An International Standard for Length – Defining the Metre

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Abstract

At present the metre is defined by the distance travelled by light in a vacuum over a specified period; but where did it all start? The history of the Metre is interwoven with the turbulent history of the Republic of France. Armed with a new instrument capable of allowing improved measurement of length members of the Royal Academy of Science set out to measure the meridian of the earth, as the earth itself was to be the basis for the this new measure of length.

This paper will examine the work done by these pioneering metrologists, and the difficulties faced in the name of science, the result of which was the 1889 definition of the Metre, an Artefact manufactured from a Platinum-Iridium Alloy, and was to change the way the majority of countries measure and specify length today.

1. Introduction

Modern Science has defined the metre as 'the length of the path travelled by light in a vacuum during an interval of 1/299 792 458 of a second'. This definition was adopted by the 17th CGPM IN 1983. This definition replaced an earlier definition adopted in 1960 which defined the metre based on the wavelength of krypton 86 radiation. [2] At the time that the metre was conceived there is little doubt that the scientists involved in this process has little idea that the meter would be defined in this manner, but they did share one common ideal with the latter day metrologists, that being, that the definition should be universal, based on a physical measurement that was not subject to arbitrary change, such as the size of the feet of some or other monarch.

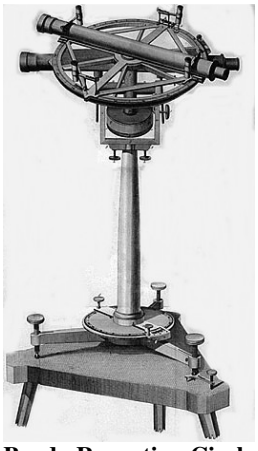
In 1792 two French astronomers at the time of the beginning of the turmoil of the French revolution set off to measure the length of the Meridian that ran from Dunkirk to Barcelona and from this information calculate the distance from the North Pole to the equator. One metre was to be 1/10 000 000 the distance from the North Pole to the Equator. The measurement was entrusted to Delambre and Méchain two scientists know not only for their ability but also for their integrity. Theirs was to be a task of monumental importance, a task on which their integrity was at stake.

The meridian had previously been measured 50 years previously by César-Francois Cassini de Thury (Cassini III), however the two scientists who were to be assisted by Jean-Dominique de Cassini (Cassini IV) had at their disposal a new instrument that would allow for increased accuracy, the Borda repeating Circle.

2. The Borda Repeating Circle

Jean-Charles de Borda

Jean-Charles de Borda was born in Dax in the South West of France on the 4th May 1733. At the age of seven, Jean-Charles was sent of to study at the Cóllege des Barnabites in Dax where he studied Greek and Latin. At the age of eleven he was then sent to study at the Jesuit college of La Flèche where he studied mathematics, science and metaphysics, courses designed for a career in the military. In 1755 Jean-Charles received his first commission in the Light Cavalry Corps. In 1756 he was accepted as an associé (associate) of the Académie des Sciences in Paris, and later in his career was accepted as a full member.


Borda Repeating Circle

Borda proposed the design of the Repeating Circle in 1785 based on existing instruments used for navigation on ships. The instrument consisted of two small telescopes mounted on fixed rings that could be moved independently of each other. The first telescope could be rotated until the first object was sighted, and was then locked in position; the second telescope was now sighted on the second object, and locked in position. The angle between the two could now be read off the scale. In order to reduce any measurement error the instrument was designed to allow the two rotating rings to be locked together using a screw. The two telescopes now coupled together were moved so that the 2nd telescope was sighted on the first object and the 1st telescope locked in position. The 2nd telescope now unlocked and sighted back on the 2nd object, the measured angle was now twice the angle measured between the 1st and 2nd objects. By using this principle it was possible to reduce the possible error for each subsequent set of measurements taken.

The Borda repeating circle allowed distances to be measured by using the principle of triangulation.

3. Triangulation

Triangulation is the process whereby the location of a point can be determined by measuring the angles to in from two known points along a fixed baseline. This technique has been in use since the 14th Century for the purposes of Mapmaking or Cartography. A Dutch mathematician used this method in 1615 to survey the distance between Alkmaar and Bergen-op-zoom (Netherlands), two towns separated by one degree on the meridian. This information was then used to calculate the circumference of the earth.

This technique was later used to measure one degree of latitude along the Paris Meridian by Cassini III, and later used to by the three savants from the Academy of Sciences tasked with the measurement of the self same meridian in April 1791.

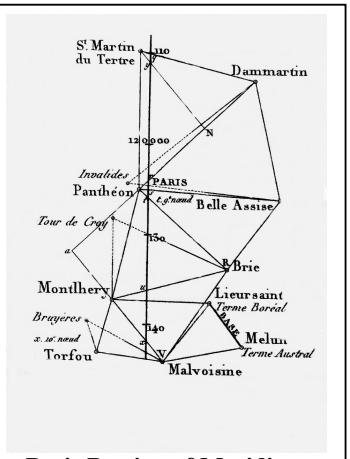
4. The Meridian in Paris

On 24 June 1792 after receiving the King's authorization Jean Baptiste Joseph Delambre began his quest with a review of the observation stations used during the 1740 Cassini Survey to determine their suitability for the purpose at hand.

The Cassini survey of 1740 had used the belfry of the church of Saint-Pierre on Montmartre, adjacent to the current Basilica of Sacré-Coeur. Even today Montmartre provides a panoramic view of Paris. Delambre was disappointed to find that many of the sites used during the 1740 survey were no longer visible due to the development of surrounding buildings. A disappointed Delambre was forced to search out alternative sites for his survey.

