John Harrison (1693–1776) and Lt. Cdr Rupert T. Gould R.N. (1890–1948)

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(Note: This article is based on extracts from the full biography of Gould, ***Time Restored: The Story of the Harrison Timekeepers and R.T. Gould, 'The Man who Knew (almost) Everything'***, published by NMM & Oxford, 2006)

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An introductory story

On a summer morning in 1949, Muriel Gould invited her children for a picnic in the village of Ashtead in Surrey. Cecil, now 31, and Jocelyne a year younger, had started lives of their own well before the war, but both son and daughter kept in regular touch with their mother and there was nothing unusual about the invitation. The picnic itself, however, *was* unusual because of the venue Muriel had chosen for the lunch. The family met that day in Ashtead churchyard, the blanket laid out by the grave of Muriel's late husband, Rupert. Lead capital letters, inlaid into the top of the large, horizontal white marble slab read: 'RUPERT THOMAS GOULD, LIEUTENANT COMMANDER, ROYAL NAVY, HOROLOGIST, AUTHOR AND BROADCASTER, BORN SOUTHSEA 1890, DIED CANTERBURY 1948'.

The funeral had taken place 10 months before, but of the family, only Rupert's son Cecil had been there among a small handful of mourners. It was also Cecil who had chosen the epitaph on the tombstone, and the emphasis on Gould's professional achievement and the absence of any memorial to a 'father' or 'husband' was not an oversight; twenty-two years before, Rupert and Muriel had undergone a bitter judicial separation and had hardly met thereafter.

So the picnic, which finally brought together these two diverse and conflicting aspects of their father's life, his career and his family, was always a bit of a mystery for the children. Their mother never did explain what it had been about; in later years Cecil supposed it might have been a case of his mother, in her own particular way, saying farewell to her husband, reconciling and resolving a ten-year partnership which had, after all, originally been loving. But the separation had been disastrous for Rupert, who lost his wife, his home, his closest friends, his job and custody of his children.

Rupert Gould – 'the man who knew (almost) everything'

By the time of his death at just 57 years old, Rupert Gould was enjoying celebrity status; he was nationally famous for a multitude of achievements and Cecil's epitaph characterised his father's public image well. But there was another very different side to this curious life; severe depressions, crippling bouts of overwork and the emotional struggles he faced during his short span, witnessed by his family but unknown to his public audience, directed the course of his life at every turn.

Ironically, Lieutenant Commander Gould's role as a Navy Officer, the title of which he carried with him all his adult life, was the least successful of his contributions. Rupert Gould was however possessed of an exceptional mind; he was a veritable polymath, and his extraordinary knowledge and his dissemination of it in his books and radio broadcasts was what made him a household name in his day. Of all the subjects he became expert in, it was Horology, the study of clockmaking and timekeeping, where he made his greatest contribution: he had an all-consuming obsession with the subject and was one of the 20th century's finest antiquarian horologists.

Gould's fascination for clocks and watches began in childhood and, with an interest already present, it is no surprise that when the young naval officer, studying navigation at Greenwich, encountered that indispensable instrument for finding longitude, the marine chronometer, he should do so much more than simply learn how to use it. In just four years, beginning at the age of 29, Gould prepared and wrote the definitive history of the instrument. *The Marine Chronometer, Its History and Development*, first published in 1923 and reprinted many times since, was so beautifully written and so thoroughly researched, it still has no equal on the subject in the 21st century. We tend to think of accessible books on technical subjects as very much a recent phenomenon and in this sense Gould was a long way ahead of his time.

In studying the subject it was Gould who rediscovered the great marine timekeepers of John Harrison, corroding in store at the Royal Observatory at Greenwich. These incredibly complex and intricate machines were the prototypes which led to the successful marine chronometer and are of monumental importance in the history of science. In fact, as Dava Sobel reminds us in her bestseller *Longitude* (Walker/4th Estate, 1995), Harrison's fourth timekeeper 'H4' proved to be the first of all precision watches, winning for him the famed £20,000 Longitude prize money, and marking him out as one of the 18th century's greatest scientific achievers.

Although famous in his day, Harrison's life had virtually been consigned to history until Rupert Gould retold his extraordinary story in 1923. Not only did he see Harrison's greatness recognised once again, Gould then dedicated over 15 years of his life to restoring the timekeepers to their former glorious working condition. The first three large machines were the greatest challenge, with H3, the most complex of all, having over 700 parts needing restoration. Every stage of the work was recorded by him in 18 meticulously detailed notebook/diaries and his work has not only preserved these timekeepers for posterity, but has enabled us to understand them in every aspect. What is even more remarkable is that these Herculean tasks were all done, to use Gould's own words, as a labour of love, and carried out in his own time; he would only accept repayment of expenses. For his contribution to horology alone the name of Rupert Gould should be remembered in perpetuity.

The polymath

But Gould was much more than simply an horologist. Blessed with an almost photographic memory and an insatiable appetite for knowledge, in the course of his life he became expert in many other fields, accumulating a truly astonishing breadth of learning. He was the epitome of the popular philosophers and 'men of knowledge' who were a feature of the mid-20th century, revered by the public for their knowledge and encouraged by establishment bodies such as the BBC as examples of intellects to be admired and emulated. And the fact that Gould was essentially an amateur, albeit a consummate one, made his broad knowledge all the more remarkable. Always the strictest of academics, he nevertheless appeared to be the typical gentleman dilettante in the many things he did. He had no formal academic degrees and on the only occasion when he entered a profession, his first career as a Navy officer, he was obliged to bow out, being quite unsuitable emotionally and psychologically to cope with the rigours of wartime.

