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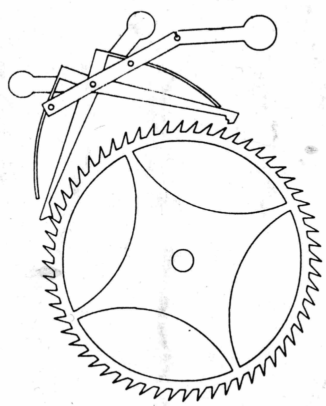

The making of the Gurney Clock and the findings of the Harrison Research Group

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Blue tags - Committee & Speakers

Pink tags - Members of Norwich Branch BHI
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Coloured stickers on tags denote coach to use on Gurney Clock Excursion

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HARRISON SEMINAR

Administration:-
Timothy Treffry

Lectures:-
Jonathan Betts

Exhibition:-
Andrew King

Secretary:-
Alwyn Oliver

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session 1

An Introduction to the Harrison Research Group

Jonathan Betts

The Harrison Research Group is simply an informal collection of people with one general interest in common; the study of the life, thoughts and works of John Harrison. There is however an unspoken driving force behind all the members of the group; the belief that in spite of great fame and fortune (which came a bit late in the day for him), John Harrison has never received the serious recognition he deserves for his work.

From his own times when King George III himself supported Harrison in his struggle to acheive just rewards from the Government, he has had a series of champions. It was only in this century however; with the researches of Lt Cdr Rupert Gould who not only described the marine timekeepers clearly for the first time in his magnum opus '*The Marine Chronometer*' but also was responsible for their 'ressurection', that we saw the first of Harrison's really great champions. Soon after Gould's death there appeared another fine historian, the late Col Humphrey Quill, who's researches culminated in the publication of the definitive biography in 1966. Quill's biography, itself a great champion of Harrison, is important for introducing the other important aspects of Harrison's work; his development of high precision land based timekeepers and a mention of his thoughts on the musical scale.

But there is an irony in all these champions of Harrisons in that they have all tended to present an unbalanced and faint-hearted assessment of his works; giving the laurels with one hand and taking them away with the other. For example, as is well known, Harrison's attempts to express himself clearly on paper were not very successful but we now know that a large part of his thinking is explicit in the extant manuscripts and texts if one only takes the trouble to get to know his style and 'language' and 'translate' them. Gould however, would have us believe they might as well be the work '*...of a partially intoxicated scrivener...*' and Quill describes them as '*...gibberish...*' Gould and Quill leave one with the impression that Harrison won the longitude prize more by sheer determin-ation; finally persuading a timekeeper designed on poor principles to do the trick after 100's of hours of struggling. In the last analysis one can't help deducing from these authors that all he really contributed to marine chronometry was the maintaining power which bears his name. The H.R.G. intends to show that this is positively not the case and that there were other important contributions which have never received the credit they deserve.

It is no coincidence that Harrison was interested in music. His under-standing of how oscillators behave was very detailed and complete and his work on balance controlled timekeepers, the pendulum clocks, and vibrating strings and bells all had this in common. His experimental technique, his scientific method as evidenced by his writings, also deserves far better recognition. It was in Humphrey Quill's work that the beginnings of the H.R.G. was seeded.

A proof copy of Quill's biography found its way to Martin Burgess, prior to publication, and his interest in Harrison and especially in the grasshopper escapement (already firm, having made a number) began to grow. Burgess eventually published an article in 1971 in *Antiquarian Horology* following one by Col Quill; both on the grasshopper escapement. An interesting correspondence ensued in the letters' columns of the journal, from Bill Laycock, Charles Aked and Martin Burgess. Laycock and Burgess met and became good friends; they were encouraged by Col Quill to further research Harrison's writings. When, in 1974, Burgess was commissioned to build a regulator clock by Barclays Bank to be presented to Norwich, he decided to attempt a design on Harrison principles and to rely on Laycock, as an engineer, to provide the scientific and technical support. Laycock's researches into Harrison's writings culminated, in 1976, with the publication of '*The Lost Science of John, Longitude, Harrison*.' and was complemented by a BHI lecture in January 1976.

Naturally, all interested in Harrison attended and it was here that the core of the H.R.G. met each other for the first time, all looking to Martin Burgess and the Norwich clock project as the focal point. With the tragic death of Bill Laycock in the same year, Burgess lost the scientific support he needed for the building of the Norwich clock and another interested party, Mervyn Hobden, suggested that the relevant people should form a loose association or group and meet to exchange ideas and news on a regular basis. The first meeting took place in 1981 at the Old Royal Observatory where the majority of Harrison's timekeepers are preserved. The group has met there, usually annually, ever since.

The main members of the group are: Martin Burgess, Mervyn Hobden, Andrew King, Dave Harrison, Anthony Randall, Charles Coad, Beresford Hutchinson, Peter Hastings and Jonathan Betts. Several will be speaking at the seminar on the subjects with which they specialise within the group.

session 1

The Problem of finding Longituge at Sea and how it was solved by John Harrison: The Background Story

Heather Hobden

What were the problems of finding longitude at sea? How did John Harrison's accurate timekeeper provide the solution? Why did he have such a long struggle to achieve recognition for his achievement? In a short space of time it is not possible to go into all the details of such a long and intricate story, instead we shall look at the highlights of the general background. We shall be looking first at the problems faced by navigators from earliest times in finding their position on open featureless oceans and the events leading up to the setting up of the Board of Longitude. Then we shall be taking a fresh look at John Harrison's background, his early life in Barrow on Humber, and conclude with a discussion of the reasons for the reluctance of the Board of Longitude to give him its award.

An Account of the Discovery of the Scale of Musick

Charles Lucy

Since Pythagorean times it had been believed that musical harmonics were caused by simple whole number ratios of string length and frequency. So that for example if A was at a frequency 220 cycles per second (Hz.) the fifth above (that would be E) is at one and a half (3/2) times the frequency or exactly 330 Hz. The fourth (D in this case) was believed to be at one and one third (4/3) times the fundamental frequency i.e. 293.333Hz.

This system was thought to be simple to measure and believed to be correct, until attempts were made to apply it to explain other harmonics which could be heard, by beat frequencies but not enumerated. Literally thousands of books and millions of hours have been consumed in attempts to construct a better mathematical model of musical harmonics. The textbooks on music and acoustics used throughout the world at present still state that harmonics are caused by whole number ratios. Many of these books contain drawings showing sine waves for frequencies of a fundamental and a fifth and how every sixth time the peaks coincide, as though this is an exact scientific law. Nevertheless, no model except the system which I am about to explain based on John Harrison's book *Concerning Such Mechanism*..... can provide an infinite mathematical model, which can express the harmonic relationship of all possible musical intervals to known accuracy and levels of harmonic consanance and dissonance. Being a systems analyst with a strong musical background, I was familiar with the traditional model, but like everyone else who delved a little deeper, I also knew that it didn't explain all the harmonics which I could hear. For many years I had experimented with alternate mathematical models, but none satisfied me as representing a working system which explained all the harmonics I could find on a musical string.

One Sunday in 1985, having read every book I could find on the subject, I was lying on the floor playing with a calculator, and digesting a much appreciated lunch, at a friend's house. My hostess, Dorice Hannan, the psychic, (for sake of a better term) returned from upstairs and said, 'Charlie, my friends upstairs tell me that you're looking in the wrong place.' 'Tell me more.' 'Well, they say that what you're looking for is in some way related to that funny Greek letter like a 'p'.'

The following day I had a meeting with Mr Chew, retired curator of musical instruments at the Kensington Science Museum, and told him that I had a hunch that musical harmonics were in some way related to Π.

'That's what John Harrison thought.' he replied.

That was the first time I had heard of John Harrison.

But with assistance from Cedric Jagger, Charles Allix, Andrew King, Martin Burgess, and particularly Mervin Hobden, I was able to resurrect and interpret Harrison's musical ideas.

