

## A5\_4 Water Under the Bridge

G. Lipscombe, J. Penney, R. Leyser, H. J. Allison

*Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.*

November 14, 2014

### Abstract

The paper looks into Michael Faraday's attempted experiment in 1832 to determine whether he could detect a current from the interaction of the water in the River Thames with the Earth's magnetic field. It is found that he could have measured a maximum current of approximately 66  $\mu\text{A}$ , a value near the limit of sensitivity for a galvanometer from around that period in time. It is also found that the water speed required to power a 60 W light bulb exceeds  $700 \text{ ms}^{-1}$ , showing that the Waterloo Bridge could not generate sufficient power from the flow of the Thames to be a useful power source.

---

### Introduction

In January 1832 Michael Faraday attempted to observe what he referred to as "the electricity obtained by magneto-electric induction" from the motion of salt water through the Earth's magnetic field. He ran a copper wire along the Waterloo Bridge in London and attached to the ends plates of platina that were submerged in the Thames to complete the circuit. Unfortunately Faraday did not obtain the results he was looking for. He did, however, observe some deflections on his galvanometer that he attributed to material defects in the plates and inhomogeneities in the river water, among other reasons. Though the three-day experiment was unsuccessful Faraday still believed that a current was present as currents were observed in a laboratory setting using artificial magnets and brine as the conducting fluid [1].

As described by Faraday's law of induction, an electromotive force (hereafter referred to as an emf) is induced when a conductive fluid is moved through a magnetic field. This drives a current that is orthogonal to the magnetic field and the direction of the fluid's motion and it is the emf that converts the kinetic or thermal energy of the fluid into electrical energy. This process is known as magneto-hydrodynamic (MHD) power generation.

Though they operate differently to other power conversion systems, MHD generators are heat engines and so they are limited by their Carnot efficiencies. However, as they require no moving parts they can operate at much higher

temperatures than, for example, turbo-generators – allowing for greater efficiencies [2].

### Theory

The current created by the motion of charges in a conducting fluid caused by an induced emf can be described using a generalised form of Ohm's law:

$$J = \sigma(E - u \cdot B), \quad (1)$$

where  $\sigma$  is the conductivity of the fluid,  $E$  is the induced electric field, and  $u$  is the velocity of the fluid through a magnetic field,  $B$ . By defining a load parameter [3],  $k$ , as

$$k = \frac{E}{uB}, \quad (2)$$

rearranging it for  $E$ , and substituting this into equation (1), we find

$$J = \sigma(kuB - u \cdot B). \quad (3)$$

The electrical power per unit volume generated by an MHD generator is

$$\frac{P}{V} = -J \cdot E, \quad (4)$$

where  $P$  is the power generated and  $V$  is the volume of water flowing between the plates per second. By substituting equations (1) & (2) into equation (4) we obtain:

$$P = \sigma u^2 B^2 k(1 - k)V. \quad (5)$$

The volumetric flow rate,  $V$ , is the product of the water velocity,  $u$ , the length of one side of the (square) plates,  $w$ , and the distance between the plates,  $l$ :

$$V = uwl, \quad (6)$$

Combining equations (5) and (6) gives the power generated:

$$P = \sigma u^3 B^2 k(1 - k)wl. \quad (7)$$

This is equated to

$$P = IU, \quad (8)$$

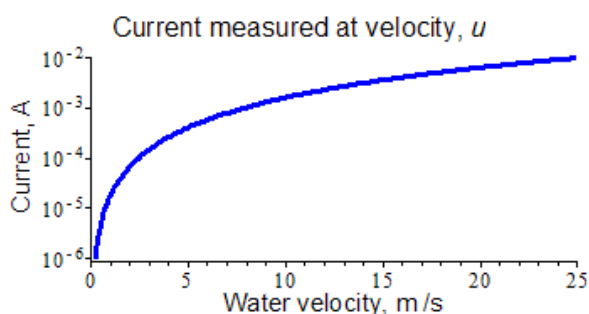
where  $I$  is the electric current and  $U$  is the voltage, which is the product of the water velocity,  $u$ , the magnetic field,  $B$ , and the distance between the plates,  $l$ , [2]:

$$U = uBl. \quad (9)$$

Combining equations (7), (8), and (9) describes the current induced as a function of the water velocity:

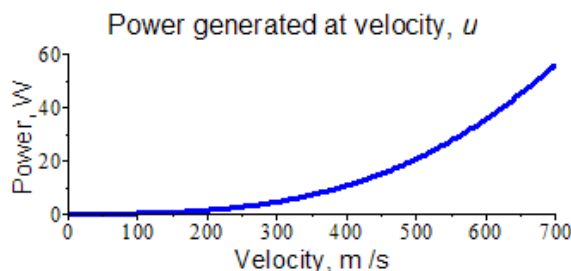
$$I = \sigma u^2 Bk(1 - k)w. \quad (10)$$

## Results and Conclusions



**Figure 1.** A graph of measured current as a function of velocity.

Figure 1 shows the current produced as a function of water velocity in the experiment conducted by Faraday in 1832. Here the Earth's magnetic field,  $B$ , is  $4.9 \times 10^{-5}$  T, the conductivity of sea water,  $\sigma$ , is  $5 \text{ Sm}^{-1}$  [4],  $w$ , the length of the sides of the platina plates is 0.254 m (10 inches) [5], and the load parameter,  $k$ , is set at 0.5 so that equation (11) is maximised. Given that the maximum water speed in the Thames is around 4 knots [6] ( $2 \text{ ms}^{-1}$ ), Faraday could have measured a maximum current of approximately  $66 \mu\text{A}$ . As an example, a galvanometer from the early 20<sup>th</sup> Century can measure currents as small as  $20 \mu\text{A}$  [7]. Faraday would, therefore, have been looking for currents at the limit of his instruments and so it is not unsurprising that he only measured deflections (on the galvanometer) that were “very



**Figure 2.** A graph showing the power generated as a function of water velocity.

irregular” and “[due to] other causes than that sought for” [1].

Figure 2 shows the power generated by the motion of the water as a function of water velocity. The graph was created using the same values as that in Figure 1, with the addition of the distance between the plates,  $l$ , being 700 feet [5] (213.36 m). A maximum water speed of 4 knots is entirely inadequate for power generation purposes, producing only  $1.4 \mu\text{W}$ . In order to power a light on the bridge (for example, a 60 W filament light bulb), the water speed would have to exceed  $700 \text{ ms}^{-1}$ .

## References

- [1] M. Faraday, *Experimental Researches in Electricity*, 2<sup>nd</sup> ed. (Richard and John Edward Taylor, London, 1849), Vol. 1, p. 55
- [2] N. V. Khartchenko, *Advanced Energy Systems*, (Taylor & Francis, 1998), Ch. 8
- [3] Teno, J., Brogan, T. R., Petty, S. W. et al., “*Research Studies and the Development of MHD Generators and Accelerators*”, AEDC-TR-70-14, January 1970
- [4]<http://www.lenntech.com/applications/ultra-pure/conductivity/water-conductivity.htm> Accessed: 2014-10-23
- [5] Michael Faraday and Platinum, (Unknown author), *Platinum Metals Rev.*, 1991, 35, (4), p.222-227
- [6][http://www.pla.co.uk/assets/NEW\\_Inner\\_PRINT\\_FINAL.pdf](http://www.pla.co.uk/assets/NEW_Inner_PRINT_FINAL.pdf) Accessed: 2014-11-03
- [7]<http://www.sil.si.edu/digitalcollections/trade-literature/scientific-instruments/pdf/sil14-51697.pdf> Accessed: 2014-10-23