He may have appeared to play the role of dilettante, but anything he took an interest in was studied in extraordinary detail. Had he not been well recognised as a polymath, he could easily have been remembered independently by small, specialist-interest groups. He was a pioneer in, for example, the study of tennis, of clocks, typewriters or on unsolved scientific mysteries such as the Loch Ness Monster phenomenon, of which, as will be seen, he wrote the first systematic study. These same wide interests led to Gould being asked to give a weekly wireless broadcast on *The Children's Hour*, the BBC's programme for younger 'listeners in'. Gould was billed as *The Stargazer,* though astronomy was only one of many subjects he chose to talk about. Few whose childhoods included listening to *The Children's Hour* forgot the talks given by 'the man who knew everything'. And in the 1940s it was inevitable he would be invited to join that select coterie who broadcast on the BBC's Home Service as *The Brains Trust*, the celebrated panel of experts answering questions of all kinds from listeners. Gould was notable as the welcome foil to the famous Professor of Philosophy, Cyril (‘it all depends what you mean by…’) Joad. Brains Trust producer Howard Thomas remarked that Gould was the only member of the panel never, in the history of the programme, to have been contradicted.

Only in exceptional men and women does one find a brain which combines a profound scientific understanding with the vivid imagination and artistic talent necessary to write and illustrate with the skill demonstrated by Rupert Gould. His published works are notable for their engaging style and characterful, clear illustrations. There is no doubt then that he was exceptional, yet in many ways he was everyman, subject to the times in which he lived. It is a cliché to say that the personalities of talented people often contain a mass of contradictions, but it is certainly true in this case. Gould was handsome and very large in stature, standing 6' 4” tall without his size 13½ shoes. Being intellectually strong and socially confident, with something of a commanding presence, an acquaintance might have expected him to possess a tough and rugged mentality. But severe depressions and overwork led to a complex and emotionally chaotic life, punctuated by four major nervous breakdowns. And it was not only overwork which kept Rupert from the marital home. A mind like his needed regular intellectual stimulation, something which, in spite of many fine qualities, his wife was unable to provide in large measure. *The Sette of Odd Volumes*, a literary dining club founded by the noted antiquarian bookseller, Bernard Quaritch in the 1870s, was ideally suited to Gould’s needs, and regular meetings of the Sette provided another forum for his intellectual pursuits, but another ‘nail in the coffin’ for his marriage.

Had fate served him different opportunities, who knows what one might have been able to say about R.T. Gould. Had his academic schooling continued on conventional lines it seems certain he would have excelled, probably resulting in a University professorship, a perfect role for a personality like his. In fact, if the Harrison timekeepers hadn’t stolen his heart in 1920, Gould was considering studying for the Bar which, with his great memory and pungent wit, would have been another magnificently appropriate career for him. The reality however, though important and productive in its own way, was not to be so straightforward. But from whatever aspect one considers it, his was an interesting and important contribution. He knew the value of his achievement but he also knew he’d made many mistakes along the way; Cecil recalled that at the end of his father’s short span, when dying in Canterbury Hospital, Rupert talked about the many triumphs and disasters that had brought him to that end. One wonders whether, that day in Ashtead churchyard one year after his death, his family were also reflecting on his extraordinary life.

Longitude, John Harrison and the Marine Timekeepers

In the early 21st century, over fifty years after Gould's death, studies in the history of Science and Technology are increasingly teaching us to appreciate and commemorate the vital role played by the backroom boys of technological history: the ones who preserve and record the evidence. In conserving, illustrating and interpreting the scientific and technical evidence left behind, men such as Gould are now beginning to take their proper place alongside the great inventors and scientists; they are just as important in our understanding of the advances that were made. Gould's greatest achievement in this respect was his restoration of the great Longitude timekeepers by John Harrison; a few words of explanation may be useful.

Up until the middle of the 18th century, navigators had been unable to determine their position at sea with accuracy and they faced the huge attendant risks of shipwreck or running out of supplies before reaching their destination. It was, as Dava Sobel has described it: 'the greatest scientific problem of the age'.

Knowing one's position on the earth requires two very simple but essential coordinates; rather like using a street map where one thinks in terms of how far one is up/down (one's Latitude) and how far side to side (one's Longitude). The latitude, how far north or south of the equator one is, is relatively easy to find by the height of the Sun at midday or (in the northern hemisphere) by the height of the pole star; sailors had been finding their latitude at sea for centuries. The longitude is a measure of how far *around* the world one has come from home and has no naturally occurring base line like the equator. The crew of a given ship was naturally only concerned with how far round they were from their *own particular* home base.

Even when in the middle of the ocean, with no land in sight, knowing this longitude position is very simple... in theory. The key to knowing how far around the world you are from home is to know, at that very moment, what time it is back home. A comparison with your local time (easily found by checking the position of the Sun) will then tell you the time difference between you and home, and thus how far round the Earth you are from home. The Earth can be divided up, like the segments of an orange, into 24 one-hour time zones, the 24 hours making up the whole 360 degrees round the earth and each hour's time difference equivalent to 15 degrees of longitude.

The great flaw in this 'simple' theory was – how does the sailor know time back home when he is in the middle of an ocean? The obvious, and again simple answer is that he takes an accurate clock with him, which he sets to home time before leaving. All he has to do is keep it wound up and running, and he must never reset the hands throughout the voyage.

This clock then provides 'home time', so if, for example, it is midday on board your ship and your 'home time' clock says that at that same moment it is midnight at home, you know immediately there is a twelve hour time-difference and you must be exactly round the other side of the world, 180 degrees of longitude from home.

The principle is indeed simple, but the reality was that in the 18th century no one had ever made a clock that could suffer the great rolling and pitching of a ship and the large changes in temperature whilst still keeping time accurately enough to be of any use. Indeed, most of the scientific community thought such a clock an impossibility. Even the great Sir Isaac Newton considered it so. But the stakes were high, especially after 1714 when the British government offered the huge sum of £20,000 for a solution to the problem, with the prize to be administered by the splendidly titled *Board of Longitude*.

John Harrison

It was this prize, worth about £2 million today, which inspired the self-taught Yorkshire carpenter, John Harrison (1693–1776), to attempt a design for a practical marine clock. History relates that, after a life dedicated to achieving this seemingly impossible goal, resulting in the creation of an extraordinary series of five prototype timekeepers, Harrison succeeded in his goal. With the work of a small band of horological pioneers following in his footsteps, the practical marine chronometer became a reality. From the early years of the 19th century and through the following century and a half, chronometers served in regular use aboard Navy ships and merchant vessels alike.