As a result of experiments with pendulums, monochords and a bass viol, Harrison found that the mathematics of musical harmonics were related to II. He found that the pitches which musicians hear as harmonics and scales were caused by the multiple addition of two types of interval.

1) The Larger note as he calls it; This is a ratio of 2 to the 2II root or in BASIC computer terms 2↑(1/(2*ii)), which equals a ratio of 1.116633 or 190.9858 cents, approximately 1.91 frets on a conventional guitar. (L)

and

2) The lesser note, which is half the difference between five Larger notes (5L) and an octave. i.e. (2/(2 ↑ 1/(2*ii))) ↑ 5) ↑ (1/2), giving a ratio of 1.073344 or 122.5354 cents, an interval of approx. 1.23 frets. (s)

The equivalent of the fifth (i.e. seventh fret on guitar) is composed of three Large (3L) plus one small note (s) i.e. (3L+s) = (190.986*3) + (122.535) = 695.493 cents or ratio of 1.494412.

The equivalent of the fourth (fifth fret) is 2L+s = 504.507 cents.

I appreciate that this totally contradicts, what we were all taught in 'O' level physics about the harmonic series being caused by whole number frequency or string length ratios, but follow this idea carefully. Assume that the octave ratio is two. That is by halving the length of a string exactly the pitch or harmonic which is sounded is double the frequency (an octave). Let this octave be a complete circle. Imagine a clockface. The twelve hour positions each being thirty degrees apart represent the twelve notes of the twelve note equal temperament
scale. Each interval being one semitone or 100 cents.
Save this image we will come back to it later.

Now considered the layout of a conventional piano keyboard. In each octave there are seven 'white' notes and five 'black' notes. The 'white' notes represent the naturals, and the 'black' notes serve as sharps or flats. The interval between the white notes which are separated by a black note is a Large interval (L). That is C to D; D to E; F to G; G to A; and A to B.

The interval between the adjacent white notes is a small interval (s). E to F; and B to C.

An octave consists of 5 Large plus 2 small intervals. The major scale is in the pattern L + L + s + L + L + L + s = 5L + 2s. The minor scale (white notes starting from A) is L + s + L + L + s + L + L = 5L + 2s.

Now we return to the clockface.

The radian is the angle where the distance around the circumference is equal to the radius. Imagine a slice from a circular cake where all three sides are of equal length. This slice with an angle of 57.2958 degrees represents one Large interval. If we cut the five Large intervals, we are left with a slice of 73.5210 degrees, which represents two small intervals. By cutting this remaining slice into two equal pieces of 36.7605 degrees we now have five Large slices and two small slices, which with any crumbs left on the plate or knife, represent the complete octave.

Back to the piano. If we build the pattern L + L + s + L + L + L + s which represents the major scale starting from F we need to flatten the B to B flat. If we do the same starting from G we will need to sharpen the F to F£. We can continue doing this ad infinitum, and generate any number of notes we would like in an octave, the flats being generated through the fourths (F), and the sharps through the fifths (G). In consequence we can describe any frequency ratio or interval in musical terms. It may require many orbits or octaves of sharps or flats but eventually we will find it by cumulative addition to whatever level of accuracy we should require. The result of this system is beautifully simple, for not only does it work musically and mathematically, it also suggests something very significant about our understanding of musical acoustics. The harmonic series based on whole number ratios seems to be true of the octave, as a mirror image on each side of the node is produced, but for all other integer ratios are only poor approximations. The traditionalists usually now ask about beat frequencies, to which I reply,

'How accurately have you measured the pitch of your *integer* harmonics?'

It seems that what is happening is that the movement of a vibrating string or sine wave, which had previously been assumed to be in two dimensions, is really in three or more dimensions, in a pattern which is similar to a coiled spring, and that the 'old' thinking had only been considering the cross-section of this pattern.

The patterns of this discovery seem to exist not only in the audible frequencies, but also through the electro-magnetic, x-ray, microwave and light frequencies, and as Mervin Hobden's specialisations are in these fields, I am sure he will be able to illuminate the physics, and philosophical implications, better than I can from my systems, musical and arithmetic viewpoint.

Interestingly, there is still a 'missing treasure' in connection with Harrison's musical ideas. John Harrison's *A True and Full Account of the Foundation of Musick, or, as principally therein, of the Existance of the Natural Notes of Melody*, an unpublished manuscript of 182 pages, which is catalogued as item 8961 in *Bibliotheca Chemico-Mathematica* issued by Messrs. H. Sotheran of London in 1921, is still missing.

I wonder what further musical secrets it contained.

The Early Wooden Clocks of John Harrison

Andrew King

John Harrison remains unique in the history of horology - an enigma whose intricacies have only now, within the last two decades, been slowly unravelled to reveal a remarkably original thinker.

Although best known as the pioneer of the marine time-keeper his initial horological work was with pendulum clocks. Harrison started his lifetime's work in the pursuit of precision timekeeping with these early clocks which were unique in design and construction. In 1730 Harrison stated that he was well aware at the time when the 1714 Longitude Act was passed, and indeed for years later, that no fixed clock existed, let alone a portable time-keeper, which would meet the exacting requirements of the Act. It was generally doubted that any portable time-keeper could ever be capable of meeting the conditions.

With this in mind Harrison steadily developed his first pendulum clocks and within fourteen years he was confident that a successful marine time-keeper could be built. it was at this stage that he designed his first Sea clock and took his proposals to London for a reaction and to seek future support.

Clocks of an all wood construction were never made on a serious basis in England. The wooden clocks made by harrison are by far the best designed and most carefully made clocks of their kind ever built. Every detail is thought out with the greatest attention in terms of the materials used as well as the fundamental mechanics employed in the design. Harrison never made anything in a particular way without having a soundly based reason for it. Every detail exists for a good purpose.

In this talk how these clocks were made will be explained exactly as will be the history behind them. It will be suggested that if these wooden clocks had not been made and tested successfuly the marine time-keepers would never have emerged.

The Isochronous Pendulum System of John Harrison

Martin Burgess FBHI and Mervyn Hobden

Harrison developed his system for accurate pendulum timekeeping before 1730. He continued to refine it throughout his life right up to his death in 1776 but, because of his early isolation from other horologists, the development of his thought and the methods he employed were quite different from that of other clockmakers.

Much has been written about Harrison's various mechanisms. The closest look at his pendulum technology was conducted by Laycock and published by him in his book *The Lost Science of John (Longitude) Harrison*, in 1976. But all these calculations, speculations and writings, as Laycock would have been the first to agree, were only theories which would need to be tested. It would be necessary to build a modern Harrison Regulator and conduct experiments on it just as Harrison himself would have done. The Gurney Harrison Regulator is the result of this experimentation. This lecture is a description of what has to be done to build an accurate Harrison clock.

The lecture is composed of four basic sections but the sections interlink and overlap and tell the story in the chronological order as our knowledge increased.

In the first section the evolution of Harrison's thought and his approach is compared with that of other clockmakers. All clocks keep perfect time in that they always sum the effects of their own internal workings and the effects upon them of changes in their environment. The task of the clockmaker is to make the rate of the clock keep perfect pace with the rotations of Planet Earth. Other clockmakers attempted to improve their clocks and with this they had considerable success but Harrison studied all the causes of the fluctuations of rate and attempted to balance the errors against each other. His method is very slow because his oscillator (a seconds pendulum) is very slow but it embraces the integrated working of the whole clock as part of the oscillating system and does not only attempt to improve this or that part of it in isolation.

Other clockmakers then and since have tended to accept theories often proposed by academics who were not themselves clockmakers and then build clocks to meet the demands of those theories even though there can never be enough data for any theory to give perfect results in a working clock. The clocks were the product of thought but no real effort was made to allow the clock or the data generated by it to dictate to the clockmaker. The clocks were not suited to having many adjustments made to them once they had started to work.

