

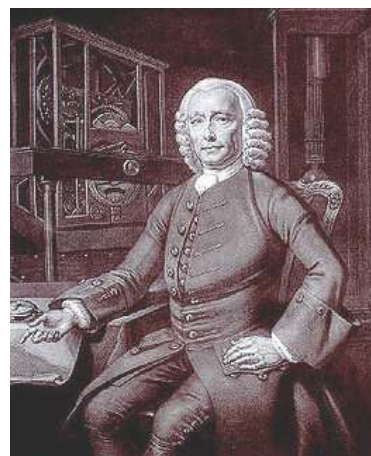
The Harrison Clocks

John Harrison (24 March 1693 – 24 March 1776) was a self-educated English clockmaker. He invented the marine chronometer, a long-sought device in solving the problem of establishing the East-West position (longitude) of a ship at sea, thus revolutionising and extending the possibility of safe long distance sea travel in the Age of Sail. The problem was considered so intractable that the British Parliament **offered a prize of £20,000** (comparable to £2.87 million in modern currency) for the solution. (Harrison came 39th in the BBC's 2002 public poll of the 100 Greatest Britons.)

John Harrison was born in Foulby, near Wakefield in West Yorkshire, the first of five children in his family. His father worked as a carpenter at the nearby Nostell Priory estate. The house where he was born now bears a blue plaque. Around 1700, the family moved to the North Lincolnshire village of Barrow upon Humber. Following his father's trade as a carpenter, Harrison built and repaired clocks in his spare time. Legend has it that at the age of six while in bed with smallpox he was given a watch to amuse himself, spending hours listening to it and studying its moving parts.

He also had a fascination for music, eventually becoming choirmaster for Barrow parish church. Harrison built his first longcase clock in 1713, at the age of 20. The mechanism was made entirely of wood, which was a natural choice of material for a joiner. **Three of Harrison's early wooden clocks have survived.** In the early 1720s Harrison was commissioned to make a new turret clock at Brocklesby Park, North Lincolnshire. The clock still operates and like his previous clocks has a wooden movement, made of oak and lignum vitae (very dense, oily hard wood). Unlike his early clocks it incorporates some original features to improve timekeeping, such as the **grasshopper escapement** (a control device for the step-by-step release of a clock's driving power). Between 1725 and 1728 John and his brother James, also a skilled joiner, made at least three precision pendulum-clocks (now in private collections). John invented the **gridiron pendulum**, consisting of alternating brass and iron rods assembled so that the different expansions and contractions cancel each other out. Harrison was continually assisted both financially and in many other ways by **George Graham**, the watchmaker and instrument maker who lent him a large sum on the basis of trust. Harrison was introduced to Graham by the **Astronomer Royal Edmond Halley** who also championed Harrison and his work. This support was important as Harrison is reputed to have found it difficult to communicate his ideas in a coherent manner.

Harrison's lifetime was an era when trade and navigation were on an explosive increase around the globe due to the maturing of other technologies, and also **due to geo-political circumstances**. On such voyages, cumulative errors in dead reckoning frequently led to shipwrecks and lost lives. Avoiding maritime tragedies due to navigation errors became an imperative to him. If an accurate clock could be built and if such a clock set at noon in London at the start of a voyage, it would subsequently always tell you how far from noon it was in London at that second, regardless of where you had travelled. **By referring to the clock when it is noon locally (i.e. the Sun is at its highest in the sky where you are) you can read, almost directly from the clock face, how far East or West you are from London.** For instance, if the clock shows that it is midnight in London when it is noon locally, then you are half way round the world, (e.g. 180 degrees of longitude) from London. Such a maritime clock had to be not only highly accurate over long time intervals, but relatively impervious to corrosion in salt air, able to tolerate wide variations in temperature and humidity and in general durable while able to function at the odd angles and pitch and yaw typical of decks under strong waves and storm tossed conditions. Many leading scientists including **Newton and Huygens doubted** that such a clock could ever be built. In 1730 Harrison created a description and drawings for a proposed marine clock to compete for the Longitude Prize and went to London seeking financial assistance. He presented his ideas to Edmond Halley, who then referred him to George Graham who personally loaned Harrison money to build a model of his marine clock. It took Harrison **five years to build Harrison Number One or H1**. He demonstrated it to members of the Royal Society who spoke on his behalf to the Board of Longitude. The clock was the first proposal that the Board considered to be worthy of a sea trial. In 1736, Harrison sailed to Lisbon on HMS Centurion and returned on HMS Orford. On their return, both the captain and the sailing master of the Orford praised the design. The master noted that his own calculations had placed the ship sixty miles east of its true landfall which had been correctly predicted by Harrison using H1. This was not the transatlantic voyage demanded by the Board of Longitude, but the Board was impressed enough **to grant Harrison £500** for further development. Harrison moved on to develop H2, a more compact and rugged version. In 1741, after three years



