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The Celestial Bodies Time Our Watches

Astronomy, Time and Precision

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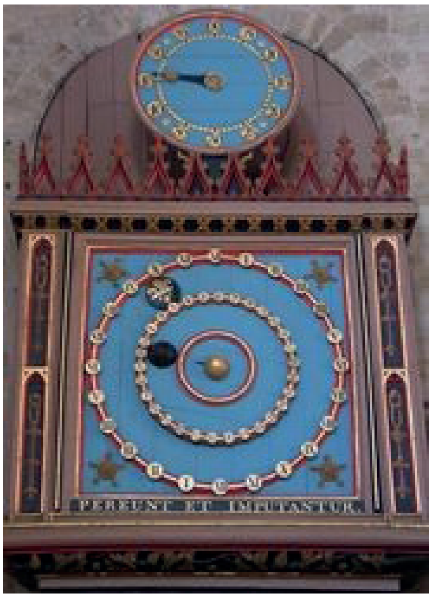

Figure 1.

Figure 2.

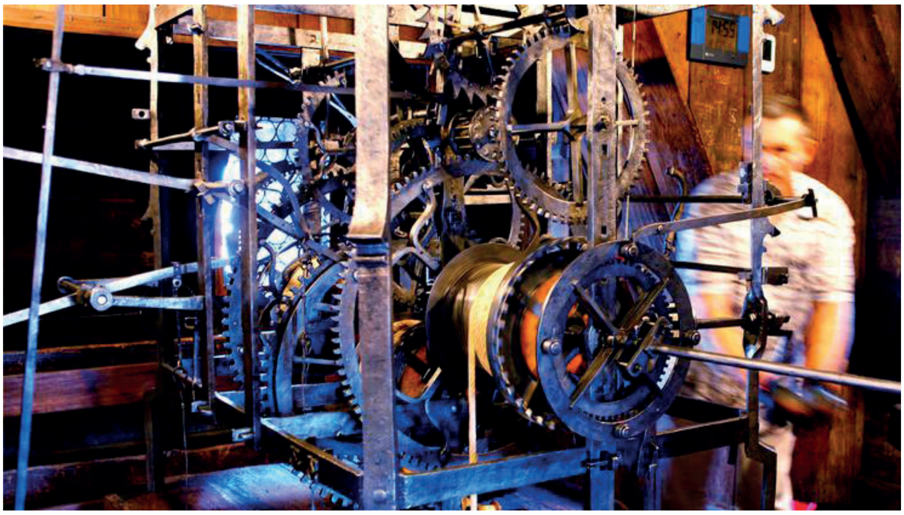

Figure 3.

Time and Astronomy

It is said that watches measure the time, though no one can precisely explain what this ‘time’ that we experience really is. In reality, watches actually count expired epochs or units of time. These epochs, without exception, are based on instances which periodically occur in the sky and on facts which were first observed by astronomers thousands of years ago. This raises the issue of trying to display the principles of some of these astronomical incidences on watches, although for various reasons it will never be possible to do this both exactly and mechanically.

The oldest relic of a mechanism with astronomical displays is presumably the Antikythera Mechanism. In China also, mechanisms with astronomical indications were probably built as early as 2000 years ago.

In the Renaissance, mechanical clocks with astronomical displays were built everywhere in Europe, mainly for cathedrals, castles, guildhalls and other representative buildings. My personal favourite is still the big Astronomical Clock in the Minster of Strasbourg in France. There is also the Astronomical Clock in the Cathedral of Saint Peter in Exeter, **Figure 1**. It is a beautiful example of an astronomical display of this era.

In my hometown, the old city of Solothurn in Switzerland, an astronomical clock from the sixteenth century still shows the positions of the sun and moon in the zodiac as they are at the time, **Figure 2**. It also shows moon phases. As early as 1454, a mechanical movement was installed with a mechanical bell-striker in what was subsequently called the *Zeitglockenturm*, or ‘timebelltower’. However, this movement was quite inaccurate and it was removed in 1544. Lorenz Liechti from Winterthur, Switzerland, built today's movement as a replacement, **Figure 3**. The clock supplemented it with a group of three mechanically animated figures – a knight, a king and Death – and with the astronomical displays we know today. However, Lorenz Liechti died before the work was completed. Joachim Habrecht from Schaffhausen (Switzerland) was commissioned to finish the clock. Incidentally, Joachim Habrecht was the father of Isaac Habrecht, who built the second clock in the Minster of Strasbourg.

Originally, the clock movement had a verge escapement, and only in 1755 was it rebuilt into a pendulum clock. The pendulum has a length of about 13 feet and the entire movement consists of approximately 10,000 individual parts. Today, every 24 hours, the three weights (284 lb, 225 lb and 66 lb) are still pulled up, approximately 30 feet, by hand. All these monumental mechanisms show the close connection between time and the movements of celestial bodies.

These astronomical complications are still popular for wristwatches whose mechanisms are, obviously, very much smaller than those of their ancestors in stately buildings. This is where my qualification helps to miniaturise these complications.

