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SPARKS FROM STEAM

The story of the Armstrong hydroelectric generator

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The mysterious explosion of three large oil tankers in 1969 would not appear to have any connection with the peculiar happenings in an isolated Northumberland Colliery in 1840. However, there might have been no explosions had the dangers of the electrification of wet steam and high-pressure water been better appreciated by those responsible for the cleaning out of large oil tanks

It was the autumn of 1840. Queen Victoria, who had recently married Prince Albert, had been on the throne three years. As yet the Industrial Revolution was barely under way and it would be another two years before the Queen would dare to travel on the railway. The scientific world was in session at the British Association meeting in Glasgow, and some idea of the lowly status of electricity and magnetism may be gained by noting the tiny part of the agenda devoted to those subjects. Only two contributions featured in the proceedings; Prof. Jacobi describing his experiments on electromagnetic ship propulsion and a notice of Uriah Clarke's exhibition of the extraordinary power of an electromagnet on a gigantic scale. In Newcastle upon Tyne, William Armstrong, a young unknown solicitor of scientific bent, later to become one of the most powerful industrialists of the 19th century, had begun to investigate the possibility of using hydraulic power to drive machinery.

First electric shocks

The Cramlington Colliery Railway was not far from Newcastle and had been built to take the coal from the colliery to the Tyne. At Seghill there was a 28 hp winding engine, which was used for hauling the waggons up one inclined plane from the colliery to Seghill and also to let them down another plane from Seghill to the Tyne. One day, in late September, the engine driver noticed a steam leak between the safety-valve flange and the seating (Fig. 1) on one of the two boilers driving the engine.[1] Thinking that the boiler pressure was too high he tried lifting the safety-valve weight. To do this he had to stand in the steam flow and, as soon as he touched the safety valve, he 'felt a curious pricking sensation in the ends of his fingers'. As he was enveloped in a cloud of steam and could not see properly, he thought that he had merely hit his fingers rather hard against the weight.

Over the next few days the weather was fine and dry and he experienced sensations of increasing strength. On the 2nd October, he plucked up courage and told his workmates, who likewise experienced strange sensations. Patterson the engine driver was an observant man and organised some elementary experiments. He put his hand gently on the safety valve and, as he did so, he saw a spark. This was then repeated by the whole party. They found the strongest spark occurred when the experimenter stood in the direct steam blast rather than in the surrounding cloud of steam and that if he stood on the brickwork supporting the boiler he could give strong sparks to the bystanders when they brought their hands to his. It was his graphic and accurate description of the observed phenomena that was to arouse interest in Newcastle.

Before long, the news of 'something uncanny like'[2] had reached the ears of the colliery engineer Mr. Marshall. He thought the boiler was in danger of explosion, a common occurrence in those days, and sent for Messrs. Hawks of Gateshead, the builders.[1] For, as he said at the time, 'When there was fire on the outside of the boiler, he did not know what there might be within'. Mr. Golightly of Hawks arrived on the scene, pronounced the boiler safe and then returned home, surprised and puzzled on account of the sparks. He mentioned the matter to a friend, a Mr. Smith, and Smith and Hugh Lee Pattinson went up to Seghill to investigate on the 11th and 12th October.

They found that, by placing one hand in the steam current and touching the boiler with a penknife held in the other hand, they could get a small but distinct spark. The best effects were obtained by holding a large shovel in one hand and the penknife in the other, when they obtained a spark of $\frac{3}{8}$ in. An electrometer produced strong divergence, but ran into trouble with condensing steam. So Mr. Smith was left standing on an insulated stool in the boiler house, holding a shovel in the steam, while Pattinson retreated to somewhat drier conditions in the engine house. The shovel was connected to instruments in the boiler house by a long piece of copper wire, which was supported at intervals on sticks of sealing wax held by assistants.

By this time there was a large crowd from the Pit Row or pitman's houses near the colliery who 'attracted by the novelty and singularity of the circumstances gathered about us, filling the engine house and looking on with great curiousity and interest. A circle of 16 of these men and women was formed and they received together, much to their surprise and merriment, a powerful shock from the charged (Leyden) Jar. This was several times repeated, the numbers receiving the shock varying each time from 12 to 20.'