Saint-Pierre Montmartre

On 10 August 1792 Delambre was ready to commence with his first definitive measurements. The delicate equipment was set up at the Collégiale at Dammartin. He was to attempt to sight a lit parabolic reflector set up on Montmartre. The only flames he was however to see that night originated from the Palais des Tuileries, the Royal palace had been stormed by 10 000 Parisians, the King held prisoner, and hundreds of his Swiss guard massacred. Montmartre commanded a strategic position above Paris and any attempt to light a parabolic reflector would have spelt disaster. The monarchy in France had come to an end.



Paris Portion of Meridian

Delambre was now forced to find an alternative to Montmartre, and he close the golden dome of Invalides, The instruments were set up at Saint Martin-du-Tertre, and after waiting for 3 weeks for a clear day, and for Invalides to be visible, Delambre and his assistant were only to find that Invalides was obscured by a low hill and were again forced to seek an alternative. This time they chose the Dome of the Parthenon. [1]

Invalides

5. Measuring the Northern Base Line

The Baseline ran from Melun to Lieursaint a stretch of highway known today as the N6. Two masonry markers each containing a copper plug were erected at the two ends. Above each a wooden tower was erected. Delambre arranged from the rows of tress on either side of the highway to trimmed back so as not to obscure the line of sight between his observation points, a task which took 6 weeks. Four rulers each 12 feet long made from Platinum, set in wood, alongside a copper bar allowing for the relative expansion to be measured.

The measurement process involved the laying of the rulers, the alignment and level were checked, the temperature was measured, and the results recorded. After the recording of the fourth ruler the first was removed, and placed at the end of the fourth, and so the process was repeated. At night their progress was marked with a metal stake, aligned with a plumb line. The measurement of this 6 mile distance took 41 days. [1]

6. Caught up in the Revolution

Caught in the turmoil of the revolution Delambre had been detained, arrested and forced to explain on numerous occasions to crowds of peasants the intricacies of the task that he faced. The revolutionaries were by in large ignorant, and suspect of that which they did not understand.

A change of fortune in September 1792 occurred when the National Convention voted to make Delambre and Méchain emissaries of the people's government. What had commenced as a mission supported by the King had become a mission enjoying the sanction of the people. Luckily for these astronomers, savants, and early metrologists the desires of both the king and the people's representatives coincided, a desire to establish universal measures, foster fair trade, and so they were able to continue with their important work of defining a universal measure, a measure for all peoples, for all time. Their work encompassing hundreds of thousands of measurements, and sightings was to take another seven years. [1]

7. Coming up short

American Professor and writer Ken Alder having researched the 3 Volume monumental document recording the details of the survey of the meridian, noted that the principle author, Delambre recorded that his own original records and those of the south going expedition leader Méchain had been placed in the archives of the Paris observatory. Curious to see the records and calculations that had defined the metre, Professor Alder travelled to France to find something that he found both startling and scandalous. The original records left by Delambre were meticulous, whilst those of Méchain were on loose pieces of paper, written in pencil and unsigned. In the records produced by Méchain, Delambre noted that since he had not told the public what it does not need to know, he had suppressed all those details which may diminish the importance of their mission.

What Professor Alder had discovered is that the metre came up short by approximately 0,2 mm per metre, that the two astronomers had suppressed their knowledge of the error, in order to preserve their reputation, and possibly their lives. The revolutionaries had previously used the guillotine on scientists, or placed in jail those who had falsified data before and may have done so in this case. Of course it did not help the case of those who lost their lives that they had political affiliations not in sympathy of those of the revolutionists.

So what went wrong? Méchain as leader of the South going expedition was required to perform astronomical measurements to determine the latitude of Barcelona. Having completed this task he was set to return to Paris, his task completed. This was however not to be as war broke out between France and Spain, and he suffered a personal accident, rendering him bedridden for a period. Méchain chose to use the opportunity to re-measure the latitude for Barcelona, and was to arrive at a different answer, a discrepancy that he could not explain, and a discrepancy that he decided not to disclose to anybody.

Besides this error that they knew of, they also discovered something that had not been previously known, firstly, that the earth was more misshapen than previously assumed, and secondly that each meridian was unique. This alone could invalidate their mission, and the premise that the 'metre' would be universal measure of length, common for all nations, and unchangeable, could not be true.

8. The Role Players

Pierre Francois Andre Méchain leader of the Southern measurements was born 16 August 1744. Méchain had worked in the Naval Depot for Maps in Versailles. In 1782 he was admitted to the Académie des sciences, and in 1799 he became the director of the Paris Observatory. Pierre died of yellow fever on 20 September 1804 in Spain after he had returned in an attempt to resolve the differences in his Barcelona measurements.

Pierre Méchain

Jean Baptiste Joseph Delambre leader of the Northern expedition was born on 19 September 1749 in Amiens, Northern France. In 1788 he was elected as a foreign member of the Royal Swedish Academy of Sciences. In 1801 Napoleon Bonaparte appointed Delambre as the permanent secretary for mathematical sciences of the Academy of Sciences. In 1804 Delambre succeeded Méchain as the director of the Paris Observatory.

Jean Delambre

9. In Summary

The history of the modern measurement system owes much to pioneers like Delambre and Méchain without their tireless efforts the modern SI system of units may not have existed in its present form. The errors introduced are here and will live with us for countless millennia, but along with the errors came the lessons that were learned, lessons that allowed science to move forward.

This paper has drawn extensively on the research of Prof. Ken Alder and recorded into his book 'The Measure of All Things', and anyone wishing to research this theme further is advised that this is the ideal starting point.

10. Definitions

- Savant – From the French '*savant*' – knowing. In English an expert or wise person.

11. References

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