Harrison approached the problem with the very best scientific attitude far in advance of his day. He so designed the clock that it could dictate to the clockmaker what to do next to bring the errors into better balance after long drawn out experimental testing. Everything in his design can be subjected to experimental tests to see if that element has been constructed and adjusted correctly.

The second section describes the Gurney pendulum design and the design of the cheeks. These are compared with what Harrison built for the late regulator and we will show how our own work is not anything like as good as that of Harrison. The cheeks are vital to the isochronism and are very hard to make and adjust but they are only one of the elements which have to be brought into agreement and they have to be adjusted over and over again because any other adjustment requires their re-adjustment.

The third section describes the escapement unit of the Gurney Harrison Regulator in detail. It has about 500 parts. It will be fully illustrated with many slides showing how it is built up, what all the parts do and how they interact. Some parts are compared with the construction of the late regulator, some fall short of what Harrison did, some may be improvements.

The fourth section describes the testing of the various parts, the changes which had to be made to them and the delicate and protracted business of attempting to balance the temperature error, the circular error, the barometric error and the escapement error. Graphs will be presented which show the stability of the clock in spite of very violent treatment of the pendulum, (strong draughts, big change of energy input and pushing the pendulum into quite different arcs with a probe). A graph will be shown which demonstrates why any use of cheeks at traditional pendulum arcs was always doomed to failure and that attempts to use them amounted to a confidence trick against the client because proper testing would have shown that they did not work. Results will be displayed which show how the clock behaved in the workshop. Some remarks will be made which will indicate the way forward in the bringing of the Gurney Clock into better adjustment to cope with the conditions which are being experienced on site.

The Gurney Clock

The Gurney Clock, which was commissioned by Barclays bank to commemorate the bicentenary of the Gurney Bank one of their constituent institutions, was handed over to the City of Norwich on July 3rd 1987 in a ceremony reported in the *Horological Journal* the following September.

The initial commission was to Martin Burgess but the project grew to include the expertise of horologist/animator Peter Haward, Norwich City Architect Roy Foyster, sculptor Michael Barber and glass etcher James Knight.

The work of Burgess and Haward is described below in extracts adapted from the *Horological Journal*

Burgess HJ July 87
The whole clock is like a huge triangular museum showcase of glass and steel, 20 ft high. Two time drums for the hours and minutes show through three windows at the top. The animation fills the floor space. All this moving mechanism is driven by electricity but the regulator signals to it to move on every half minute.

The regulator has a back-board is ground flat mild steel weighing 200 lb. Screwed into it are 22 stainless steel pillars which carry the movement. All the main wheels are of duralumin for lightness, lacquered with Frigilene. At the bottom is the deree plate and the sensor for the Radiocheckrate. The brass cased, lead filled, 15 lb weight gives out 44 ft./lb. a week. It can run the clock for almost seven days but is constantly rewound when the clock strikes. The winding is very slightly faster than the fall in case of power cuts. The top of the weight carries a stopwork which discharges the winding click when the weight is right up. The weight drives the clock through a Huygens endless chain. There are nine spikes on the winding ratchet and 18 on the hub, which carries the 2ft great wheel and the double ended sun and moon hour hand. The hours are on a half ring dial and each end of the hand passes them ant-clockwise every 12 hours. The 192 cycloidal teeth on the gret wheel drive a roller pinion of eight. Each roll is on an oil-less, stainless steel ball race so the energy consumption is extremely low and the drive appears absolutely constant.

The minute wheel turns clockwise once an hour and carries the minute hand past a dial ring. The poised minute hand carries a poised cam which lifts two mercury switches. When these drop, the right hand switch is delayed by the swinging cock on the right and this signals to the minute drum to move on if there has been a power cut. The centre of the minute hub is terminated by a boss of green Connemara marble. On the right of the minute wheel and close to its rim is a latch which latches the train so that the whole excapement unit can be removed without running the weight down.

The cycloidal teeth of the minute wheel drive the remontoire wheel through a roller pinion of eight, turning once in four minutes. The driving faces of the remontoire wheel teeth are cycloidal but their backs are cut away both to lighten the wheel and to act as ratchet teeth held by a click, so that the remontoire spring does not unwind if the hands are set back. The remontoire drives a four-bladed fly hrough a roller pinion of six. Its arbor carries the detent blade and the detent lifting cam. The blade is halted by a pin on the detent which is lifted out of locking every half-minute. The lifting is done by a pivoted claw acting on an eight-pin ring on the 'scape arbor, the fly arbor cam makes one revolution lifting the claw out of engagement with the pin and lowering it ready for the next pin. This superb detent unlocking mechanism was invented by Harrison and used by him in H2, H3, H4 and the late regulator. It needs an article all to itself.

The remontoire spring is of ni-span C to give a constant torque in changing temperaure and runs between five and six setups. The remontoire wheel sets it up an 1/8th turn every half minute. The 'scape wheel has 120 teeth and its abor carries a four-bladed secondhand which turns past a quadrant dial engraved with the seconds anti-clockwise. The wax filled engraving on all the dials is by Edward Archer.

The 'scape drives the pendulum through a grasshopper escapement. This grasshopper has the proper geometry to give the correctly proportioned impulse and it is the first to do that since Harrison's day. Any maker in the last 200 years could have made it if they had bothered to read pp. 25 and 26 of *'Concerning....'*; and had understood why they needed to follow it. The whole subject is too large to go into here. The pallet arms and composers are of dural mounted on lignum vitae bushes turning on a hard, highly polished, gold pin. The pallet pads are also lignum vitae. The crutch arbor is a complicated unit superbly made by Anthony Randall. I could not have made it. It is of brass, hard gold-plated, and carries very accurate knife edges which rest on accurate grooves machined in brass-mounted quartz blocks set in the bearing boxes. The box covers are provided with sapphire end stones and the arbor itself is adjustable for length to bring down the end shake to a minimum. The crutch is invar with stainless steel forks and connects to its arbor though beat-setters to get the pallet unlock at the same arc on both sides.

The 3 lb, brass cased, lead filled, lenticular pendulum bob is split down the middle to expose the compensaor which is of pure iron plated with nickel. It sits on the rating nut but does not touch the invar pendulum rod to avoid stick-slip. The nut is graduated in seconds for rough regulation but the rod continues under the bob and carries a gilded brass nut, one turn of which makes a difference of 1/10th, second a day. The 1/4-inch seconds pendulum rod has about the same weight per unit length as Harrison's nine-rod gridiron. The pendulum has a Q of only 5,000, which is about the same as the only original Harrison pendulum extant so the energy consumption at 6 1/8 derees semi-arc is about the same. The suspension spring is of ni-span C and hangs between gilded brass cheeks. To obtain isochronism the cheeks, the spring and the escapement have to be in perfect harmony, no easy matter to be done in our age with no past experience. To get it even roughly right took me seven years. The clock is certainly able to go to one second in 100 days. The longest run I had, not more than a second fast and not more than a second slow in the workshop, was 80 days and this before I had the system fully adjusted. How it will behave in Chapelfield Gardens is totally unknown.

On the left of the escapement unit is the reed switch which signals to the rest of the clock every 30 seconds. The contact is closed by the same cam on the fly arbor which lifts the detent claw, lifting a magnet over the reed.

The Gurney Harrison Regulator is only the timekeeper of the Gurney Clock and is only a small part of the whole machine. Many brains have been given a free hand to interpret their own parts in their own way and many hands have built it. All the artists nd craftsmen and engineers live and work in East Anglia. The whole clock remembers 1775 and shows in several different ways the close relationship between the Bank (Barclays) and the City. This is especially true of the very complicated animation by Haward Horological Ltd. with sculpture by Michael Barber. There is edge lit engraved and etched glass by James Kinght and the whole interior is lit up at night. The building, designed by Roy Foyster, is itself a most unusual and interesting structure. Probably no public clock like this exists anywhere else in the world.