One admires the resourcefulness of Pattinson who devised such an effective way of handling a milling crowd of curious onlookers and who instilled a healthy respect for the processes of scientific investigation by turning the whole affair into a grand social occasion. Full marks too to Henry Smith for intrepid investigation. How many of us would carry out such an investigation with a similar disregard to personal safety, schooled as we are in the dangers of electricity?

Meanwhile a rival group of investigators, including

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William Armstrong had reached the scene. Armstrong wasted no time in reporting his findings to Faraday. In his first letter he describes the circumstances in their essentials omitting mention of the inhabitants of Pit Row.

In his second letter he has had time to carry out some experiments suggested by Faraday, and reported the presence of electricity when the safety valve was blown. In his third he mentioned that he had carried out experiments on locomotive boilers, and suggests to Faraday that 'I have little doubt that you will meet with similar phenomena in greater or lesser degree if you try some of the locomotive boilers at any of the London Railway Stations.' Whether Faraday carried out this suggestion is not recorded. It would be interesting to know how the railway companies would have received the idea.

Faraday passed on the first two letters to the London and Edinburgh *Philosophical Journal* where they appear beside letters written direct to the Journal by Pattinson. The result was a long correspondence stretching into 1843 in which Armstrong took the major part.

By November 1840 he and Robert Nicholson, engineer to the North Shields Railway, had obtained 2 in sparks from engines in the engine sheds.[5] 'By abruptly raising the valve when the engine shed was dark the edges of the lever and the margin of the brass cup which surrounded the valve were rendered distinctly luminous with rays of positive electricity which were strongest the instant the valve was lifted and then quickly subsided, becoming very faint after the lapse of a second.'

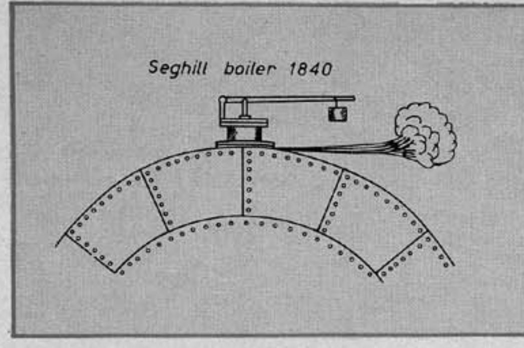
Experiments

Armstrong was interested in where the steam became electrified and how it became so, and he constructed special apparatus (Fig. 2). By measuring the potentials at the points *e*, *c* and *b* he was able to determine that electrification took place as the steam entered the atmosphere and was not in an electrified state within the boiler.

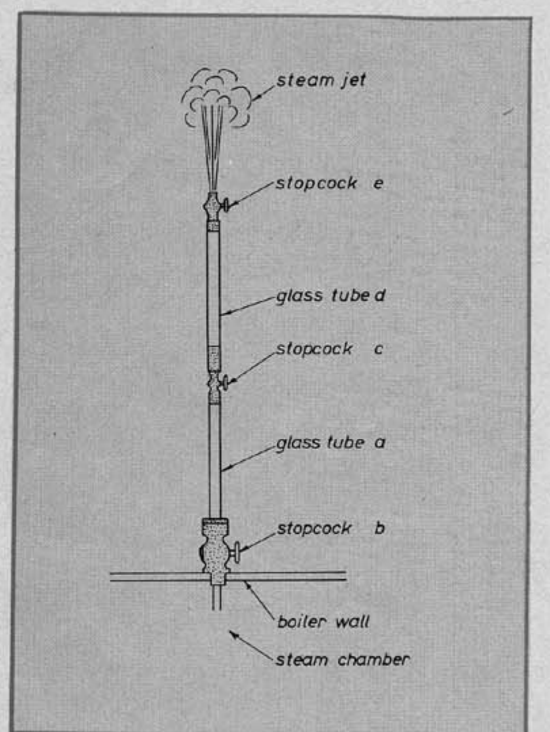
Pattinson was not to be outdone.[6] He obtained 4 in sparks from the Wellington belonging to the Newcastle and Carlisle Railway. Concluding a letter dated the 18th November 1840 to the *Philosophical Journal*, he says: 'It is certainly somewhat curious to consider the splendid locomotive engines that we see daily in the light of enormous electrical machines, but this they undoubtedly are'.