John Harrison (1693–1776) in the engraving by Tassaert (c.1768) after the portrait by Thomas King (c.1765). Harrison's extraordinary series of five prototype marine timekeepers led to the solution to the longitude problem, and the fourth, H4, was also the first of all precision watches (NMM ref: PAG6373).

It was these fantastically complex and abstruse timekeepers of Harrison's that, after a century and a half of neglect, Gould restored to their former glory during the 1920s and 30s. In order to convey the magnitude of what Gould achieved with the restoration of these machines, it will be helpful to explain a little of Harrison's development work, and the nature of the timekeepers themselves.

The Government prize of £20,000 was the highest of three sums on offer for varying degrees of accuracy, the full prize only payable for a method that could find the longitude at sea within half a degree. If the solution was to be by timekeeper (and there were other methods since the prize was offered for any solution to the problem), then the timekeeping required to achieve this goal would have to be within 2.8 seconds a day, a performance considered impossible for any clock at sea and unthinkable for a watch, even under the very best conditions.

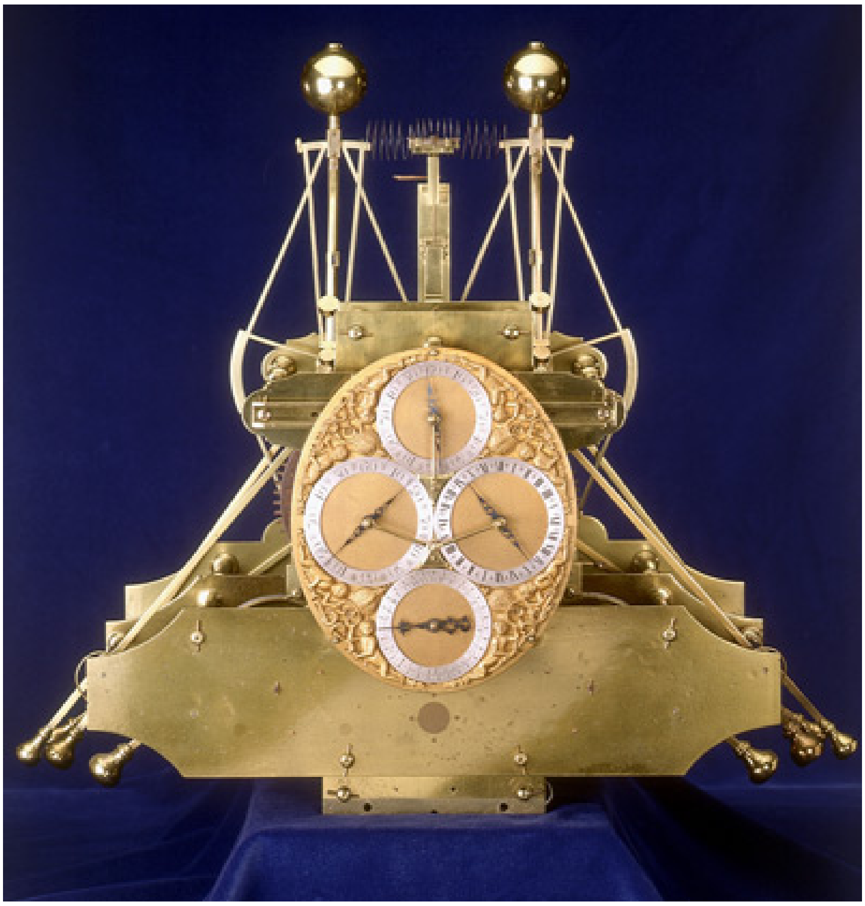
At the time, the only precision timekeepers, of any kind, were pendulum clocks. In the 1720s Harrison himself was making such clocks, which he claimed were capable of maintaining an accuracy of better than one second in a month, in spite of the fact that they were mostly made of wood. To achieve this high precision, Harrison incorporated several extremely ingenious new ideas, including a mechanism to automatically compensate for the effects of temperature. All clocks and watches, rather like the people who use them, tend to go slow when they experience a rise in temperature. Harrison invented a special form of compensated pendulum, using a grid of brass and steel wires, to ensure his clock kept time, whatever the temperature.

He also designed his clocks to run without the need for any oil, the ‘Achilles heel’ of clockwork: in the eighteenth century clock oil was derived from animal fat and often quickly deteriorated into a kind of acidic glue. By designing and incorporating bearings that used rolling contact, instead of sliding contact, Harrison’s anti-friction bearings cleverly side stepped this problem. No one before Harrison had ever made a mechanical clock to work without oil, and very few have done so since.

Watches on the other hand, were universally dismissed, being seen as jewellery, and not as serious timekeepers. Even the very best pocket watches of the day could only keep time to within about a minute a day and their timekeeping was generally thought of as impossible to improve. So clocks looked like the logical instrument to develop, but a pendulum clock would be of no use at sea, owing to the ship's motion. So Harrison decided to create something based on his precision long case clocks, but made to withstand movement and wide temperature changes.

And so it was that in 1728 John Harrison began to design a series of ‘sea clocks’, as he called them, which were to become the most celebrated and arguably the most important timekeeping devices ever constructed in the history of mankind. These were the machines that led Harrison to prove, in the face of universal skepticism, that a marine timekeeper was a practical possibility. Harrison’s machines led directly to the solution to the longitude problem, immeasurably strengthening the British Royal and merchant navies and saving of countless lives at sea over the following two centuries.

Harrison eventually built five timekeepers, the last two in the form of large watches, and since the 1950s they have generally been referred to as ‘HI’ to ‘H5’. It should be noted that the term *marine chronometer* was not widely used until after Harrison's death. The word ‘timekeeper’, however, had very special significance in the 18th century. It was only used to describe a portable machine capable of high accuracy.



