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Lord Kelvin's Atlantic Cable

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Abstract:

Lord Kelvin’s work on the Atlantic Cables was an early case of science greatly helping technology. By applying his knowledge of mathematics and physics to the practical problem of telegraph cables, Kelvin successfully joined in communication the Old and New Worlds.

Introduction

It is the goal of every high-tech company today to move knowledge from the lab to production as quickly as possible. Especially when dealing with the more open-ended research, it is often difficult to apply scientific knowledge to practical uses. One of the most impressive applications of science to technology was William Thomson's 1866 Atlantic cable success. By use of science and mathematics, Thomson was able to successfully lay a telegraph cable across the Atlantic Ocean and usher in a new era of communications.

"The Cable Empire"

Tying together Britain's vast empire in the late nineteenth century was an intricate and far-reaching network of telegraph cables. British cables literally went around the globe; connecting England with its numerous colonies and trading partners. By 1902, Britain had hundreds of cables including crossings of the Atlantic and the Pacific Oceans allowing communication to North and South America, Africa, India, East Asia and Australia. Bruce Hunt clearly expresses the importance of Cables to the British Empire:

> In the late nineteenth and early twentieth centuries Britain's global cable network was often referred to as "the nerves of empire"; information flowed in along the "mighty electric nerve system", and commands flowed out, binding the empire more closely together and securing Britain's continued political and commercial preeminence. From its position at the center of its web of wires, Britain was able to deploy its naval and military forces with unprecedented efficiency and to exercise more direct control over its far-flung empire than would have been possible in an earlier age. (Hunt, 319-20)

This "mighty electric nerve system" did not appear overnight. Laying deep-sea telegraph cables turned out to be excruciatingly difficult as evidenced by the numerous early failures. Wiring the globe was an immense challenge that required the best of the British navy, scientists, and engineers. William Thomson played a large part in the success of the cables.

First Attempts

The first major ocean crossing was the Atlantic cable, and it represented a milestone and turning point in Britain's networking of the world. In 1856, led by American entrepreneur Cyrus Field, the Atlantic Telegraph Company was formed, whose sole purpose was to complete the first Atlantic telegraph cable. Among the 17 directors was William Thomson of Glasgow University. The head electrician of the project was O. E. W. Whitehouse, a retired medical doctor who had taken an interest in electricity and telegraph signaling. A more practical engineer, Whitehouse lacked the mathematics and training that Thomson had. The difference in approaches between Whitehouse and Thomson would soon be clear.

The entire project was rather hurriedly put together and, in the interest of time, cables were ordered from two different companies. Because the specifications were not exact, once the manufacturing was complete it was discovered that the cable windings from the two different companies were in opposite directions (Thompson, 340). This was just the first mishap in a series of mistakes on the first cable.

The cable laying was to be accomplished by two ships, the American frigate *Niagara* and the British battleship H. M. S. *Agamemnon.* The plan was to meet in the middle of the Atlantic and join cables, and then the *Niagara* would lay cable toward North America, and the *Agamemnon* would lay cable to Europe. On July 30th, 1857, the laying of cable was commenced. After many breakages and restarts, the cable was finally completed on August 5th, 1858. However, the celebration was cut short when the cable stopped working after a few short weeks.

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For the cable laying, Whitehouse did not wish to go to sea, citing bad health, so Thomson was asked to join the expedition as electrician and monitor the condition of the cable as it was played out. To aid him he used his newly invented mirror galvanometer, which was a very sensitive device for measuring current. It consisted of a beam of light shining on a tiny mirror backed by a small magnet. The current to be measured passed through a coil creating a magnetic field, which attracted and repelled the magnet on the mirror, deflecting the beam of light. The mirror hung by a fine thread and required very little current to move it. So sensitive was this device that it later recorded signals sent "using as battery Dickerson's cell, a gun-cap containing one drop of acidulated water and a minute anode of zinc"(Thompson, 497) through cables across the Atlantic Ocean. The sensitivity of the mirror galvanometer would prove invaluable to the eventual success of the Atlantic cable.

When the first crossing was successfully completed, Thomson handed the cable over to Whitehouse who proceeded to arrange it for use. Using his own instruments, Whitehouse had great difficulty in getting the cable to work. Instead of trying more sensitive equipment, the practical minded Whitehouse chose instead to massively increase the voltages of signals sent. It was only through immense voltages applied that his instruments could detect a current. These large voltages, it would later be discovered, hastened the cable's demise, effectively burning out the weak spots in the insulation.

Even with the huge voltages applied, Whitehouse could not get a steady signal. But he needed something to show the board of directors of the Atlantic Telegraph Company. They wanted to see that some actual cable transmissions. Since his own instruments were not producing adequate results, Whitehouse took them out of the circuit and secretly installed Thomson's mirror galvanometer. He had a clerk read the transmission from the galvanometer and key it into his own instruments that produced a printed record of the communication, which he then showed to the Board of Directors.[3] The Board thought everything was going well, and did not learn about the problems until the complete failure.

Pretty soon it became obvious that the cable was no longer working, and the Board launched a thorough investigation. When the Board learned the truth about Whitehouse's instruments and his use of increasingly large voltages to communicate, it placed the blame squarely on Whitehouse. In 1861, the

Submarine Telegraph Committee completed a report detailing what went wrong with the cable. It included testimony from Thomson and Whitehouse. Both men were asked about their professions and Whitehouse replied, “I am a member of the College of Surgeons, but not now practicing; lately I have devoted myself to electro-telegraphy, and that must be called my profession.” Thomson agreed to his description as “professor of natural philosophy in the University of Glasgow” (Smith, 676). Already it was clear that Thomson was clearly the expert in the area and Whitehouse was an amateur in comparison. The testimony exposed Whitehouse’s lack of theoretical understanding of cables and electricity, and in general made him look rather bad. When describing their testing procedures, Thomson went in great detail about “the conductivity of copper, the inductive capacity of gutta-percha [the rubber-like material used for insulation], the precise resistance of any part of the cable, and so on”. In contrast, Whitehouse described his tests as more simple brute-force attempts to drive current (Smith, 677). The conclusion of the committee was that the failure of the cable was due to improper techniques used by Whitehouse, and in search of a scapegoat to appease the investors, Whitehouse took a lot of the blame.