It is clear from subsequent correspondence, in which Pattinson took no further part, that the electricity of steam was not unknown. Volta had noticed that a red-hot cinder dropped into an insulated iron pan full of water gave a detectable reading on an electroscope. John Williams of Worcester had noted that a small insulated portable furnace could be made strongly negative in the period just after fresh fuel had been added, which he attributed to the clouds of dense smoke from the furnace. The body of knowledge was, however, diffuse, and it was Armstrong's experiments, carried out with single-minded enthusiasm, which placed the subject on a sound footing.

All through 1842 Armstrong was busy reporting his experiments.[7,8] He found similar effects occurring with compressed air (23rd January 1841), and soon we find him describing his 'evaporating apparatus' (Fig. 3).[8] This was a vertical boiler of cast gun metal with a stove underneath, 30 in deep and 4 in internal diameter. The boiler and stove were insulated on glass legs. In May 1841 he writes 'that the production of electricity by steam has several important advantages over the common method of obtaining it. An electrosteam apparatus is self acting, which leaves the operator at perfect liberty to attend the results. Its high temperature renders its action independent of dampness in the atmosphere, which so greatly impairs the energy of an electrifying machine; and finally its extreme simplicity secures it from injury or derangement.'[9]



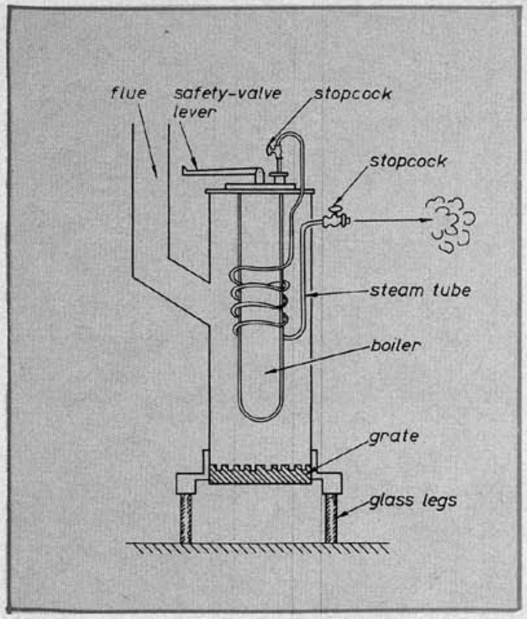
1 Source of electrified steam. Steam leaking from under the safety valve flange on a stationary boiler at Seghill gave the engineman a shock whenever he adjusted the safety value



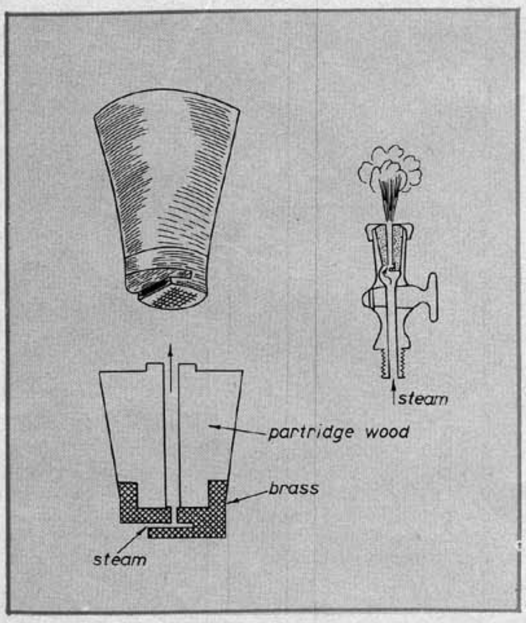
2 Armstrong's apparatus for determining the charge mechanism of electrified steam. By measuring the electric potentials at b, c and e, he proved that the steam became electrified as it entered the atmosphere and was not charged within the boiler or as it passed through the insulated tubes a and d

By the end of 1842[11] he had a more substantial wrought iron, externally fired, horizontal boiler 3·5 ft long by 1·5 ft diameter with round ends, which rested on an iron frame above the fire: the whole being supported on glass legs.