H1. Created between 1730 and 1735, Harrison's first marine timekeeper was intended as a portable version of his precision longcase clock design. It ran without any lubrication, had automatic temperature compensation and was a highly sophisticated but complex mechanism (NMM ref: D6783-1)

Harrison's First Marine Timekeeper H1

Built between 1730 and 1735, HI is essentially a portable version of Harrison's precision wooden clocks, except that it runs for only one day (the longcase clocks run for eight) and is considerably larger than the wooden movements, weighing 34 kg and standing 63 cm high. After completion this timekeeper was taken to London where it amazed and excited the scientific community. It was sent on a semi-official trial to Lisbon in 1736 and though its going on the outward journey appears to have been rather poor, on the homeward course it corrected the estimated longitude by some 60 miles and was to impress both the ship's Master and the Board of Longitude. Although not a prizewinner, H1 can be considered as the first workable marine timekeeper ever constructed.

Here it would be helpful to mention briefly, in simple terms, the names of the separate parts that go to make up the insides of a clock, the mechanism of which is generally known as the *movement*. H1 can be used to demonstrate these parts.

The anatomy of a clock mechanism

The frame

The frame holds all the working parts of the timekeeper together and in H1 this is made in brass, consisting of a series of plates, held apart by pillars.

The power source

At the 'bottom end' of a clock movement is the power source, usually a weight or a coiled spring, which is the element that drives the clock. H1 is driven by two mainsprings connected with chains to a *fusee*, a conical pulley invariably found in English spring driven clocks and which ensures a uniform driving force to the wheels of the clock.

Maintaining power

Whilst the clock is being wound up however, this source of energy is removed from driving the mechanism and so, to ensure the clock continues to run and doesn't lose any time, it is necessary to add a special mechanism called *maintaining power*. The maintaining power Harrison designed for H1 was totally automatic and this design went on to be used in virtually all chronometers made since.

The train of wheels

The wheels in the movement, which feed the energy to the timekeeping element and supply the correct motion to the hands and dial of the clock, are known collectively as the *train*. Most of the wheels consist of an axle, the *arbor*, with a large toothed wheel and a smaller toothed *pinion* mounted on it, the wheels meshing with the next pinion in the train. In H1, Harrison made the wheels out of oak, just as he had in his earlier longcase clocks, and made the pinions in the form of little rollers, using *lignum vitae*, a naturally greasy hardwood (*Guaiacum Officinale*), each roller running on a fixed brass pin through its centre.

Escapement and oscillator

Finally there is the all-important *escapement and oscillator*, a grand-sounding name for the most important part, the 'beating heart' of the movement, the bit that actually measures out the time. It was to be improvements in the escapement and oscillator, made by Harrison and a number of other clock and watchmakers before and after him, which created the 'modem' mechanical watch and clock of the 20th century. The most common oscillator in a clock is the pendulum and the usual one in a watch is a little oscillating wheel called the *balance*.

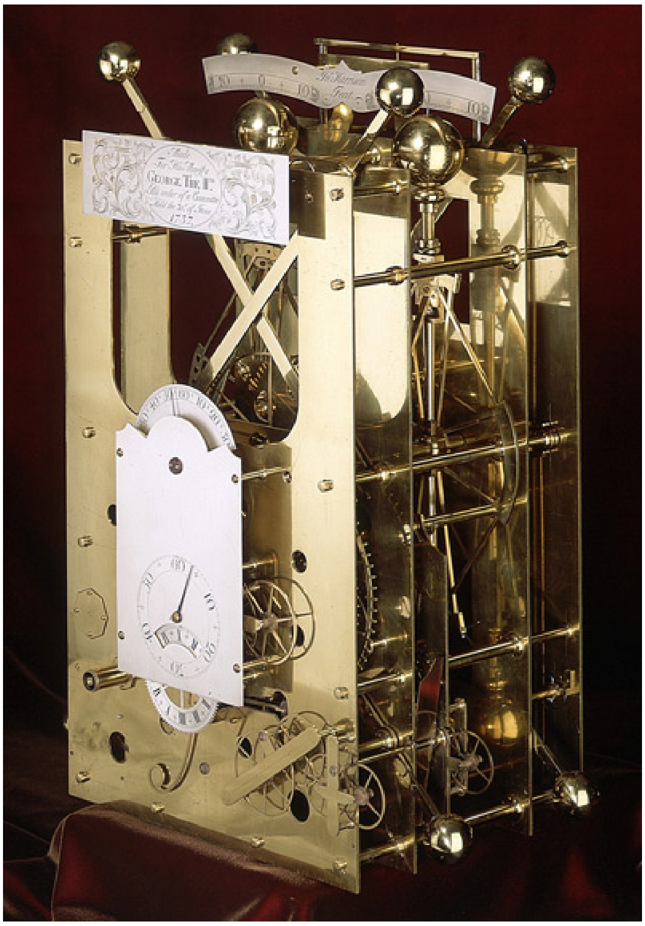
The escapement is the part which feeds in the energy, in the form of little pushes, or *impulses*, to keep the oscillator swinging, whether it be pendulum or balance. Common longcase clocks of the day used one known as the *anchor escapement*, so called because the *pallets*, the parts which receive the impulse from the wheels of the clock and transfer it to the oscillator, look like an inverted anchor.

In the 1720s, when Harrison was beginning to develop his precision timekeepers, all traditional long case clocks needed regular oiling to work properly, because the anchor escapement they used works with a sliding action and requires lubrication. So, for his precision long case clocks, Harrison invented a new type known as the *grasshopper escapement*. In this device, the pallets give impulses to the pendulum with direct pushes and without any sliding (and therefore do not need oil) ‘kicking’ back to their normal position after each impulse, the action looking rather like the legs of a grasshopper.

In H1 ‘the oscillator’ is in fact made up of *two* interlinked bar-balances. These are not wheels but are formed like dumb-bells, connected across their centres with crossed ribbons – a type of frictionless gearing between them. This ensured that any motion affecting one balance was counteracted by that same effect on the other balance. The balances are also linked with steel balance springs, of helical form, at top and bottom, providing H1 with what Harrison called *artificial gravity* (a bit like the effect of gravity on a swinging pendulum, causing it to keep returning to the centre). With this artificial gravity, when the balances were swung apart they would begin to oscillate together, each swing taking one second.

