Chapter 6 **(Oechslin: 4.1)**

Frater Fridericus's mechanism in Bamberg (1772)

This chapter is a work in progress and is not yet finalized. See the details in the introduction. It can be read independently from the other chapters, but for the notations, the general introduction should be read first. Newer versions will be put online from time to time.

6.1 Introduction

The machine described in this chapter was designed in 1772 by Frater Fridericus a S. Christophoro,[1] a discalced Carmelite from Würzburg, and constructed by the mechanician Johann Georg Fellwöck (sometimes spelled Felbäch or Felbeck) (1728-1810).[2] It was acquired for 300 to 400 gulden by the Banz Abbey, near Bamberg.[3]

By 1813, the machine was located in Bamberg, but in 1900 it was in Munich. Since at least 1937, it is again in Bamberg, now in its historical museum.[4]

The Fridericus/Fellwöck machine shows the motion of the Earth around the Sun (not pictured), the motion of Mercury, and the Earth-Moon system positioned opposite the main Earth. The Earth therefore appears twice on this machine. The representation of the motion of Mercury is clearly inspired by Neßtfell's machines.

[1] For other descriptions of this machine, see Hess [4, p. 92-98], Bassermann-Jordan [1, p. 101], Stoehr [10, p. 80], King [7, p. 232], Henck [3, p. 106-109], the 1989 exhibition catalogue [11, p. 68-69, pl. 23], and Oechslin [8, p. 35, 37, 218].

[2] See [5, p. 26] and [6, p. 112].

[3] [8, p. 222]

[4] For details on the history of this machine, see [8, p. 234] and [2]. Fowler has observed that there are similarities between the front dials of Neßtfell's machines, and the dials of some "Gutwein-clocks," clocks with geographical dials made in or around Würzburg around 1760. One of these clocks may have been made by Johann Georg Fellwöck [2, p. 26-29]. This suggests an influence of the making of these clocks on the Neßtfell and Fridericus/Fellwöck machines, or conversely.

Figure 6.1: General view of Frater Fridericus's clock in Bamberg. (photograph by the author)

Figure 6.2: The upper part of Frater Fridericus's clock in Bamberg. The Earth globe is at the front. (photograph by the author)

Neßtfell was in fact an important influence in Frater Fridericus's work, as he was his teacher, and because Fellwöck also worked with Neßtfell for the construction of his second machine.[5] This explains why Frater Fridericus' machine has an appearance reminiscent of Neßtfell's planetariums and, at first sight, Frater Fridericus' machine looks like a simplified version of Neßtfell's machine. Not only is the general appearance similar, but the front Earth-Mercury system of Neßtfell's machine is here laid horizontally. Instead, the machine of Frater Fridericus and Johann Georg Fellwöck does not display the orrery which fills most of Neßtfell's machines.

6.2 The going work

The going work is driven by a weight and regulated by a pendulum, but Oechslin doesn't give the details of the gears. All we know is that the rope arbor 4 makes a turn in 12 hours, clockwise, as seen from the left. We therefore have

$$\mathrm{V}_4^0 = -2 \tag{6.1}$$

Then

$$\mathrm{V}_5^0 = \mathrm{V}_4^0 \times \left(-\frac{13}{26}\right) = 1 \tag{6.2}$$

$$\mathrm{V}_6^0 = \mathrm{V}_5^0 \times \left(-\frac{26}{26}\right) = -1 \tag{6.3}$$

6.3 The main driving motion

The 26-teeth wheel on arbor 6 meshes with a 340-teeth contrate wheel with a vertical axis 7 (see figure 6.3). A crank can be put on arbor 6 and used to move the machine in the future or in the past. The velocity of the 340-teeth wheel is

$$\mathrm{V}_7^0 = \mathrm{V}_6^0 \times \left(-\frac{26}{340}\right) = \frac{13}{170} \tag{6.4}$$

$$\mathrm{P}_7^0 = \frac{170}{13} = 13.0769\ldots \text{ days} \tag{6.5}$$

6.4 The motion of the Earth around the Sun

The axis of the Earth is fixed on frame 26 and this frame rotates around the central axis which may be thought of the Sun. The motion of this frame is obtained using epicyclic gears located on the frame. This is somewhat similar

[5] [8, p. 226-227]