Peter Haward HJ December 1987
It was in April 1983, that my company was first approached by Barclays Bank in Norwich to discuss the manufacture of the animation for a clock controlled by a regulator designed and constructed by Martin Burgess. Various aspects were put forward following the original concept of Mr Burgess; the animation was to represent wealth in the form of bronze balls being taken from the city vaults, made to work and then being returned to the vaults with gain.

The idea of using a heraldic lion standing on one leg in front of a castle was finally agreed upon. The lion was to turn and collect a ball from one turret of the castle and then turn and deposit it in another turret, from which it would run down a track on to a large set of bank scales. There the ball would be 'weighed' and, in doing so, would wind the regualtor prior to descending to the rear of the castle. This idea in its infancy sounded simple enought but proved to be an extremely complex project.

Two large drums, ech with numbers on the outer faces, were to be arranged so that the hours and minutes were displayed high up in the centre of each side of the triangular building housing the clock. A bell would be installed in the top of the pavilion to sound the hours.

The City Architect's Department of Norwich Council designed the free standing pavilion housing both the clock and animation, using steel plate and glass. This was duty constructed by Cowells, a local firm of metal fabricators. It was assembed in an empty warehouse close to Chapelfield Gardens, the site chosen for the clock. Until this work had been done it was very difficult for me to design anything as, although the structure was in plan an equilateral triangle with 3.7-metre sides, the walls had a curve of 8 metres radius, which made obtaining accurate dimensions a problem. One requires some form of datum line from which to measure.

We were able to make a template of the pavilion's interior floor and from this we constructed an iron base on which to build our mechanism. It was necessary to make sure that all the parts would pass through the access doors for assembly inside.

and causes behind everything. In his day all pupils had to spend some time in the workshop regardless of aptitude. It used to be said that at Gresham's everyone was a scientist until proved innocent and everyone was a craftsman until shown to be non-mechanical.

Martin built his first clock while he was at school. He also did some craft research on the methods used to make mail armour. Hundreds of tons of this material were produced all over Europe in the middle ages but it is not known for certain what tools and methods were used. The strange thing was that the armour experts did not appear to mind too much that nothing was known about this craft technology. No one had tried to make mail again to find out what the problems were. Martin's methods, evolved while he was
still at Gresham's, may not be correct but if you go to the Tower of London now and ask how mail was made what you will be told will be based on Martin's articles, published by the Society of Antiquaries of London in the early 50s.

After Gresham's, Martin was at the Central School of Arts and Crafts in London for three years to study silversmithing and silver design. Here he obtained the CSAC Diploma and the National Diploma in Design. He came under the influence of some of the best designers and craftsmen and the course included bronze casting and metal spinning and sculpture. The department included engravers and diamond mounters and jewelery designers and there were all the other departments, the fashion, theatre design, cabinet making and the fine arts.

After the Central School, Martin was employed by University College, London, in the Department of Egyptology as a restorer of Ancient Egyptian Antiquities. He worked there from 1953 to 1963. He became deeply involved with The International Institute for the Conservation of Historic and Artistic Works and the Archeaologists, Antiquarians, Scientists, Museum Restorers and Art Historians in this field. It was at U.C. that he met Keith Harding later to go on to set up the big restoration workshops for clocks and mechanical music. Martin also met his future wife Eleanor whose father, Dr. Anthony Arkell was in charge of the Petrie Museum.

In the late 50s the then Headmaster of Gresham's School, Logie Bruce-Lockhart, asked Martin back to lecture on the evolution of accurate clocks and it was this which got him back into horology. For the lecture he had to make some large models of the classic clock escapements, models large enough to be seen by 30 or 40 people at once. It was these models which convinced Martin that even without a proper workshop he could make a clock which would work. The study he had to do for the lecture had shown him that in the past there had been some very unusual and exciting clocks made but that the whole art of unique mechanical clockmaking was almost dead. Then, at the end of the 50s, he met another O.G. who had just built a new house in Broxbourne and wondered what sort of clock he could put in it.

It was not a commission but what emerged over the next three years was a huge wrought iron machine which later became called the 'Broxbourne movement of the lion from the pick-up point to the release point) by an endless chain which passes round another wheel with 42 teeth. This larger wheel is turned through approximately 90 degrees by a crank arm from a geared motor shaft that control the operation of the lion.

At rest the lion faces the front, holding a ball in its paw. The animation commences with the lion turning to its left and when its paw reaches the receiving tower an ejector pushes the ball out. This is operated through a pull wire passing down the lion's leg on to a lever below the base. It can only operate when the lion is at the extreme end of travel and in the exact position for release. After the ball is dropped the lion turns back and at the same time another ball is released from the assembly point to become ready for collection. When the lion reaches this position a solenoid ejects the next ball to be caught in the lion's paw and, provided another ball or balls are on the delivery tower at the assembly point, the lion will turn the full extent and eject it as before. If, however, the last ball is taken, the electric circuitry is such that the lion stops, facing the front, with the ball in its paw.

When a ball is dropped at the receiving tower it runs down the rack by gravity until it reaches the flat scales pan, the base of which has three spring-loaded parts in its surface. These are depressed by the ball and the central portion is deep enough to prevent any further movement of the ball. As the balance of the scales is altered by the weight of each ball a switch is closed and a motor pulls the scales pan down and in doing so tips the pan, enabling the ball to roll on to another portion of the track. From this point it rolls down a three-loop spiral and into the back of the castle. From the base of the table on which the scales are fixed a lever is coupled by a pull wire to the winding levers at the rear of the concrete column on which the regulator is mounted. Each time the scales operate, the regulator is would one click on its winding ratchet. The animation is continuous 24 hours each day and this is sufficient to keep the regulator fully would but it can run for seven days without rewinding.

The sculptor, Michael Barber, modelled the lion and castle from glass reinforced plastic on a framework which we made from angle iron welded to form a rigid base for the construction and aslo to make a solid base for our ball track.

The completed clock makes a very interesting object to watch and besides being a useful timekeeper for the local people forms a focal point in Chapelfield Gardens. The scientific and historic value of the regulator made by Martin Burgess is, without doubt, the heart of the entire project. Its complexity may escape most of the visitors to the park but the animation and regulator combine to make the Gurney clock unique in catering to people at all levels of mechanical and horological understanding.

session 3

John Harrison's Technology as applied to his Balance Controlled Timekeepers.

Anthony Randall FBHI

This paper is intended to follow that by Andrew King on Harrison's early wooden clocks, to explain how the technology of these fixed timekeepers was adapted to one that would be portable and could be used for finding the longitude at sea. The subsequent development will then be described, including as many as possible of the various technical features used. These included an escapement without drop and requiring no oil, roller gearing able to work in recoil and with minimal friction, the use of anti-friction rollers, the discovery and use of the differential expansion of metals for thermal compenstion, and the way in which these and other inventions were combined together. Harrisons method of cancelling large and variable sources of error against each other will be illustrated and explained, as well as how it was applied by him with such extraordinary insight to his watches.

This is the work which, spread over some 50 years, ultimately led Harrison to win the £20,000 Longitude Prize. This huge prize was offered by the British Government in 1714, for a reliable and practicable solution to the problem of finding longitude at the end of a voyage to the West Indies.

Although his various timekeepers have been much admired, Harrison's technology was little understood in his own day or since, and has only recently been fully elucidated and appreciated for its true nature. The depth of his understanding was quite remarkable, and it has taken another 100 years or so for some of the basic principles to be re-discovered in their modern form.

The Grasshopper Escapement Correctly Proportioned

Peter Hastings

Proportion is not the first consideration usually applied to an escapement, although it was the first point made by John Harrison in his last pamphlet on precision timekeepers.