I'm not a watchmaker, though I have studied mathematics and astronomy. Before gaining this background, however, I spent many years developing ideas and concepts about displaying the movements of the Sun, Earth, Moon and zodiac signs on wristwatches, with a view to keeping them as realistic, useful and intuitively readable as possible.

My clients, who manufacture high-quality mechanical wristwatches, do not generally disclose any external help with their development and market their complicated watches as created in-house. For this reason, I cannot speak about these companies, but I can discuss the 'mathematical problem' of developing these watches.

The Mathematical Problem

As a mathematician, when I am calculating gears for these wristwatches I have to deal with the problems emanating from the fact that one needs to achieve an optimum of precision when the number of axes and the wheel size are both very limited. This is in fact a classical problem of theoretical arithmetic, or theory of numbers. To solve this problem, I have developed an algorithm which finds the most precise gear possible, with variables such as maximum numbers of wheels and teeth. Here is an example, which does not relate to a specific astronomical complication:

The task is: starting with a wheel rotating once per hour, and by using a simple gear train, ie one wheel after the other, to drive a wheel rotating as close as possible to once in 3.14159265359 hours (I have the circular number Pi in mind).

With my algorithm, I can deduce the following optimised solutions:

If for the gear reduction only two axes (four wheels) and a maximum number of 80 teeth per wheel are admissible, then one finds the following best solutions:

1. $^{62}/_{61} \times {}^{34}/_{11} \cong 3.1415797 \quad \Delta \cong 0.0000129$
2. $^{79}/_{46} \times {}^{75}/_{41} \cong 3.1415695 \quad \Delta \cong 0.0000232$
3. $^{59}/_{35} \times {}^{41}/_{22} \cong 3.1415584 \quad \Delta \cong 0.0000342$ etc.

If for this reduction, three axes (six wheels) and a maximum number of 100 teeth per wheel are admissible, then one finds the following best solutions:

1. $^{73}/_{53} \times {}^{47}/_{40} \times {}^{33}/_{17} \cong 3.141592675 \quad \Delta \cong 0.00000002$
2. $^{56}/_{97} \times {}^{51}/_{31} \times {}^{43}/_{13} \cong 3.141592694 \quad \Delta \cong 0.00000004$

etc.

Already with the best solution with two axes (as above), the driven axis would have rotated only once too often after around 90 years! Furthermore, if the best solution cannot be built due to lack of space, one uses the second, third or fourth best solution and so on.

With the help of this algorithm I have, for example, calculated the gear for the phase of the moon display in the movement of the *Sauterelle à Lune perpétuelle* by Andreas Strehler of Sirnach, Switzerland, **Figure 4**. In 2014, it gained the Guinness World Record for the most precise lunar phase wristwatch, with precision of just one day's deviation in more than two million years.

Figure 4.

From a practical perspective, such precision is, of course, fantastic in several respects. Firstly, the watch needs to be serviced after a few years and then has to be reset anyway. Secondly, the watch displays a uniform progress of the phases of the moon, while the movement of the real moon is subject to a multitude of periodical and secular deviations. At times it greatly deviates from the mean movement displayed on the watch. That said, a mechanism which is theoretically as precise as possible is fascinating and still a quest well worth pursuing.

This algorithm can also be used to optimise reduction gears to achieve solutions for transmission problems caused by lack of space in a wristwatch. Such solutions are perhaps less precise, but they are mechanically simple and therefore elegant, with fewer wheels and wheels with a smaller number of teeth to achieve the desired aim.

Some of my Current Projects

My projects usually concern the movements and current positions of the Sun, Moon and constellations of stars, including their culminations and reciprocal positions. For example, the movements of the Sun and Moon around a rotating Earth globe form a beautiful complication in which you can show the bright day side and the dark night side of the Earth. Current astrological constellations of the Sun and Moon in the zodiac can, of course, be displayed on a watch. The Tides on the Shores of the Oceans are also a phenomenon that is largely related to the movements of earth, moon and sun. Again, this can be easily and very vividly represented on a wrist watch.

Another project is the reproduction of an existing astronomical monumental clock from the Renaissance on the back of a mechanical watch. In this case, the corresponding mechanical transmissions are simplified to fit inside a wristwatch, but with the necessary know-how, these transmissions can be calculated and designed in such a way that the movements of the celestial bodies are displayed with the greatest possible precision.

A simple mechanical astronomical complication is the elongation of Venus. It shows the change of the planet Venus as a morning and evening star on a watch. I find this complication astonishingly easy to implement.

One of my more complex astronomical complications shows the rising and setting as well as the culmination of the Sun, Moon and zodiac. These always take place at the correct time, and this with a fixed horizon on the watch dial.

As far as I know, this has never been done before. I was able to implement this complex complication with a relatively simple mechanical gear train.

However, the construction of astronomical complications in a mechanical (wrist) watch is and always will be an approximation to the reality, subject to many compromises. It is precisely for this reason, however, that the solution with the highest possible precision should be found and be chosen among the huge number of possible solutions.

Author Bio

Robert A. Baggenstos is a mathematician and astronomer who was a professor at both the watchmakers' and high schools in Solothurn, Switzerland. He now conceives and calculates mechanical astronomical complications for the watch industry as an independent consultant. He still lives and works in Solothurn.

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