of building and two of on-land testing, H2 was ready, but by then Britain was at war with Spain and the mechanism was deemed too important to risk falling into Spanish hands. He was **granted another £500** by the Board while waiting for the war to end, which he used to work on H3. Harrison **spent seventeen years** working on this third 'sea clock' but despite every effort it seems not to have performed exactly as he would have wished. Despite this, it had proved a very valuable experiment. Certainly in this machine Harrison left the world two enduring legacies — **the bimetallic strip and the caged roller bearing**. Returning to London in 1758 he found, thanks to the availability of the **new "Crucible" steel produced by Benjamin Huntsman**, harder pinions and tougher and more highly polished cylinder escapement could be produced. Harrison incorporated them into his design of a watch as a timekeeping device, based on sound scientific principles. This watch incorporated a novel frictional rest escapement and was also probably the first to have both temperature compensation and **Maintaining Power**, enabling the watch to continue running while being wound. Aided by some of London's finest workmen, he produced the world's first successful marine timekeeper that allowed a navigator to accurately assess his ship's position in longitude. **He proved that it could be done**. This was Harrison's masterpiece, the "Sea Watch" (H4), an instrument of beauty, resembling an oversized pocket watch from the period. It is engraved with Harrison's signature, and dated 1759. The movement has a sweep seconds hand and runs at 5 beats (ticks) per second. It is equipped with a tiny **remontoire** (an automatically rewind timing spring). In its transatlantic trial run the watch was accurate to 5 seconds, corresponding to an error in longitude of 1.25 minutes, or approximately one nautical mile. When the ship returned, Harrison waited for the £20,000 prize but the Board believed the accuracy was just luck and demanded another trial. The Harrisons were outraged and demanded their prize, a matter that eventually worked its way to Parliament, which offered £5,000 for the design. During Harrison's second trial "H4" proved extremely accurate, keeping time to within 39 seconds, corresponding to an error in the longitude of Bridgetown of less than 10 miles (16 km). The Board in 1765 again attributed the accuracy of the measurements to luck. Once again the matter reached Parliament, **which offered £10,000 in advance** and the other half once he turned over the design to other watchmakers to duplicate.



Harrison's "Sea Watch" with winding handle

Harrison began working on his H5 while the H4 testing was conducted, with H4 being effectively held hostage by the Board. After three years he had had enough and appealed to King George III, who was extremely annoyed with the Board. **King George tested H5 himself** at the palace and after ten weeks of daily observations between May and July in 1772, found it to be accurate to within **one third of one second per day**. In 1773, when he was 80 years old, Harrison received another amount of £8,750, **but he never received the official award** (which was **never awarded to anyone**).

In total, Harrison received £23,065 for his work on chronometers. He received £4,315 in increments from the Board of Longitude for his work, £10,000 as an interim payment for H4 in 1765 and £8,750 from Parliament in 1773. This gave him a reasonable income for most of his life (equivalent to roughly £45,000 per year in 2007). He became the equivalent of a multi-millionaire (in today's terms) in the final decade of his life.

The cost of these early chronometers **was quite high (roughly 30% of a ship's cost)**. However, over time, the costs dropped to below £100 (two years' salary for a skilled worker) in the early 19th century.

Today the restored H1, H2, H3 and H4 can be seen on display in the National Maritime Museum at the Royal Observatory, Greenwich. H1, 2 and 3 are still running; H4 is kept in a stopped state because, unlike the first three, it requires oil for lubrication and will degrade as it runs. H5 is owned by the Worshipful Company of Clockmakers of London and is on display at the Clockmakers' Museum in the Guildhall, London, as part of the Company's collection.



Harrison's Chronometer H5

Following Harrison, the marine timekeeper was reinvented yet again by **John Arnold** who while basing his design on Harrison's most important principles, at the same time simplified it enough for him to produce equally accurate but far less costly marine chronometers **in quantity from around 1783**. By the early 19th century navigation at sea without one was considered unwise to unthinkable.