'*...the bare Length of a Pendulum can be no otherwise rightly considered or esteemed, but as only to what it bears....in Proportion to the Length of the Pallats...*'

Figure 1 shows a typical grasshopper escapement with the naming of its parts. The construction of a grasshopper escapement is not a trivial task and many of the older texts warn that it is difficult to make and tricky to adjust. The experience of Martin Burgess has been that provided the escapement is drawn accurately to a large enough scale then the piece parts fit together to make a working escapement with the minimum of adjustment. Fortunately, the working drawing of a grasshopper escapement could scarcely be simpler; ten straight lines, a circle and an arc.
Figure 2 shows the pattern of escapement described by Harrison in his 1730 manuscript. The necessary geometry to construct such a drawing is shown in the lower half of *Figure 2*. Note that although the entrance pallet is tangential to the escape wheel at the start of the arc it is shorter than the exit pallet which therefore lies into the escape wheel a little. This affects the impulse given to the pendulum as described later.

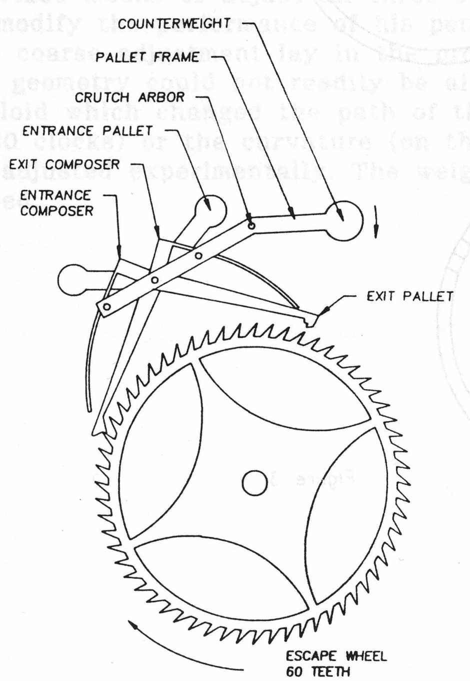

Figure 1
TYPICAL GRASSHOPPER ESCAPEMENT

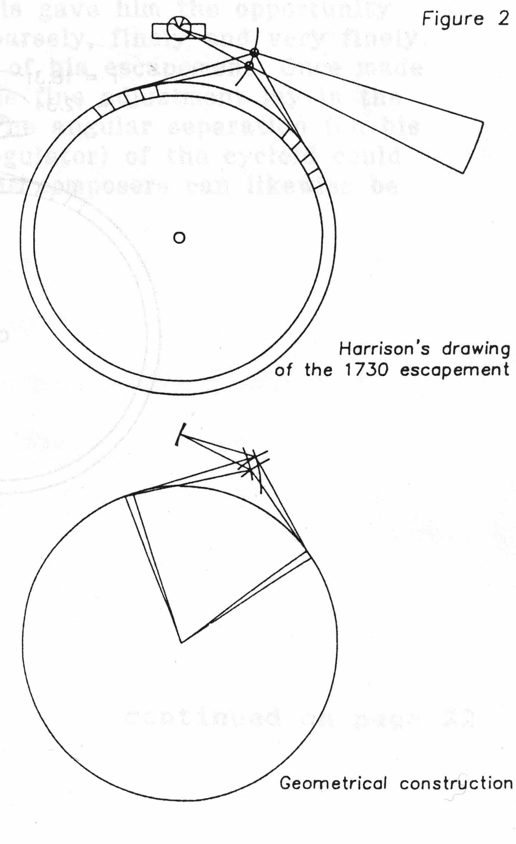

Figure 2

session 3

The first proportion of the escapement which must be correct is the arc of swing of the pendulum or as Harrison has it;

'...*the Wheel is but to move a little in a Second...but the Pendulum through a great Space.*'

The consequences are simple, the pendulum is to have a large arc of swing and the energy it loses is to be made up by a large force acting at a small distance from the crutch arbor. *Figure 3* shows how this small distance can be achieved without making the escapement components awkwardly small. The large force has the benefit tha the variations in friction will be proportionately less than if the force were small. Such friction will occur at the tooth tip, the pallet pivot and the crutch pivot. Harrison's use of materials to minimise this friction was characteristically careful.

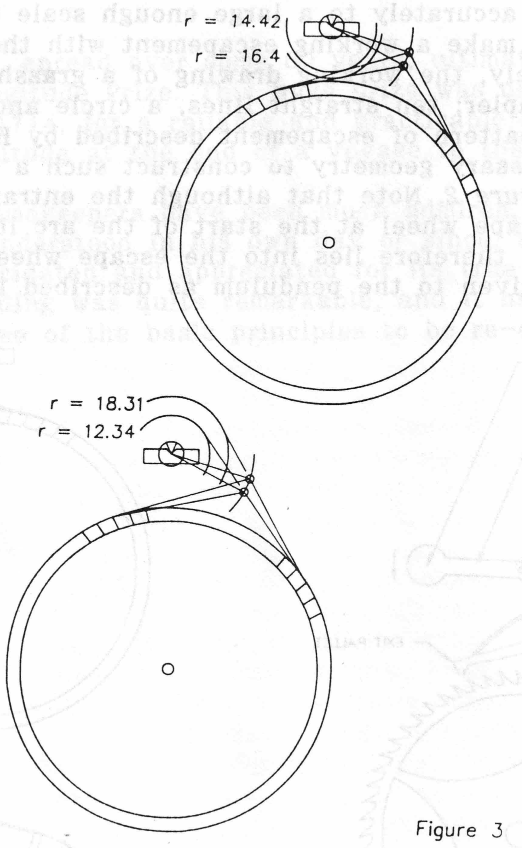

Figure 3

Despite the animation of its working, which accounts for much of the lay interest in the escapement, the grasshopper provides the gentlest of impulses to a pendulum; a steady push from one end of the escaping arc to the other. This impulse may be steady but it is not uniform. As can be seen from *Figure 3* the moment arm at the start of the impulse is smaller than at the end and the work done by the escapement on the pendulum is consequently biased toward the second half of the swing.

This bias is not equal for both pallets, the effect being more marked for the entrance pallet than for the exit pallet. This is described in a rambling footnote to pages 25 to 29 in Harrison's last pamphlet. The footnote far exceeds the contents of these 5 pages and has a footnote of its own.

This footnote contains the second proportion of a grasshopper ecapement; that the impulse at the end of the escaping arc should be 50% greater than at the start of the arc. This ratio of 3:2 must be averaged over both pallets since their actions are not identical. The consequence of this is that the pendulum will swing a little slow since it has a greater losing impulse (away from mid-swing) than gaining impulse. This will be totally overshadowed by the gaining impulse during recoil. The recoil will act as pure gain, always acting towards mid-swing, but with less and less effect as the arc increases. The effect will lessen because the same geometry which increases the impulse towards the end of the escaping arc also decreases the impulses as the pendulum drives the train into recoil.