Harrison used the oil-less grasshopper escapement in H1 and in his next two, H2 and H3. The main moving parts in all three timekeepers are mounted on anti-friction rollers so they run entirely without oil. Additionally, all the parts were counterbalanced and controlled by springs so that the machines are entirely independent of gravity, an essential for any marine timekeeper.

Harrison also adapted the gridiron principle from his pendulum in order to compensate the timekeepers for changes in temperature. (In the balance-controlled timekeepers, a rise in temperature not only causes the balances to get larger, but also the balance *springs* to become *weaker*, making the clock’s tendency to lose even greater). In H1, this compensation mechanism was originally designed to be incorporated into the balances themselves (theoretically the better solution), but had to be altered and put in the main frame of the clock by Harrison, as he couldn’t get the earlier design to be reliable.

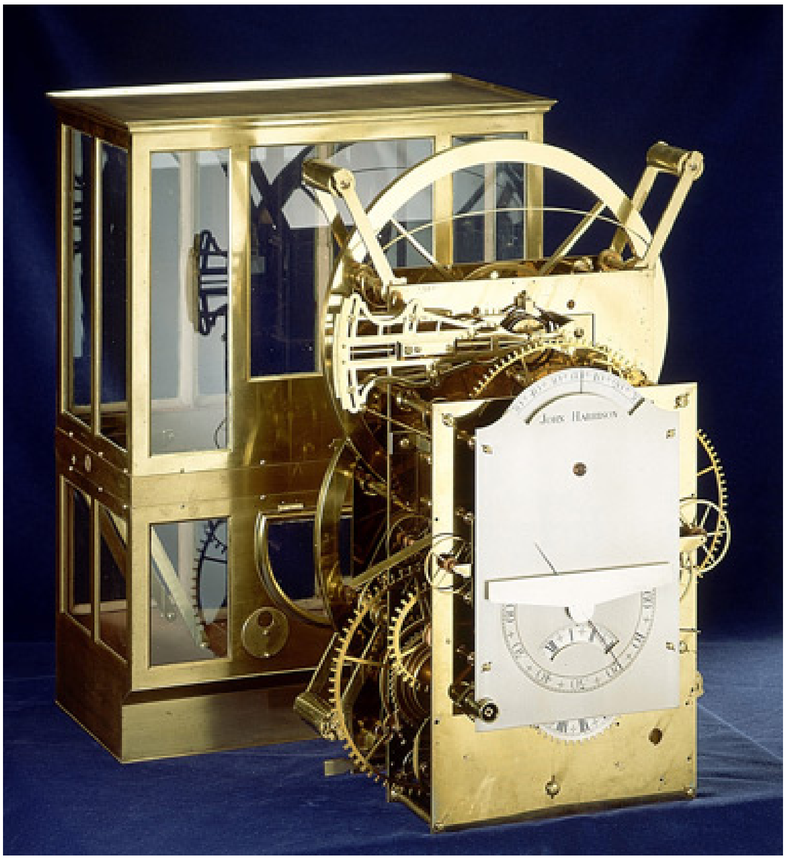


H2. Built over two years, between 1737 and 1739, H2 was a refined version of H1, with a remontoir to ensure a uniform drive to the balances. A fault in the design of the balances caused Harrison to reject the clock and start work on H3 (NMM ref: D6784).

H2

Encouraged by H1's relatively good performance, Harrison made H2 between 1737 and 1739. Larger and heavier than HI, H2 stands 66cm high, weighs over 39 kg and is made almost entirely of brass. The only wood he used in this timekeeper is in the lignum vitae parts and pallets. The concept is fundamentally the same as HI's, except that the temperature compensation is of a simplified design and Harrison fitted a device known as a *remontoir* to H2.

Even in a well made clock, small errors in the manufacture and meshing of the wheels and pinions will cause variations in the driving force delivered to the escapement. This, in turn, causes variations in timekeeping, and the remontoir is intended to remove these variations. A small spring drives the escapement independently of the main train of wheels. The function of the main train is then simply to wind up this small spring at regular intervals, as and when it needs it. In H2, this rewinding occurs every 3 minutes 45 seconds. Thus H2 is rather more complex than H1. As with H1, H2 would originally have been fitted into a glazed case and mounted in large *gimbals*, a kind of large universal-jointed suspension, to ensure it remained horizontal at all times, though the gimbal mounting itself unfortunately does not survive. Harrison discovered a deficiency in the linked bar balances when H2 was moved and, unable to correct for this, he simply set H2 aside. In spite of two years hard work he began all over again and launched into construction of his third marine timekeeper.



H3. Harrison spent nineteen years working on this immensely complex timekeeper. For many years he was convinced it would win him the longitude prize. It is the only timekeeper to retain its original carrying case (NMM ref: D6785-5).

H3

H3 was supposed to be Harrison's final word in timekeeper design and for years he was convinced it would be the prizewinner. Evidently the scientific establishment was too, as in 1749 Harrison was awarded the Royal Society's highest honour, the gold Copley medal, on the strength of his progress, and the Board of Longitude continued to support him with grant money. However, even after 19 years of painstaking labour, H3 was stubbornly refusing to reach the necessary accuracy. Although Harrison learned a great deal from this Herculean endeavour, and incorporated a number of brilliant inventions into H3, its ultimate role was solely to convince him that the solution lay in another design altogether.

H3 stands 59cm high and weighs 27kg (43kg in its case). The balances are wheels instead of dumb-bells and are arranged one above the other. Like the balances in H1 and H2, they are linked together, beat seconds and are driven by the grasshopper escapement. However, the balances are not controlled by helical springs but by one, short spiral spring, which controls the upper balance only. H3 is by far the most complex and difficult to work on. Like H2, it has a remontoir, but this rewinds every 30 seconds.

The improved temperature compensation is of an historically important design. Instead of using a grid of brass and steel rods, Harrison created a most wonderfully elegant and effective alternative. He fixed together, side by side, two metal blades, one of brass and one of steel. Because the blades are stuck together and because brass expands more than steel, when the temperature rises this *bimetal* will become curved. With one end fixed, the movement of the other end can be used to automatically adjust the timekeeper when the temperature changes. The bimetal is still very much in use today in thermostats, electric kettles, toasters, motor car direction indicators etc., and is a highly significant invention.