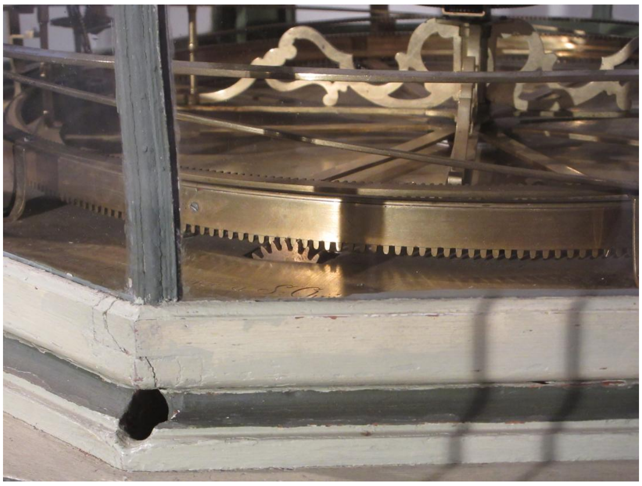

Figure 6.3: Detail of Frater Fridericus's clock in Bamberg. At the bottom, we can see the 26-teeth wheel which meshes with the 340-teeth wheel with a vertical arbor. A crank can be put in the hole to rotate that wheel. Frater Fridericus's signature is also partly visible. (photograph by the author)

to the constructions used by Neßtfell in his planetary machines. There is a train which is constrained by two relative motions. First, there is the motion of the frame 7 seen above. Second, there is the relative motion of the fixed frame 8 which carries a 498-teeth internal gear. We can therefore compute the motion of frame 8 as a function of the motion of frame 7, but with respect to the moving frame 26. We have

$$\begin{aligned} \mathrm{V}_8^{26} &= \mathrm{V}_7^{26} \times \frac{434}{32} \times \left(-\frac{14}{50}\right) \times \left(-\frac{7}{20}\right) \times \left(-\frac{20}{69}\right) \times \frac{48}{498} && (6.6)\\ &= \mathrm{V}_7^{26} \times \left(-\frac{10633}{286350}\right) && (6.7) \end{aligned}$$

that is

$$\mathrm{V}_0^{26} = \left(\mathrm{V}_7^{0} + \mathrm{V}_0^{26}\right) \times \left(-\frac{10633}{286350}\right) \qquad (6.8)$$

and

$$\begin{aligned} \mathrm{V}_0^{26} \times \left(1 + \frac{10633}{286350}\right) &= \mathrm{V}_7^{0} \times \left(-\frac{10633}{286350}\right) && (6.9)\\ \mathrm{V}_0^{26} \times \frac{296983}{286350} &= \mathrm{V}_7^{0} \times \left(-\frac{10633}{286350}\right) && (6.10) \end{aligned}$$

therefore

$$\mathrm{V}_0^{26} = \mathrm{V}_7^{0} \times \left(-\frac{10633}{296983}\right) \qquad (6.11)$$

and

$$V^0_{26} = V^0_7 \times \frac{10633}{296983} = \frac{13}{170} \times \frac{10633}{296983} = \frac{138229}{50487110} \tag{6.12}$$

$$P^0_{26} = \frac{50487110}{138229} = 365.2425\ldots \text{ days} \tag{6.13}$$

This is an approximation of the tropical year. The same value is given by Oechslin. The Earth moves counterclockwise around the center of the machine in one year.

6.5 The rotation of the Earth

Figure 6.4: The Earth globe on Frater Fridericus's clock in Bamberg. (photograph by the author)

The Earth is carried by the arbor 12 which is located on frame 26. We can compute the motion of this arbor with respect to its supporting frame:

$$\mathrm{V}_{12}^{26} = \mathrm{V}_{7}^{26} \times \frac{434}{32} = \mathrm{V}_{7}^{26} \times \frac{217}{16} \tag{6.14}$$

but we saw earlier that

$$\mathrm{V}_{8}^{26} = \mathrm{V}_{7}^{26} \times \left(-\frac{10633}{286350}\right) \tag{6.15}$$

therefore

$$\mathrm{V}_{7}^{26} = \mathrm{V}_{8}^{26} \times \left(-\frac{286350}{10633}\right) = \mathrm{V}_{26}^{0} \times \frac{286350}{10633} \tag{6.16}$$

$$= \frac{138229}{50487110} \times \frac{286350}{10633} = \frac{372255}{5048711} \tag{6.17}$$

and so

$$\mathrm{V}_{12}^{26} = \frac{372255}{5048711} \times \frac{217}{16} = \frac{80779335}{80779376} \tag{6.18}$$

$$\mathrm{P}_{12}^{26} = \frac{80779376}{80779335} = 1.0000005\ldots \text{ days} = 24 \text{ h } 0.0438\ldots \text{ s} \tag{6.19}$$

The Earth thus turns counterclockwise in slightly more than 24 hours with respect to the supporting frame. In such a model, the Earth should actually make a turn in exactly 24 hours and this is not entirely true here.[6]

6.6 The shadowline on Earth

The boundary between the day and the night is shown by a circle surrounding the Earth and this ring is made to oscillate with the help of a feeler in contact with a large tilted ring. The inclination of this ring is not clearly visible in Oechslin's photographs. This large ring is currently (2025) not correctly positioned, and the feeler is not in contact with it (see figure 6.5).