'Notwithstanding the enormous dissipation of electricity which is occasioned when the tension is great by the dust and effluvia of the fire and by the angular parts of the apparatus, I can draw sparks, twelve inches long, with great rapidity from the rounded ends of the boiler and, if a projecting ball of the proper dimensions were attached to the apparatus, much longer sparks would probably be obtained.'[10] The key to his apparatus was the design of combined steam cock and friction nozzle, of which there were several mounted in an iron vessel connected to the boiler (Fig. 4). The purpose of the



3 Armstrong's first evaporting apparatus. Steam was heated within an externally flued boiler and was fed out to the atmosphere through a friction nozzle via the pipe shown. Steam flow was controlled by stopcocks. The whole apparatus was supported on glass legs



4 Details of the friction nozzle used for generating charge. Steam was fed via a stopcock into a nozzle made partly from brass and partly from partridge wood. The eddy flow induced by the two successive right-angled bends resulted in considerable frictional charge generation within the partridge wood section

iron vessel was to provide control over the degree of partial condensation of the steam before it entered the nozzles. The hardwood discharging passage was prefaced by a brass cap of the form shown, which had the effect of turning the steam through two right-angled bends in quick succession and thereby, presumably, establishing turbulent flow, so that the frictional effects, and hence the electrical charging, would be a maximum. The charge on the steam was positive and that on the boiler negative, although, as Faraday discovered, a small admixture of oil of turpentine could reverse the polarities.

We now find Armstrong talking of the possibility of a larger machine with a boiler evaporating power equivalent to that of a locomotive engine, with hundreds of steam jets. By 1843 such a giant machine, with 46 steam jets and a proper firebox and flues, had been constructed for the London Polytechnic Institution. A similar machine was exported to the USA at about the same time.[12,13]

The Polytechnic machine, when in operation, must have been awesome and dangerous, for it produced sparks up to 22 in long and enormous quantities of steam which, in the words of one textbook of electricity, 'besides causing a deafening noise has the mischievous effect of covering everything within reach.'

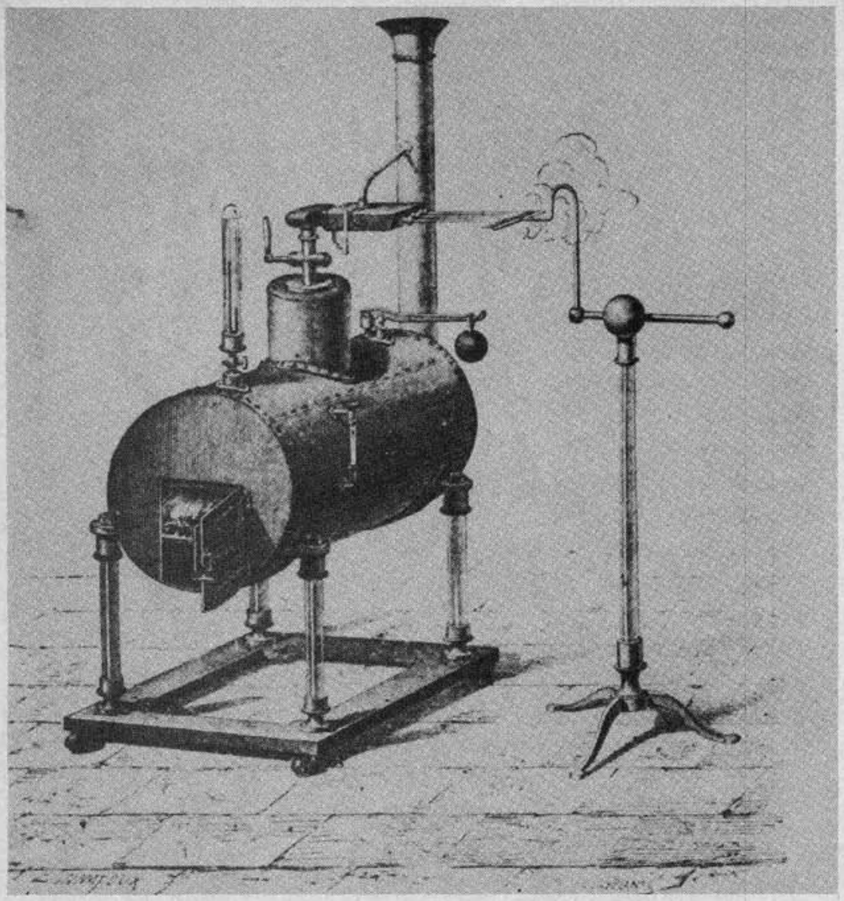
James Wylde, who used the machine on many occasions, says that 'few persons would repeat a trial of receiving a spark of two inches length; and a strong man who accidentally received one when the steam was issuing at a pressure of ninety pounds was immediately prostrated and for some time remained insensible.' A large Newfoundland dog which had the misfortune to become part of an experiment was less lucky and died. It is said that experimenters became so mesmerised by the machine that they ran the danger of letting the boiler run dry and so of terminating both the experiment and their own lives in an explosion. In its day, however, it was the most effective means of generating high voltages, and even today it remains the symbol of an ideal; the generation of electricity without moving parts.