The composers also act in recoil since the pendulum has to lift their little weight and thereby store energy. The pendulum at the fullest extent of its swing has its energy stored in a number of places; in the bob, the reversed train and the composers. Harrison was well aware of all this and provided means to adjust all three stores. This gave him the opportunity to modify the performance of his pendulum coarsely, finely and very finely. The coarse adjustment lay in the proportions of his escapement. Once made the geometry could not readily be altered. The fine adjustment lay in the cycloid which changed the path of the bob. The angular separation (on his 1730 clocks) or the curvature (on the RAS regulator) of the cycloid could be adjusted experimentally. The weights of the composers can likewise be tuned.

continued on page 22

PROGRAMME OF LE

Saturday August 27th

9.30am Participants Register in Sainsbury Centre

Exhibition Preview

SEMINAR

Main Lecture Theatre 2

Session 1 11.00am-12.30pm

Chairman: *Beresford Hutchison*

11.00am Welcome: *John Read OBE FBHI*
National Chairman BHI

11.05am An Introduction to the Harrison Research Group
Jonathan Betts FBHI

11.30am The Problem of Finding Longitude at sea and how it was solved by John Harrison
Heather Hobden

12 noon An Account of the Discovery of the Scale of Musick
Charles Lucy

LUNCH (may be purchased in UEA Cafeteria)

Session 2 2.00pm-4.00pm

Chairman: *Beresford Hutchison*

2.00pm The Early Harrison Wooden Clocks
Andrew King

2.45pm The Isonchronos Pendulum System of John Harrison
Martin Burgess FBHI
and *Mervyn Hobden*

Saturday Aug

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Peter Haward FBH

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7.45pm Buffet Sup
Toast: 'T

Response:

9.00pm Short Reci
Harrison S

11.00pm Close

Sunday August 28th

SEMINAR

Main Lecture Theatre 2

Session 3 10.00am-12.45pm

Chairman: *John Griffiths FBHI*

10.00am	John Harrison's Technology as applied to his Balance Controlled Timekeepers *Anthony Randall FBHI*
10.45am	The Grasshopper Escapement Correctly Proportioned *Peter Hastings*
11.05am	COFFEE
11.35am	Harrison's Oscillator Theory in the Context of 18th Century Science *Mervyn Hobden*
12.30pm	Non-Linear Oscillator Theory: a Modern Understanding *David Harrison*

LUNCH (may be purchased in the UEA Cafeteria)

Session 4 2.00pm - 4.15pm

Chairman: *John Griffiths FBHI*

2.00pm	Measurements of the Properties of Four Clocks by John Harrison *Douglas Bateman*
2.30pm	An Approach to Pendulum Timekeeping based on Experimental Evidence *Douglas Bateman & Henry Wallman*
3.00pm	General Discussion. All Contributors form a Panel to take Questions from participants
4.00pm	Closing Remarks

S AND EVENTS

(continued)

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 continued from page 19

A late drawing by Harrison shows an escapement which has a suitable variation in impulse. Martin Burgess this drawing to lay out the escapement for the Gurney Clock and my copy of this is shown as *Figure 4*. The pallets are no longer of equal length and consequently not quite tangential. In order to calculate the moment arm of the impulse it becomes necessary to take into account the variation of the distance from the pallet to the centre of the escape wheel. A graph of the results is shown as *Figure 5*.

The results of the analysis show;

...'*that the action of one with that of the other, are quite right*...'

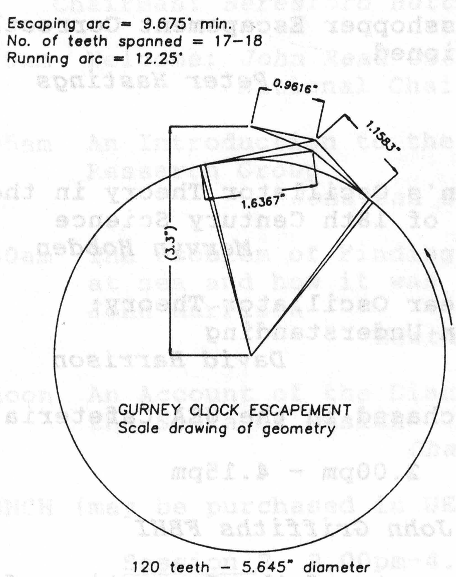
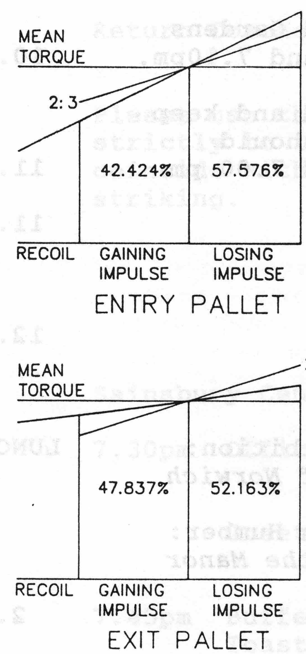


Figure 4
Escapement for Gurney clock

Figure 5



Mean impulse before mid–swing = 45.1
Mean impulse after mid–swing = 54.8

Harrison's Oscillator Theory in the Context of 18th Century Science

Mervyn Hobden

This paper address the problem of defining the level of theoretical knowledge available to the Harrisons at the begining of the 18th century. A brief review is given of the 17th century mathematics and physics with emphasis on the contrast between Continental and British establishments. Source material from the period is shown, in particular that available to mathematical practitioners, and the quality of that material is examined.

An analysis is presented of John Harrison's theoretical achievements and his contributions to non-linear oscillator theory. The elementary theory of non-linear oscillators is explained and how Harrison's ideas fall naturally to that model. A contrast is made between Harrison's ideas and those of the academic establishment of the mid 18th century. Some explanation is offered for the mediocrity of the British establishment in the field of mechanics after the death of Newton.

The development in horological thought in the decades folowing Harrison's death is also examined up to George Biddell Airy's paper of 1827. The re-emergence of non-linear analysis in the late 19th century and its application to oscillators in the 1920s is shown to be the inevitable result of the investigation of phenomena familar to the Harrison's in their early investigations.

A review is made of Harrison's technical development as evidenced both from his writings and the timekeepers. A just assessment is attempted of his achievements in scientific terms and some explanation is sought for his treatment at the hands of previous biographers.

Measurements of the Properties of the Pendulums on Four Clocks by John Harrison

Douglas Bateman

The four clocks were the 1726 longcase (now in the Time Museum, Rockford), the 1728 longcase, the 1726/28 reconstructed by Will Andrewes, and the 1745 Royal Astromonical Society regulator. Detailed findings were published by Bateman and the late Kenneth James in *Antiquarian Horology*, Vol 15, 479-489, September 1985.

This paper concentrates on the events leading up to the measurements, the personalities, (eg Colonel Quill's assistance) and the practical problems. Subsidiary measurements led to the production of a set of drawings of the 1728 pendulum and data for power requirements of the pendulums and the complete clocks. The pendulums were found to have relatively low quality factors of about 5000. The pendulum of the Gurney clock has a similar quality factor and the implications will be discussed.

An Approach to Pendulum Timekeeping based on Experimental Evidence

Douglas Bateman and Henry Wallman

For pendulum clocks there is no published evidence to support the achievement of the goal of 1 second in a 100 days <u>for successive hundreds of days</u>. It is our contention that this objective cannot be achieved using Harrison or Harrison-type designs.

It is however, our view that this goal can be reached, even with clocks at atmospheric pressure, by following certain guidelines. These guidelines are all based on experimental evidence which will show that, in the first instance, day-to-day accuracy can be improved quite easily. Again, based on the design of various pendulums (including those for scientific applications), a more rigorous design philosophy and choice of materials should lead to the sought-after long term improvements. The paper will be well illustrated and firm recommendations given.

FINIS

Douglas Bateman, 49, is a scientist at the Royal Aerospace Establishment, Farnborough, where he has worked on a variety of instrument and optical projects. In 1971 he constructed a pendulum clock with photoelectric control of impulse and amplitude. This led to a quest for the understanding of the factors that limit the performance of a clock. Many publications followed in a number of horological journals, including a major 7 part series on Vibration Theory and Clocks in the *Horological Journal* in 1977. Other projects have included an electronic clock slaved to time signals from Rugby (before the introduction of the time-of-day code) and an instrument for checking the rate of pendulum clocks. The latter won a prize in the BHI competition in 1985. Although Doug Bateman has co-operated with Martin Burgess over the rating of the Burgess World Time Clock in Schroders, Cheapside, and with a rating instrument for the Gurney Clock, he has not become a member of the Harrison Research Group owing to a reluctance to place Harrison on the very pinnacle of technical horology.

Jonathan Betts developed an interest in horology as a boy during the 1960s in the family firm of wholesale and retail watchmakers and jewellers, based in Ipswich.

