at the picture of that period sees more than 10,000 steam engines in use in England developing in all about 200,000 horsepower and many of these were used to prevent coal mines being flooded. All these steam engines, from a scientific point of view, were based on a knowledge of atmospheric pressure and the elasticity of gases. True, Carnot had already written his wonderful paper on the motive power of heat, but it received little attention.

There was practically no knowledge of the nature of heat. Indeed, until the latter part of the eighteenth century, heat was regarded as a material substance to which the name 'caloric' was given. After all, the idea was by no means absurd. The heat was supposed to fall from a high temperature to a lower one, like water falls from a high level to a lower one, and in the fall in temperature it was thought work was done. The heat was supposed never to disappear; it was believed to be indestructible. To-day we believe that work is done electrically in a similar fashion; the electricity falls from a high pressure to a lower pressure and in doing so work is done but the electricity is not destroyed. It is not therefore so very strange that the view that heat was a material substance should have been accepted in the early part of the nineteenth century. So far back as 1756 Dr. Black discovered latent heat. He had pondered over the slowness with which ice melts and water disappears in boiling and concluded, since the caloric ptt into the boiling water did not raise its temperature, that the heat was latent. James Watt, who was in close contact with Dr. Black, measured the change of volume

* From the Gustave Canet Lecture delivered before the Junior Institution of Engineers on June 28.

when water vaporised. He no doubt saw that the atmospheric engine worked best when the cylinder was hot and the condenser as cold as possible, and hence concluded that the best efficiency was obtained when the heat was introduced at a high level and rejected at the lowest possible level.

Nearly fifty years after Black's discovery of latent heat, Rumford made a great discovery. Without being able to see the minute particles of matter he concluded that they were in vibration and that this vibratory motion was heat. Heat was not a material substance; it was a mode of motion. For the first time in history, the mechanism of heat was revealed. Rumford's conclusion was vigorously attacked by the calorists, and although Davy confirmed his conclusions by experiments it was not until 1812 that he felt sure in asserting that "the immediate cause of the phenomenon of heat is motion and the laws of its communication are precisely the same as the laws of the communication of motion". There was thus an explanation of why water under reduced pressure lost heat, and therefore fell in temperature as more and more vapour was formed and removed. On evaporation, a particle of the vapour possessed more energy due to its motion than a particle of the liquid at the same temperature and of the same mass. Hence the water cooled. It was known even before the nature of heat was understood that ultimately the water in such circumstances would freeze. To-day, many of our large refrigerating machines operate on this simple principle.

The greatest engineering discovery of the nineteenth century was made, however, by Joule and others. The discovery was that heat and work are mutually convertible at a fixed rate of exchange; the law which is known to engineers as the first law of thermodynamics. The new idea was that the vibratory motion of the minute particles of matter which we call heat were integrated through an appropriate medium into a larger single motion, say, that of a fly-wheel, and thus a means of doing work was provided. The old idea that heat was indestructible was completely overthrown. Steam engines were then in existence, and it was realised that when work was done by a steam engine heat passed out of existence. If, on the other hand, work was done to produce heat a definite quantity of heat came into existence for each unit of work expended. It is difficult to realise that this principle of conversion of heat into work was unrecognised in the early days of Lord Kelvin, whom many here, including myself, knew quite well. The discovery was not only of the greatest importance to engineers; it was, I believe, the greatest generalisation in physics of the nineteenth century. Engineering could not have developed in the way it has had this fact never been discovered. Moreover, work was to be interpreted in the broadest sense whether done mechanically, electrically or by chemical combination. The engineer could at last visualise what happened to steam when its temperature was

raised and its volume was kept constant. Increase of temperature meant increased vibratory motion of the particles which bombarded the walls of the enclosing chamber in a way that Pascal could not have dreamt of. Thus the pressure of the steam was increased. If the steam were allowed to expand, the energy of motion and the pressure fell. Work had been done and some heat had disappeared.

The new doctrine met with a good deal of opposition. A doubting scientist remarked to Mayer that if the theory were correct water would be warmed by shaking. Several weeks later Mayer proved that it was. A somewhat similar story is told by Lord Kelvin who met Joule carrying a thermometer near Chamonix. Joule told him that he wished to demonstrate that at a waterfall there was a rise in temperature due to the work done on the water itself.

It is in this way that the scientist sees the birth of the prime mover. To-day the knowledge of the internal mechanism of gases is fairly complete, the nature of heat is known and Carnot's cycle of operations is fully appreciated. All that is necessary to convert heat into work or work into heat is a suitable medium. Steam was the first medium chosen, flame or the heated products of combustion has also been chosen, mercury has been experimented with, and ammonia and sulphur dioxide are used for special purposes. In all cases the medium is in motion and it is the total heat, or total internal energy of the medium which changes during the working cycle.