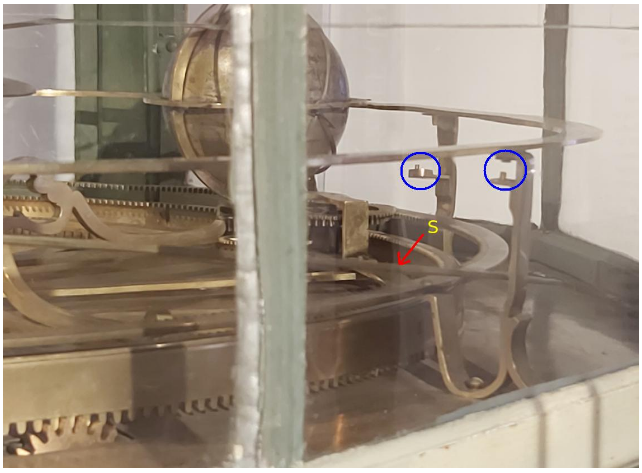

Figure 6.5: The tilted ring S for the shadowline of the Earth on Frater Fridericus's clock in Bamberg. This ring should go through the two fixations circled in blue, but doesn't. The feeler for the shadowline therefore is not in touch with the tilted ring, as it should normally be. (photograph by the author)

6.7 The Mercury system

The Mercury system is located on a fixed central frame which is not given any particular name by Oechslin. Mercury rotates on an circular orbit which is offset from the center of the machine, thus producing an eccentric motion which is that of frame 28. The motion of this frame within the fixed frame is

[6] See also Oechslin's observations on Frater Fridericus' machine [8, p. 198].

obtained by the rotation of the frame 26. We have

$$\mathrm{V}_{28}^{0} = \mathrm{V}_{26}^{0} \times \left(-\frac{108}{26}\right) \times \left(-\frac{40}{40}\right) = \mathrm{V}_{26}^{0} \times \frac{54}{13} \tag{6.20}$$

$$= \frac{138229}{50487110} \times \frac{54}{13} = \frac{287091}{25243555} \tag{6.21}$$

$$\mathrm{P}_{28}^{0} = \frac{25243555}{287091} = 87.9287\ldots \text{ days} \tag{6.22}$$

This is an approximation of the orbital period of Mercury. The same value is given by Oechslin.

Around the path of Mercury, a tilted slope of about 5.6° (figure 6.6) is used to move Mercury up and down, thus simulating the angle of its orbital plane, whose actual value is about 7°.

Figure 6.6: The central part of Frater Fridericus's clock in Bamberg, with the motion of Mercury. The tilted ring causes Mercury to move up and down. (photograph by the author)

A hand goes from the axis of the Earth to Mercury and extends to the outside dial. This supposedly serves to show the geocentric position of Mercury, but it can only work if 1) the ratios of the orbits of Mercury and the Earth are correct, and 2) if the outside dial is at an infinite distance, which of course it isn't. We can however see if the orbits are represented to scale. Mercury's semimajor axis is about 57.9 million kilometers, and Earth's is about 149.6 million kilometers, thus a ratio of about 2.58. On Frater Fridericus' machine, the ratio is about $221/61 = 3.62$, and this is a very bad approximation, and also a surprising one, given that the relative distances of the planets were already well known at the beginning of the 17th century. Consequently, it appears that the representation of the geocentrical position of Mercury is quite bad. It is not very accurate and only gives a vague idea of where Mercury is located in the sky. A better result would have been obtained if the orbits had been to scale, and if the hand for Mercury's position had been obtained as a parallel to the Earth-Mercury line and going through the center of the machine.

Finally, the central Mercury system also carries the year. This is obtained as follows. The arbor 29 is part of the fixed frame of Mercury. This arbor carries a 4-teeth or 4-pointed star wheel which advances by one tooth when the frame 26 makes one turn, that is, every year. The arbor 29 thus makes a turn in four years and carries a hand showing the cycle of four years.