Following the BHI course at Hackney College (1972-1975) he worked at Keith Hardings in London for one year, where he developed a great interest in horological conservation and then set up in private business restoring and conserving precision clocks and watches. In 1980 he was appointed Senior Horology Conservator at the Old Royal Observatory, Greenwich where he has, for the last six years, been responsible for the conservation of the Harrison timekeepers. (Taking over this duty from The ??? Chronometer Workshops at Herstmonceux on their closing). It is for his practical knowledge of the construction of the Harrison timekeepers that he is primarily a member of the Harrison Research Group.

Since 1981 he has been a Council Member of the BHI and was, in 1980, appointed Horological Adviser to the National Trust in a private capacity.

Martin Burgess FIIC, FSA, FBHI, was born near Hull in 1931, but for almost all of his life his home has been in East Anglia in the village of Boreham in Essex.

He was educated at King Edward VI Grammar School in Chelmsford and from the age of 12 at Gresham's School, Holt, in North Norfolk. Gresham's has been the main influence in Martin's life. Almost everything he has managed to do has its roots there. It is a remarkable place. Set on the Holt-Cromer ridge there is no land between it and the North Polar ice cap. The diamond pure air is so strong that, after stuffy London, a visitor can feel almost drunk on it. Founded by Sir John Gresham in 1555 the school has for many years specialised in science and scientific thought. Martin learned early to accept nothing without testing it and looking for reasons

The first part we constructed was a triangular frame standing on three legs and supporting a centre post 1 1/2 inches in diameter to carry the two drums, which themselves are 8 feet in diameter and 20 inches wide.

As it was necessary for them to be passed through the doors, they were each constructed from six curved iron frame segments clad with aluminium sheet. The segments were bolted together on to supporting rods radiating from two hexagonal iron plates in the centre. Each plate was mounted on ball bearings and great care was taken to obtain a very good butt joint between each section. The outside faces of the drums were painted after they had been assembled inside the building in order to prevent the joints showing. Then the numbers were applied in 24-carat gold leaf.

The drums are turned by two separate units which operate on pegs fitted round the inside edges, the upper drum for the hours has five pegs for each hour and is numbered from 1 to 12 three times; the lower drum for the minutes is also numbered three times and has one peg for each minute, s each drum has a total of 180 pegs. Each set of numbers is repeated three times in order to display the time simultaneously on the three sides of the pavilion. On the hour drum every fifth peg is slightly longer than the others and an electric stop is arranged so that when the drive motor unit is switched on it will run until the next long peg operates the stop switch. This ensures that a numeral is always centred in the window. Every half-minute when the regulator remontoir operates, an electric pulse is sent to the motor on the minute drum; the first pulse turns the drum and the second resets the mechanism.

Fixed to one leg of the framework is the strike counting unit. This has two snails in the centre, turned by the hour drum by a chain drive through 3:1 ratio bevel gears. It turns, therefore, once in 12 hours and keeps in step with the numerals on the drum. When the minute drum reaches the 59th minute it releases a rack which drops on to one of the snails and, at the hour, a synchronous motor fitted with a lifting pawl counts the rck back to zero and, in so doing, pulses the hour bell hammer; it also sends a pulse to the lion which now starts delivering and collecting the balls from the castle.

The second snail, set half-an-hour out from the strike snail, also has a rack which is allowed to drop on to it when the 30-minute mark is shown in the windows. This operates the ball lifter unit concealed in the castle. As a ball is raised past a central point a wire link is pulled which advances the second rack one tooth. This continues until the rack is in its zero position, by which time the correct number of balls have been raised for the next hour. The balls are delivered at one minute 10-second intervals, so, at 11.30 when the first of the 12 balls is raised, it will keep running for approximately 14 minutes until all 12 balls have been lifted into the tower on the lion's right and are ready for collection when noon is struck. Incorporated in this counting unit is a switch to silence the bell at sunset and reconnect it at sunrise.

The lion is modelled around a square steel post which has a round tube fitted inside. At the upper end of this is a bronze plug. This entire unit stands on a round steel post with a conical top, fixed vertically to the base framework. At the lower end of the round tube is a chain wheel with 25 teeth. This is turned through 170 degrees approximately (the angle of

Clock'. In this clock Martin was attempting to forge out a new avenue for mechanical horology which would still have a function when electricity and electronics had taken over the run-of-the-mill timekeeping in daily life. The new clocks were to be seen as sculpture where all the mechanical parts were to be exposed as part of an overall design. It was very difficult to get the conventional horologists to even understand what was being attempted. The Broxbourne Clock was built by Martin in a shed in the garden in Boreham while he was still working as a restorer in London. It was done at weekends and in holidays over a period of three years.

In 1963 Martin married Eleanor and at Christmas he left U.C. He had a proper workshop built for himself in Boreham. When this was finished he started to make sculptural clocks full time. The most notable of these was the big clock at the headquarters of J. Henry Schroder Wagg & Co., Merchant Bankers of Cheapside in London. This clock has the largest great wheel in the world being ten feet in diameter. Every effort was made to make this clock accurate but though its pendulum has a very high Q rating (as measured by Douglas Bateman) of 36,000 and is impulsed only once a minute, it never keeps time to better than a minute a year in spite of temperature controlled surroundings.

The Schroder clock was installed in 1969 and already by then Martin was starting to get very interested in the Regulator technology of John Harrison. His interest was sparked off by Col. Quill's life of Harrison published in 1966. How was it that Harrison had claimed these great accuracies for his pendulum clocks at this early date when all the modern materials and effort which had gone into the Schroder clock did not produce results anything like so good? And the Schroder clock had been made according to principles which all the horological books said should produce the best timekeeping.

A twenty-minute documentary film was produced about the work of Martin and Eleanor Burgess and the building of the Schroder Clock and this went round the cinemas. It won awards in Italy and Australia and was highly praised in the U.S.A. It has since been on U.K. television twice.

At the end of the 60s, Martin met Col. Quill and understood for the first time that, like the mail making, the technology and science of Harrison's Regulator clocks had not been properly explored. Col. Quill was keen to have this problem looked at and gave Martin great encouragement, supplying him with photostats of Harrison's writings. Quill and Burgess both published articles about the Grasshopper Escapement in *Antiquarian Horology* in 1971 and these brought William Laycock on the scene. The Grasshopper has a special significance for Martin. By itself it has little contribution to make to accurate timekeeping but in conjunction with the whole of Harrison's technology and scientific method it holds the key to success. A grasshopper holding a key is the crest of the Gresham family and is thus the crest of Gresham's School.

In the early 70s Martin was working on the Armillary Sundial Emblem to go outside the BHI Headquarters at Upton Hall. This was installed in the summer of 1976. At the same time Martin was helping Bill Laycock with the findings in January 1976 and later that year produced his book *The Lost Science of John (Longitude) Harrison.* Unfortunately Bill Laycock died at the end of '76 so, though by then Martin had started to build the Harrison Regulators, he did not live to see the work progress very far.

In the summer of 1974 Martin was approached by the Norwich City Council and Barclays Bank. Design work for the Gurney clock took until early 1975. Then the tool designing and making was started.

After the death of Bill Laycock a group of Harrisonophiles which later became called the Harrison Research Group, gathered round Martin and their research has gone far beyond just the question of building a Harrison regulator. Martin says that without the constant help and support of the Group he could not have made the regulator far less conducted the tests to bring it to time.

Peter Hastings was born and raised in Edinburgh he was educated at George Heriot's School, showing an aptitude for science and engineering. This led him to take a BSc in mechanical engineering at the Heriot-Watt University. His working life has been spent in the world of aerospace engineering, designing precision mechanisms for a commercial company before escaping to the Royal Observatory in Edinburgh where he currently designs infrared astonomical instruments. His relaxations include his work at ROE, country dancing, music (as a non-combatant), hillwalking, cycling and getting involved in arcane horological investigations.