Another important device Harrison created especially for H3 was the *caged roller bearing*. This was the ultimate evolution of his anti-friction designs and was the predecessor of the caged ball bearing, a device used in virtually every machine made today. The caged roller bearings are employed in H3 in an extraordinarily abstruse mechanism known as an *isochroniser,* designed to ensure that the swings of the balances take the same time whether those swings are large or small.

H3 consists of over 700 parts and, with its remontoir, the isochroniser, the temperature compensation and all the antifriction devices, it is the most complex and difficult to understand of all Harrison's timekeepers. Just as it had given Harrison the greatest heartache, it was to give Gould the most trouble during its restoration in the 20th century.

John Harrison’s ‘RAS’ regulator. Built approximately in parallel with H3, this was Harrison’s ‘state of the art’ fixed pendulum clock. He claimed timekeeping as good as a second in one hundred days from it (NMM ref: D6786-1).

The ‘RAS Regulator’

In parallel with his work on H3, from 1740, Harrison was also busy working on an equivalent *regulator* (a high accuracy, fixed, pendulum clock) to supersede his wooden precision clocks, now 15 years old. The clock, now known as the ‘RAS regulator’ (The clock belongs to the Royal Astronomical Society) was, as far as we know, never finally adjusted by Harrison. Nevertheless, he predicted that one day this regulator would be able to keep time with variations no greater than one second in a hundred days. This was far more accurate than clocks of any kind until the 20th century, and the RAS regulator is therefore of exceedingly high importance in horological history. Although weight-driven and pendulum-controlled, it is similar to H3 in many ways, employing caged roller bearings, the grasshopper escapement, a 30 second remontoir and working without oil of any kind. Both H3 and the RAS regulator are depicted in the background in Harrison's portrait of 1765.

Harrison's Fourth Timekeeper H4

In 1753, Harrison commissioned John Jefferys, a London watchmaker, to make a watch following Harrison's own novel designs. Harrison discovered with this new watch that, if made with certain vital improvements, it had the potential to be an excellent timekeeper. He began to realize, after all this time, that he had been following the wrong path with his earlier experimental marine clocks. Harrison discovered that timepieces with a relatively small, *high frequency* oscillator (such as a fast beating, watch balance), if made to the correct proportions, are much more stable timekeepers when they are carried about, than the earlier ‘portable clocks’. This apparently simple discovery is one of Harrison's great achievements.

So, while ostensibly still working on H3 in the late 1750s, Harrison was in fact busy developing a new watch design, inspired by his success with the Jefferys watch. His fourth timekeeper that resulted from this development was just 13 cm in diameter and weighed 1.45 kg. It is thus completely different from the earlier machines. Both externally and to some extent internally, it looks like a very large, contemporary pocket watch, even to the extent of having pair cases (with an inner case for the movement and a protective outer case around it).

H4 (left), 1759, ‘the most important watch in the world’, alongside Kendall’s copy, K1, 1769. K1 enabled James Cook to navigate with great accuracy during his second and third voyages of discovery and was dubbed by him his ‘trusty friend’. (NMM ref: B5165). The oscillating balance, under the beautifully pierced and engraved upper part of the movement, was one of the main keys to the design’s success. Harrison agreed that the copy K1 was even more beautifully made than his original.

Technically, however, it is different from an ordinary watch in a number of significant ways. Apart from being exceedingly finely constructed, its balance is much larger, although still relatively light, and oscillates at a higher frequency. It swings to and fro no less than five times a second, giving the balance a great deal more *stored energy* when running, which renders it much less vulnerable to physical disturbance. Temperature change is compensated for by using the bimetallic strip, a smaller version of H3’s device. It also contains a miniature remontoir, rewinding every seven and a half seconds, to ensure a constant power source. Creating a remontoir on this small scale demanded the highest accuracy and quality of manufacture and H4 is an absolute *tour de force* of horological design and construction. Naturally this means that, even for an experienced watchmaker, H4 is a tremendous challenge to dismantle and adjust.

A type of *verge escapement* (the sort used in common watches) was fitted, of a highly modified form, which ensures that the balance is isochronous as in H3's balances. Although Harrison was unable to miniaturize the anti-friction devices, and H4 requires oil on all its bearing surfaces, jewelled bearings were fitted in many places to reduce friction to a minimum. This was not the first time jewelled bearings had been used in watches, but was relatively early for such an extensive use.

H4 was completed in 1759 and was sent by the Board of Longitude on two official trials to the West Indies. The story of H4's glorious triumphs in these trials and the Government's reluctance to payout the prize money are told in excellent detail by Gould in *The Marine Chronometer* and cannot be covered in detail here. Suffice to say that Harrison's timekeepers, as the foundation for the modern marine chronometer, saved countless lives and innumerable ships and cargo, and placed John Harrison as one of the greatest of the 18th century's scientific achievers. Indeed, one can also say that H4 was not just the world's first practical marine timekeeper, it was the first of all truly accurate watches, the 'father' of every precision watch which came after.

In 1765 the Board of Longitude reluctantly agreed to give Harrison £10,000, half the prize money, insisting on a full disclosure of the construction of the watch, the details of which were then published in *The Principles of Mr. Harrison's Timekeeper*, in 1767.

The Kendall timekeepers

On the instructions of the Board of Longitude, a copy of H4 was made, in 1769, by Larcum Kendall, that watch being known today as ‘K1’. At the same time Harrison and his son William were making a second marine watch, now known as ‘H5’, in an attempt to meet the Board of Longitude's changing requirements for winning the remaining half of the prize money. Kendall's copy was shown to the Harrisons, father and son, who both agreed that it was even more beautifully made than their own watch; a very remarkable compliment. On its first commissions, K1 distinguished itself in service with the greatest navigator of the day, Captain James Cook, on his second and third pioneering voyages to the South Seas. Cook, who was originally skeptical about its merit, eventually referred to it as his ‘trusty friend’ and his ‘never failing guide’, a great ‘celebrity endorsement’ for Harrison’s design.