Armstrong's painstaking research on the electrification of steam and his development of the hydroelectric generator brought him into the limelight, and in 1846 he was elected to the Royal Society on the recommendation of Wheatstone and Faraday amongst others. Subsequently, he turned his mind to other things, e.g. hydraulics and gunmaking. To the end of his days, however, he called his hydroelectric machine his 'first electric love',[14] and, when he was an old man in his eighties, he returned to it briefly. By then, the Wimhurst machine had been developed, and he and his collaborator Prof. Froud found the latter more suited for their purpose. They wrote up their results in a fascinating book called 'Electric movement in air and water', which has some remarkable Lichtenberg figures within its pages.

Effects' nuisance value today

One small hydroelectric generator still exists and lies behind a glass case in the Newcastle Museum of Science & Engineering. However, the 'Armstrong effect' as it is still known in the North East is not so confined and still continues to turn up in unlikely places and to exercise a considerable nuisance value from time to time.

The frictional electricity generated by steam escaping from fractured steam pipes, or by burst aerosol cans, or by moving dust is often sufficient to generate incendive sparks that can ignite gases and set off explosions. Bearings are sometimes damaged in large low-pressure turbines, where the steam is very wet, by static electric charge if precautions are not taken to earth the shaft. Rommel had to halt his troops during his first rapid advance towards Libya in 1941 because of explosions which occurred in the German tanks as they advanced.[15] These explosions were first thought to be due to mines, but were eventually traced to the fine wind-blown sand causing a build-up of static charge on the tanks which, when a tank reached a patch of ground with a greater conductivity, was suddenly discharged, with the formation of a spark and a consequent explosion. The cure was simple; to earth each tank via a length of chain. Fortunately, from our point of view,



5 Hydroelectric generator, in its final form. The boiler, with internal flues, stood on four glass legs. Steam was fed from the boiler into a multiple friction nozzle. Charge was picked up on the comb shown. A similar machine is in the Newcastle upon Tyne Museum of Science & Engineering

the delay was sufficient to alter the subsequent course of the campaign.

The Armstrong effect has also been exploited in certain forms of electrostatic spray gun in which the paint droplets are charged up to a high potential by friction as they emerge from the spray nozzle.[16] Such paint guns are used because they permit paint savings of between 25 and 75%; the adhesion of paint to sharp corners is also enhanced.

Nevertheless knowledge of the electrostatic effects of moving particles is not particularly widespread; indeed electrostatics is the cinderella subject of most electrical engineering courses. In December 1969, three very large oil tankers[17] suffered severe damage from explosions in their cargo tanks. It seems that all three were in the process of washing out their tanks with high-pressure water jets, and that the frictional charge generated was sufficient to cause the explosions. This illustrates how easy it is for a body of fundamental knowledge, once well disseminated, to become forgotten with the passage of time. Had the ship owners appreciated the Armstrong effect they would no doubt have used different tank cleaning procedures and so avoided danger.

We have now come full circle. The moral is that we should be keen students of the past if we want to avoid costly mistakes in the present. Sparks from steam, water, flour or sand may seem unlikely hazards, but they can be deadly.

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