Peter Haward joined the model development workshop of Sangamo Weston, Enfield, Middlesex, at the age of 15 years, after less that two years technical education at Tottenham Polytechnic College, London.

While at Sangamo he got involved in clockwork, timing devices, and later in the electro-mechanical timing equipment on which his future work was largely based.

Men with mechanical flair are seldom called to the fighting services, even in wartime, and Peter stayed with his company throughout the duration of the war and for a further two years, but served in the Home Guard, and many-a-night slept on the gun site at Bullsmoor Lane, Enfield. He fire-watched on other nights at Sangamo Weston.

Peter joined Thwaites & Reed in 1947 and stayed there 27 years, making clockmaking his career. In his latter years he was technical director. Immediately after the war much of the work was the repair and refurbishing of tower clocks in from all parts of London, and one of Peter Haward's first jobs was to restore the astonomical clock at Hampton Court, London. He worked on it again, some 12 years later, in 1959.

Over the years Peter has produced four replicas of the planetarium of Giovanni de Dondi from a translated manuscript. The original was made in

1364. The first replica, which took two years to complete, is now in the Smithsonian Institute, Washington, USA, and another is in the Science Museum, London. The three later replicas were made in Peter's own workshop, at that time a space no larger than a domestic garage.

Peter left Thwaites & Reed in 1974. He was then 49 years of age; not the best time to seek employment with a new company even with a high reputation for craftsmanship and quality. Using his home workshop he continued working, but now for himself, and in 1975 formed Haward Horological Ltd. Two years later he moved to his present establishment near Ipswich.

Since 1976 the firm has produced the Al Jazari water clock for the Islamic exhibition in the Science Museum, London, the three-dial turret clock at Buckingham University, the Wellgate and Pollock clocks, and the Richard de Wallingford clock for Seth Attwood's 'Time Museum'.

In recent years Haward Horological, a real family business involving wife Pamela, son Ian and daughter Stella have specialised in animated public clocks which, in addition to their contribution to the Gurney Clock, include Sheffield's Orchard Square Clock and the McVities Clock currently on show at the Glasgow Garden Festival.

Heather Hobden has been writing about the history of astronomy and horology for many years, is a frequent contributor to *Antique Clocks* magazine, and has had many other articles, papers and books published on the history of astronomy or on clocks and timekeeping (including, for example, the official guidebooks on the Hampton Court Clock first commissioned in 1970). More recently she is known for research on tracing the origins of cognitive time perception and the development of early methods of timekeeping. She also teaches astronomy and horology for Adult Education classes. She is presently living in Lincoln with her current husband Mervyn Hobden, founder of the Harrison Research Group, grown-up twin sons and a small black cat called Snowy.

Mervyn Hobden is employed as Chief Development Engineer in the Microwave Division of Marconi Electronic Devices Ltd., Lincoln. His interest in horology dates back to the early 1970's while serving in the Royal Air Force. On leaving the RAF in 1975 he worked for a period in the Chronometer Section of the Royal Greenwich Observatory as a Craftsman Watchmaker. His association with Harrison started with his introduction to the Lincolnshire Clockmaker Tom Hyde who first made him aware of the lack of appreciation of Harrison's curious machines. In the late 1970's correspondence with Martin Burgess lead to the setting up of the *Harrison Research Group* - a relationship that prospered when it was discovered that Martin brewed excellent home made beer. He lists his interests as the History of Science and Mathematics, Navigation, Non-Linear Oscillator Theory, designing very quite crystal oscillators and drinking *Bateman's XXX* which he privately admits was the real reason for a move to Lincolnshire rather than Harrisonian attractions. He lives in the suburbs of Lincoln with his wife Heather, twin sons, and a very literate and media-aware black cat called Snowy.

Andrew King has been working in the horological world since 1961 and has been a noted restorer of clocks for a number of years for many collectors and several museums.

His interest in the life and work of John Harrison started c. 1971 and despite all the previous research that had been done on the subject he has been able to unearth much new information and even artifacts which have helped to place a totally new and revealing light on John Harrison. He has also assisted the investigation into the *Lost Science* by the construction of a pair of early wooden regulators of the type which Harrison claimed in 1730 were capable of holding a rate of one second per month.

Since 1980 Andrew has been designing and making clocks. As an artist/ craftsman he has been producing original horological concepts as a new art form utilising many of John Harrison's ideas.

Charles Edmund Hampden Lucy was born on Monday 7th October 1946, in Cheltenham, Glos.

At twelve, having begun to learn violin, piano, recorder and clarinet, he settled on guitar and voice as his principle instruments. It was probably this early contact with music, which caused Lucy to be intrigued with the well known puzzle of the connection between musical scales and mathematics.

Leaving Hanley Castle Grammar School in 1964, he travelled in Europe and the Middle East for a year, giving him chance to experience and play with musicians from other cultures. On his return to England, Charles was married and after a short stay in Canada, returned to London where his first daughter was born in 1968.

As a family man Lucy studied work study, organisation and methods, accountancy and systems analysis, working in a number of different industries including three years with the National Health Service.

In 1975 he moved to California living and working in Los Angeles, in systems for clay pipe manufacturing, mail order, and precious metals, during this period he had the opportunity to expand his musical education and experience, working with professional popular musicians.

After his second marriage in 1977, he moved to New York, working in systems for manufacturing electronic components, meat processing, and banking. It was at this time he became full-time involved in musical composition, sound and record production. He has written two musicals, and the theme music for *The Shooters* with ABC Television for David Hartmann, and the title song for the Australian children's series *Kangaroos, Koalas, and Kids*. Lucy is a writer and publisher member of the American Society of Composers, Authors and Publishers. Six of his songs are recorded on foreign record labels.

He now lives in Fulham and runs Lucy Scale Developments, which produces and markets software, and designs and markets musical instruments based on his developments of Harrison's musical discoveries. Lucy also gives lectures and demonstrations on musical tuning and acts as a consultant to the music and computer industries. He is currently working on his second book about music, physics, and John Harrison, which he hopes will be a 'best-seller' in the early nineties.

Anthony Randall had his formal education at Eastbourne College and Manchester University, B.Sc. in Applied Physics, 1960. Became interested in horology at an early age; and a Fellow of the British Horological Institute in 1964.

Studied for two years at the Technicum Neuchatelois watchmaking school at La Chaux-de-Fonds in Switzerland, 1963-4. Worked for a few months with George Daniels in London, before moving to Birmingham to teach horology at the School of Jewellery and Silversmithing, 1965-71.

Wrote Chronometer Catalogues for the British Museum, and for the Time Museum, Rockford. Awarded the Kullberg Medal by the Stockholm Watchmakers Guild, 1983, and the Clockmakers Company Prize, 1985.

Especially interested in precision mechanical horology, past and present, and in the design and contruction of special pieces employing new ideas.

Henry Wallman, 73, has had a distinguished academic career in mathematics at Princeton University (PhD 1937), and at the Institute for Advanced Study. During the war he worked in radar at M.I.T.'s Radiation Laboratory. After the war he was Associate Professor of Mathematics at M.I. T. He then led the study of radar at the Chalmers University of Technology, Goteborg, Sweden, where he became Professor of Applied Electronics in 1948. His professorship was converted to that of Medical Electronics in 1967, when he also became a professor at the Medical Faculty. In 1968 he was granted the degree of Doctor of Medicine, honoris causa. He is a member of the Royal Swedish Academy of Sciences. He has retired to Israel and unfortunately cannot be in the UK at the time of the seminar. Professor Wallman has had a 40-year old interest in horology including its history, books on horology and methods of measuring, recording and presenting time. He has published little on horological matters but is fairly well known by his letters to organisations and many individuals. Along with his co-author he does not share the belief that the Harrison clocks or methods can achieve anything out of the ordinary in terms of timekeeping.

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