In the same way as the first steam engine was an atmospheric one, that is, it worked by virtue of atmospheric pressure, so the first 'gas' engines were atmospheric. The Rev. W. Cecil produced the first in 1820; it was "an engine which is moved by the pressure of the atmosphere upon a vacuum caused by explosions". Later, Samuel Brown made engines for commercial purposes in which there was produced a partial vacuum by flame with subsequent extinction of the flame by a jet of water. It is of interest to note that Brown applied his engine to pump water, to propel a carriage and to propel a small paddle boat. There was, however, no internal combustion engine in the modern sense until some years after Joule (1843) had made his famous experiments. It was then apparent that the energy of chemical decomposition and combustion which takes place on an explosion could be converted into work, and that a definite relationship existed between the chemical energy and the work it was possible to produce.

The story I have told will, I know, appear far too simple to many to explain why the industrial revolution started when it did, and not a thousand years before. It may be that the engineer with that wonderful intuition of which we are all aware would have developed the steam engine without any knowledge of the properties of gases and with no knowledge of what heat is and what happens when chemical combination takes place. But the progress would have been very slow and,

I fear, the efficiency of the engines would have been low. There is little doubt that the early engineers sought scientific knowledge on gases and utilised it in their designs, and there is even less doubt that in modern designs the thermodynamical expert and the designer are either the one and same person or are in intimate contact. In that great engineer, Sir Charles Parsons, we had the combination of the two. The defects of the steam reciprocating engine were clear to him, and he applied all his inventive genius to bring his turbine nearer and nearer to one working in Carnot's cycle than which none can be more efficient. Parsons triumphed because he was not only a great engineer but also a great physicist. He knew thermodynamics better than most physicists of his generation, and the result of beautiful design in closest accord with thermodynamical principles can be seen in the great steam turbines in our electrical generating stations.

Let us consider the effect of the discovery of the prime mover. In the early part of the nineteenth-century Stuart, in his "Anecdotes of the Steam Engine", opened his introduction with the following lines :

"Some years ago the ten thousand steam engines which then were reckoned to be in Great Britain were estimated to perform daily the labour of more than two hundred thousand horses, equal to the power of twelve hundred thousand men expending their energy to the greatest mechanical advantage. But as machines require neither rest nor relaxation and can operate without impairing their power during those portions of time usually assigned for a cessation of animal labour, these ten thousand engines could develop from sunrise to sunrise a power superior to that of four and a half millions of labourers ; an effect greater than the entire manual labour of England."

To-day in factories, industrial undertakings and electricity supply undertakings in Great Britain, steam reciprocating engines and steam turbines develop more than 20 million horse-power, equivalent to 450 millions of Stuart's labouring men. On such a basis every man, woman and child in this country has on an average ten slaves working for him in the factory and supply stations in the form of steam power. This power turns the machines in our factories for producing manufactured goods, operates generators for the supply of electric light, heat and power, sweeps many of our floors, carries us up in lifts, causes great pumps to force water to our cities, and operates numerous other mechanisms, including those for which the steam engine was first invented, namely, pumps for freeing the mines of water. In addition to these 20 millions of steam horse-power, probably another 20 millions are produced on the railways for the transportation of people and goods and we must add to this total the power of internal combustion engines, of which there were none in Stuart's time. To-day the rated horse-power of private motor-cars is above 15 millions, and that for motor lorries is above 12 millions. For motor

vehicles alone there is therefore a total of 27 millions rated horse-power.

How many mechanical slaves in all the people of Great Britain have at their command it is very difficult to say. In the United States an estimate has been made that every individual there has an average of 900 of such slaves, and this is on a much more moderate basis than that of Stuart's, the new basis being that 1 horse-power is equivalent to the power of 10 men. In Great Britain we are no doubt more modest in our demands, but it is, I think, obvious to all that the harnessing of coal and oil in the service of man is easily the greatest contribution of the engineer or anyone else to our materialistic progress.

This story of the prime mover is, of course, a totally inadequate account. Many of the men I have talked about are not even classified as engineers, while some of the really great engineers like Boulton, Stephenson, Otto and Daimler have not even been mentioned. I must express my apologies. In excuse, I can but say that the work of these great men is very well known, and that I could not adequately deal with the work of one of them in the course of a single address. I hasten to say that my admiration of the inventive genius of these and others is unbounded and though to-day the solutions of the troubles they overcame may appear to be small, it is as Milton said :

"Th' invention all admired and each how he
To be th' inventor missed ; so easily it seemed
Once found which yet unfound most would have
thought impossible."

As some form of compensation I propose to sound a note of praise about the latest large power station which the engineer has erected. I refer to the Battersea Power Station, which is one of the bright spots in our industrial England, inasmuch as coal is burned and power produced practically without smoke.

In the olden days the engineer burnt his fuel to raise steam, and by pouring out huge volumes of smoke and otherwise polluting the atmosphere, he showed little regard for the feeling of his neighbours. There are many such to-day, indeed far too many ; but the more modern engineer is aware of the harmful effects of atmospheric pollution and is trying to abolish them. Experiments show that this veil of pollution in our atmosphere curtails the ultra-violet light from the sun by as much as 50-75 per cent, and this deprives our bodies of their proper share of sunlight. This air sewage, as it has been aptly called, damages vegetation and destroys our buildings, and it is believed that there is correlation between the sulphur compounds in it and the health of the people.