A particular problem with the H4/K1 solution however was the great complexity and consequent cost of the instrument. K1 cost the Board £500; just 50 such instruments would be the equivalent of the cost of a whole 2nd rate ship of the line for the Royal Navy. So Kendall was commissioned to design and build a simplified version, now known as ‘K2’. This watch, made in 1771, was issued on a number of voyages of exploration, the most famous being in 1787, when it joined Lt. William Bligh on the Bounty, the ship that was the subject of the famous mutiny on that voyage. The watch was taken by the mutineers to Pitcairn Island and was only returned to England in 1840, after a series of adventures in South America. A further timekeeper, even simpler in design, was made by Kendall in 1774 and issued to Captain Cook on his third voyage of discovery to the south seas. It is known today as ‘K3’.

The ‘H’ & ‘K’ prefixes

It was Gould who introduced the ‘H’ and ‘K’ abbreviations for some of the timekeepers, but it is curious to note that, although from the outset, in the 1920s, he referred to the Kendall watches as K1, K2 and K3, he didn’t use an ‘H’ prefix for any of the Harrisons until 1939. One wonders if his familiarity with the Royal Navy’s K class submarines (he had his own clockwork model of the submarine ‘K2’) first inspired the use of those terms for the Kendalls. The Harrisons on the other hand were always referred to as ‘No.1’, ‘No.2’, etc., until 1939, when hurriedly packing up the timekeepers as WW2 approached, Gould scribbled the abbreviation ‘H4’ for the watch. Then, in correspondence with David Evans (1919–1984) of the Royal Greenwich Observatory (RGO) chronometer workshops, the term H4 was used again in 1945. Only in 1952, four years after Gould’s death, was the term ‘H1’ formally adopted for use in an article on that timekeeper by D W Fletcher. It was then only in the early 1960s that the others began to be referred to in their abbreviated form, the first reference to the complete series, with the prefixes H1 to H5, being in the catalogue to the National Maritime Museum’s exhibition *Four Steps to Longitude*, published in January 1962.

H5. Visually simpler in design than H4, H5 was of very similar technical construction. The watch was tested, with great success, by King George III at his private observatory in 1772. (Clockmakers’ Company. NMM ref: D6768)

H5

Harrison’s second watch, H5, completed in 1770, was technically very similar to H4, but with slight improvements to the escapement and compensation, and with a simplified appearance to the movement and dial. By this date Harrison was desperate for the recognition that his watch had solved the longitude problem. Rightfully feeling he deserved the remaining prize money, Harrison sought the support of King George III, himself a keen amateur ‘natural philosopher’ and very interested in advances in watch-making.

The King tested H5, with extremely good results, at his own private Observatory in Richmond and then promised the Harrisons his support. This resulted in a Parliamentary debate and the award to Harrison of the remaining prize money, as a bounty from Parliament. This, including expenses, came to £23,065, considerably more than the total prize money, though Harrison still complained that he had been short changed!

It cannot be claimed that Harrison's design for H4 is identical with the modern chronometer, but there is no doubt that those who followed Harrison, and who were responsible for simplifying and standardizing the chronometer, based their ideas extensively on his work.

The critical features of the modern marine chronometer

In simple terms, the critical features of the modern marine chronometer were four:

- First, the balance, which oscillates and keeps the time, is on the scale of a watch (as opposed to large clockwork) but is relatively large and runs at a relatively high frequency, with *high energy stored* in it, as it swings.
- Second, the balance is *detached*, i.e. it is allowed to swing freely and is only impulsed (i.e. given pushes by the escapement to keep it swinging) very briefly, just as the balance passes the middle of its swing.
- Third, the swings of the balance are *isochronous,* i.e. whether the swings are large or small they take the same time. In the modern chronometer this is ensured by making the balance spring of the correct *form*.
- Fourth, the chronometer is compensated for changes in temperature by incorporating some form of compensating device *in the balance itself*.

It is interesting to note that H4 itself only has one of these features (the first) and yet performs very well. The type of oscillator is thus perhaps the most critical of all these features.

The first man to achieve all four features in a successful chronometer was the London watchmaker John Arnold (1736–1799). There is considerable evidence that his work was based on Harrison's ideas, much of it taken from Harrison's published description of H4 (1767). As we have seen, Harrison understood the need for a balance with compensation, H1 originally had such a device, and he published a statement confirming the principle in 1775, which Arnold later quoted as his source.

The majority within this next generation of chronometer pioneers were English, but the story is by no means wholly that of English achievement. One French name, Pierre Le Roy (1717–85) of Paris, stands out as a major presence in the early history of the chronometer. Another great name in the story is that of the Lancastrian, Thomas Earnshaw (1749–1829), a slightly younger contemporary of John Arnold's. It was Earnshaw who created the final form of chronometer escapement, the spring detent escapement, and finalized the format and the production system for the marine chronometer, making it truly an article of commerce, and a practical means of safer navigation at sea over the next century and half.

The period of neglect

One of the conditions in qualifying for Board of Longitude prize money was that the Harrison timekeepers became the property of the government. In October 1765, Harrison was instructed to hand over H4 though, after much pleading from Harrison, the Board reluctantly allowed him to keep the three large timekeepers a little longer. Then, on 23 May 1766, these too were taken from him. Harrison's *bête noir*, the Astronomer Royal Nevil Maskelyne turned up, without warning, at Harrison's Red Lion Square home with an un-sprung cart!

Once back at the Observatory, all three machines were subjected by Maskelyne to a timekeeping trial, a completely pointless exercise. These were not the prize-winning timekeepers, neither were they in a fit condition for good running after their rough ride down to Greenwich. Following the inevitably disappointing results, they appear to have been displayed as curiosities in rooms at the Observatory. The astronomer Jean Bernoulli III recorded having seen two of them in 1769 and the artist John Charnock, visiting the Observatory around 1770, depicted H2 in a little watercolour sketch. Soon after this they appear to have been put away in storage, not to see the light of day for over half a century.