This was not the first time Thomson and Whitehouse had disagreements. Before the first cable crossing, Thomson had applied his knowledge of Fourier heat transfer to cable telegraphy. He showed that the flow of current through a long conductor was analogous to the movement of heat in a metal bar. Thomson described his use of Fourier mathematics in a letter to his old teacher J. P. Nichol:

> The analysis [of the electric telegraph] is you will see all Fourier’s – that w[h] you set me to read & which I took up with so much delight after my session of Natural Philosophy under you. This – the first piece of physical mathematics I ever took up, has been since Fourier’s time ready & *quite complete* for the telegraphic problems, including every practical detail – resistance in receiving instruments (radiating power of the end of a bar), imperfect insulation (loss of heat from the sides of a bar) &c. (Smith, 682)

By applying Fourier mathematics to electricity in the cables, Thomson discovered the “law of squares” where the retardation in the current pulse was proportional to the square of the distance traveled. For example a cable 2 miles long would have 4 times the retardation of a cable 1 mile long, so the result received would be only ¼ the strength of the result with the 1 mile cable.

By using his “law of squares”, Thomson discovered the importance of having a high-quality cable for the Atlantic crossing. Because of the great length of the Atlantic cable, reducing the resistance was extremely important. First the quality of copper needed to be very good to have a low resistivity. Second, the diameter of the copper conductor needed to be large to allow currents to flow easily. The thickness of the conductor in the second Atlantic cable was increased almost three-fold from 107 lbs. per nautical mile to 300 lbs. per nautical mile (Thomson, v.3, 443-4).

Whitehouse disputed Thomson’s “law of squares” and this led to a long argument on the pages of the magazine *The Athenaeum*. Whitehouse did not buy into Thomson's theoretical work, citing evidence against the "law of square". However, it was later pointed out that Whitehouse had misinterpreted the data, and Thomson's theory was indeed correct (Thompson, 330-1).

Thomson's mathematical breakdown of problems contrasted with Whitehouse's see-if-it-works approach. Thomson had done analysis on the copper conductor used in the first cable, and finding it of poor conducting quality. The conduction of the cable had never been tested, and Thomson found that some of it conducted no better than iron (Thompson, 350). This was one thing that he would change on the next cable.

Another thing he would change was the strength of the cable. By analyzing the forces involved in laying the cable, Thomson discovered that the original cable was only able to bear 2.05 times it's weight in the deepest water, and so was rather likely to break due to the stresses involved. The next cable would be made over twice as strong, able to bear 4.64 it's own weight in the deepest water (Thomson, 443-5). The forces on a cable draped into the ocean are very complex, involving fluid friction, gravity and the movement of the boat. The many breakages of the first cable were caused by lack of understanding of the forces involved. Thomson used mathematics to understand why the cable broke and fixed the problems in the second cable.

Conclusion

After new funding was raised, the second cable was started on July 14th, 1865. With the suggestions of Thomson, this cable was stronger and had a larger conductor made of higher quality copper. Because of the enormous weight of the new cable, there was only one ship in the entire British navy capable of carrying it. This was the 22 thousand ton *Great Eastern*. Thomson again accompanied this expedition to make sure the cable was always working. By maintaining contact with Ireland using his mirror galvanometer, he was able to instantly detect faults and fix them usually before the bad part of the cable became submerged. After laying out over half of the cable it broke, and a new cable was started the following year. This second cable successfully made it to America, and the broken cable was grappled to the surface, and spliced. On July 28th 1866, under the guidance of Thomson, the cable was completed. It was a complete success. On November 10th, Queen Victoria knighted William Thomson at Windsor Castle in recognition of his work on the cable. On November 28th, Sir William Thomson gave a crowded lecture on the Atlantic cable at the Glasgow Athenaeum. Afterward, the chairman recognized Thomson's work and pointed out his application of "abstract science" to practical use:

> The chairman, in moving a vote of thanks, observed that the … Atlantic cable was one of the greatest testimonies to the value of abstract science; and that while the audience could not fail to admire what they had heard of his fellow-labourers in this great work, they had heard nothing of what Sir William Thomson had himself done. He was certain that if any one of Sir William's fellow-workers had delivered an address, they would have heard a

> great deal of his labours amongst them. (Thompson, 508)

Thomson's accomplishment was one of the greatest applications of science to technology of all time. In an 1871 address to the British Association at Edinborough, Thomson expressed his thoughts on the undertaking and the relationship between science and technology:

> This leads me to remark how much science, even in its most lofty speculations, gains in return for benefits conferred by its application to promote the social and material welfare of man. Those who periled and lost their money in the original Atlantic Telegraph were impelled and supported by a sense of grandeur of their enterprise, and of the world-wide benefits which must flow from its success; they were at the same time not unmoved by the beauty of the scientific problem directly presented to them; but they little thought that it was the immediately, through their work, that the scientific world was to be instructed in a long-neglected and discredited fundamental electric discovery of Faraday's… (Thomson, v.2, 161)

It was only through his knowledge of science that Thomson did what others had failed to do before him. Anyone seeking to apply science to practical application should look to William Thomson's Atlantic cable as a prime example that has forever changed the world.

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