So if I were now asked where the application of science to engineering has reached its highest stage of development, I should instance the Battersea Power Station. Perhaps I am prejudiced.

I have this evening in a humble way been endeavouring to pay tribute to Rumford and Joule and other great scientists. The Battersea Power Station pays tribute to Faraday in a manner which justifies me in regarding the modern engineer as one who fully appreciates the work of his brother engineer who concerns himself with the minute electrical machines of Nature which the eye cannot even see.

This is a copy of the inscription on the Foundation Stone of the Station :

THE LONDON POWER COMPANY, LIMITED
ON ST. GEORGE'S DAY
IN THE YEAR OF THE CENTENARY OF MICHAEL FARADAY'S
GREAT DISCOVERY
THIS STONE OF COMMEMORATION
UNVEILED AT A MOMENT ABOUT NOON AND BY A
WIRELESS MESSAGE FROM OTTAWA BY
HIS EXCELLENCY THE GOVERNOR-GENERAL OF CANADA
THE RIGHT HONOURABLE THE EARL OF BESSBOROUGH,
G.C.M.G.
A FORMER DIRECTOR OF THE COMPANY
WAS PLACED AS A LANDMARK IN THE DEVELOPMENT OF
LARGER LONDON'S LIGHT AND POWER
AND TO SERVE AS ANOTHER MEMORIAL
OF THE SCIENTIFIC HERITAGE DERIVED
FROM FAMOUS ENGLISHMEN
BATTERSEA POWER STATION 23RD APRIL 1931.

In the engine room, which looks like the nave of a modern cathedral, there are at present two steam turbines with an output of 120,000 kilowatts and soon there will be a third, making a total output of 220,000 kilowatts or nearly 300,000 horse power. When I visited the Station I saw very few engineers and technicians. There was only one in the main engine-room, and he wore a spotless white coat. The 100 tons of coal which the furnaces consume every hour had never once been man-handled from the moment the mechanical grabs lifted 5 tons of it at a time from the ships alongside the wharves, until the time at which the

remnants were finally removed as ash. The stoker aisle, as long as an average street, was absolutely deserted. The toiling, half-naked stoker, shovelling coal into white-hot furnaces, has no place at Battersea. Instead I saw one man controlling the six furnaces in action from a desk panel in accordance with instructions from the combustion engineers' office high up in the building. In that office the pressure, temperature and everything it is necessary to know about the steam-generating plant can be obtained from distant recording instruments and recorders by the twist of a knob. In this way, two or three men control the firing and generation of steam raising equipment, each of the six units of which generates a quarter of a million pounds of steam an hour at a pressure of 650 lbs. per square inch. What goes out of the chimneys is steam and not smoke; it is the steam of the water used in cleaning the smoke in the flues. The gases from the furnaces are driven by fans into washers in which they are sprayed with water so that 20 per cent of the sulphur is removed. They then pass into the scrubbers proper which are arranged in the main flue between the two chimneys where, by the action of moist iron filings, a further 70-75 per cent of the sulphur is removed. Further on, the gases are treated with an alkaline solution and finally passed through moisture eliminators. The wash water used to purify the gases passes away through aerating tanks and filter beds outside the Station for purification before return to the river. With its three great steam turbines the horse power available will be greater than that of the 10,000 steam engines which were reckoned to be in Great Britain at the beginning of last century, a power superior according to Stuart to that of four and a half millions of labourers.

Here, indeed, is a fine example of the engineer's service to man.

(To be continued.)

The Museum of Practical Geology

IN his report for the year 1933*, the Director of the Geological Survey and Museum of Practical Geology has included a short history of the Museum from its inception to the present day. The occasion was appropriate, for at the end of that year the Museum finally closed its door to the public, thereby placing one more milestone on the road of development of a characteristically British institution.

The prime cause of the Museum's foundation was the private geological mapping undertaken by De la Beche in Cornwall and Devon by arrangement with the Board of Ordnance. Four sheets of the Devon 1-in. map, geologically coloured, were published in 1834. In 1835 the Board of Ordnance

decided to establish a department to deal with the geological colouring of its maps. It was known as the Ordnance Geological Survey, De la Beche was put in charge, and the Treasury allotted £300 a year for its upkeep. By this time, however, so much material had been collected by De la Beche that he was compelled to ask for suitable housing for it, and in 1837, Woods and Forests provided accommodation in a house in Craig's Court, Charing Cross; by 1839 the collections were in a fair state of order. In the same year a small laboratory was installed for the analysis of rocks, minerals and soils, with R. Phillips, the curator, as chemist. In 1838, T. Sopwith, with the support of De la Beche, had read a paper before the Newcastle meeting of the British Association, on the need for the conservation of mining records; this, the Association backed by a resolution which

* Report of the Geological Survey of Great Britain and the Museum of Practical Geology (Summary of Progress) for the Year 1933, Part 1. H.M. Stationery Office. Price 1s. 6d. net.