The watches H4 and K1 were of course considered as usable *chronometers* (the term being introduced, in its contemporary sense, by John Arnold in 1780). There is no evidence however that H4 was ever issued for formal navigational purposes, even then being considered an historical relic. After Cook's two south sea voyages, K1 enjoyed a brief but eventful career as a ship's chronometer, sailing with Capt. Arthur Philip in Sirius, part of the 'first fleet' to Australia in 1786-1790. Then, after repairs by Thomas Earnshaw, K1 was lent to Sir John Jervis, later Earl St.Vincent and First Lord of the Admiralty, who kept it for nearly ten years.

From the early years of the 19th century H4 and K1 were pensioned off and preserved as historic instruments. The evidence is that they were in fact quite well cared for and neither ever got into the kind of state the larger machines were to suffer in later years.

H5 was never government property and remained in the hands of the Harrison family until 1869, when it was sold to the Scottish shipbuilding magnate and collector, Robert Napier (1791–1876) of Gareloch. The Napier collection was sold at auction by Christies in 1877 and H5 was bought by the art dealer W.Boore of the Strand. Boore offered H5 to the Clockmakers Company, but it was turned down on the grounds that H5 was only really a copy of H4 and was of insufficient interest! However, in 1891 the Rev. H. L. Nelthropp finally persuaded the Court of the Company to acquire it, at the princely sum of 100 guineas. H5 has always been the best preserved of all the timekeepers and remains to this day in pristine condition in the care of the Company.

The first three, large timekeepers were to suffer a very different fate. After more than 50 years in poor storage, it was decided by the Astronomer Royal, John Pond (c.1767–1836) in 1824, that the timekeepers should be cleaned. They were sent to John Roger Arnold, son of the celebrated chronometer maker John Arnold, and the principle supplier and repairer of chronometers for the Observatory at the time. As so often happens with complex but low priority projects such as these, the cleaning of the three timekeepers seems to have been considered a low priority by Arnold and ten years passed by without the work getting started. In 1835, Pond was replaced as Astronomer Royal by a 'new broom', the super-organised, autocratic George Biddell Airy (1801–92), who was to reign at the Observatory for an amazingly productive and ordered 46 years.

One of the first things Airy did was to conduct an inventory of the Observatory’s instruments and he quickly discovered that the Harrison timekeepers were with Arnold, by now in the partnership of Arnold & Dent. Airy wrote in October 1835 asking for the immediate return of the clocks and the company replied two days later asking for a little more time. They reported that H1 was in ‘…a complete state of decay…’, H2 was basically sound and H3 was suffering from rust on the steel parts, the glazed case having a broken glass panel, allowing moisture in. They also reported that very little was known about the timekeepers and, as no plans of them appeared to be available, they proposed to have some technical drawings done.

Over five years went by and Airy was obliged to write again requesting a date for the return of the timekeepers. After another slight delay, the clocks finally went home to Greenwich at the end of August 1840. They had probably been surface cleaned, but were evidently not in working order, though a set of drawings, some of them in very fine colour wash, had been done by the draughtsman, Thomas Bradley. Five of these beautiful plans of H1, H2 & H3 are still preserved in the RGO Archives at Cambridge University Library.

For another eighty years the timekeepers languished in the stores at the Observatory, though for H2, H3 and H4 there was a brief respite in 1891 when they were exhibited at the Naval Exhibition in Chelsea. H1 was by that time considered too badly deteriorated to display, but H2 and H3 were exhibited in their un-restored state. H4 had been cleaned by the noted watch and chronometer maker, James U. Poole, the year before.

Notwithstanding the brief moment of glory for H2, H3 & H4 in 1891, all the timekeepers were out of order and neglected again when, on that fateful day, 5 March 1920, Lt Cdr Rupert T Gould came to visit the Observatory in search of these neglected and largely forgotten masterpieces.

The Restoration of the Harrison Timekeepers

The restorations began straight after Gould had visited the Observatory.

H1 was cleaned during 1920 to remove the extensive corrosion from the metalwork, but was not put into working order as there were several missing parts (it was in by far the worst condition of all the timekeepers).

H4 was overhauled next in 1921. It needed little work except cleaning and adjusting to put it into working order, after which it was displayed in a special showcase at the Observatory alongside K1.

The restoration of H2 took from the end of 1923 to late 1924, after which it was exhibited at the British Empire Exhibition in 1925 and then on to the Science Museum in South Kensington for 10 years.

H3 was as troublesome to Gould as it had been to Harrison during its creation. Work began on its restoration just before H2 left Gould’s house in 1924 but, after returning (in pieces) to the Observatory twice in the ensuing years, it was finally completed in 1931 joining H2 at the Science Museum the following year.

The RAS regulator was restored and a new pendulum and showcase made between early 1927 and early 1929, at which point it was set up in the Library at the Society. Later it was loaned to the Royal Observatory at Herstmonceux and came on loan to the National Maritime

Museum in 1976 when it was given a new mahogany showcase. This was then replaced with a glass showcase in 1992.

H1 was finally taken on again for complete restoration to working order between 1931 and 1933. This work included new balance springs and parts of the temperature compensation mechanism. Gould also redesigned the original ‘string-pull’ winding to work more conventionally, with a key.

After Gould’s celebrated lecture, to the Society for Nautical Research, on ‘Harrison and his Timekeepers’ at the Drapers’ Hall in 1935, when all the timekeepers were exhibited together working, H1 to H4 were loaned for one year to the Science Museum. They were all then set up in the new NMM galleries in 1937, but were removed again in 1939 and sent to Cambridge for protection during WW2. Sadly, during this time they all became somewhat dirty again, but by 1945 Gould was becoming too ill to continue the work and the MoD Chronometer Department took on their re-cleaning, H1 having its original-type pull-winding restored.

During all of these restorations, from 1920 to the 1960s, there were inevitably small parts removed from the timekeepers, and Gould and the MoD staff were careful to keep all these relics in little boxes as part of the original timekeepers. All of these are now preserved in the collections and can be seen under the Harrison Relics.

A full biography of Rupert T. Gould, *Time Restored*, is now in print and can be purchased through the NMM online shop,
www.nmm.org.uk/index.cfm?SelectedProductPLUNo=81481