This arbor also carries a 4-teeth wheel meshing with a 10-teeth (or stars) wheel on tube 30, which carries the units of the year and makes a turn in 10 years. This motion is transferred to a wheel on arbor 31, and this arbor carries a finger which advances a 10-pointed star wheel on arbor 32. The latter carries the tens of the year and makes a turn in 100 years. The machine also seems to show the hundreds and thousands, but Oechslin did not describe them in his drawing. They may be constructed similarly, or perhaps only set manually.

6.8 The lunar system

The lunar system is located on the frame 26 and also makes a turn in one tropical year. It is always opposite the main Earth sphere.

The motion within this system is derived from arbor 13, which parallels the Earth arbor 12 seen earlier. Both of these arbors carry 32-teeth wheels which mesh with the internal 434-teeth gear on frame 7. We therefore have

$$\mathrm{V}_{13}^{26} = \mathrm{V}_{12}^{26} = \frac{80779335}{80779376} \approx 1 \tag{6.23}$$

6.8.1 The mean motion of the Moon

The Moon is on frame 19 which carries an 127-teeth internal gear. The motion of this frame is derived from that of arbor 13:

$$\begin{aligned}
\mathrm{V}_{19}^{26} &= \mathrm{V}_{13}^{26} \times \left(-\frac{15}{101}\right) \times \left(-\frac{50}{37}\right) \times \left(-\frac{50}{28}\right) \times \left(-\frac{12}{12}\right) \times \frac{12}{127} && (6.24)\\
&= \mathrm{V}_{13}^{26} \times \frac{112500}{3322193} = \frac{80779335}{80779376} \times \frac{112500}{3322193} = \frac{324559828125}{9584452767556} && (6.25)\\
\mathrm{P}_{19}^{26} &= \frac{9584452767556}{324559828125} = 29.5306\ldots \text{ days} && (6.26)
\end{aligned}$$

This is an approximation of the synodic month. The same value is given by Oechslin.

The phases of the Moon are shown on a fixed ring fixed on frame 26.

6.8.2 The lunar nodes

The lunar nodes are on frame 25. The motion of this frame is also derived from that of arbor 13, using in particular two worms. We have

$$\mathrm{V}_{25}^{26} = \mathrm{V}_{13}^{26} \times \left(-\frac{1}{66}\right) \times \left(-\frac{20}{20}\right) \times \left(-\frac{1}{103}\right) \tag{6.27}$$

$$= \mathrm{V}_{13}^{26} \times \left(-\frac{1}{6798}\right) \approx -\frac{1}{6798} \tag{6.28}$$

$$\mathrm{P}_{25}^{26} = -\mathrm{P}_{13}^{26} \times 6798 \approx -6798 \text{ days} \tag{6.29}$$

This is an approximation of the period of precession of the lunar nodes and the value is negative because the nodes are retrograding. The same value is given by Oechslin.

The frame 25 carries a tilted slope (figure 6.7) which is used to move the Moon up and down, so as to simulate its motion in an inclined orbit. The inclination in this machine is a little bit more than 5 degrees.

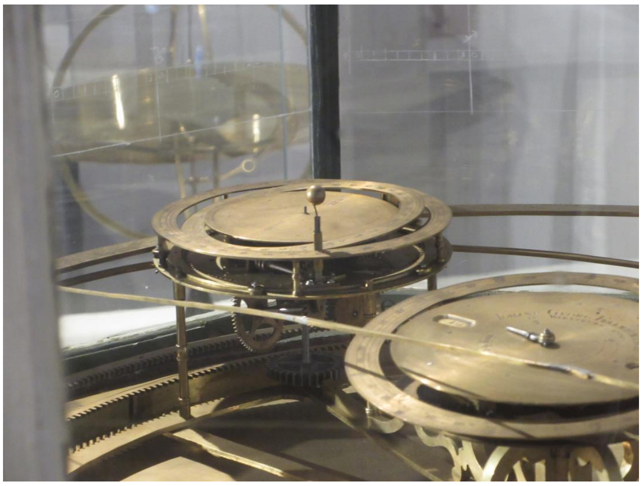

Figure 6.7: Detail of Frater Fridericus's clock in Bamberg. In the back, there is the part for the motion of the Moon. The internal tilted ring is used to move the Moon up and down. (photograph by the author)

6.8.3 The line of apsides

The lunar apsides are on frame 22. The motion of this frame is also derived from that of arbor 13, using in particular two worms. We have

$$\mathrm{V}_{22}^{26} = \mathrm{V}_{13}^{26} \times \frac{1}{32} \times \left(-\frac{32}{32}\right) \times \left(-\frac{1}{101}\right) = \mathrm{V}_{13}^{26} \times \frac{1}{3232} \approx \frac{1}{3232} \tag{6.30}$$

$$\mathrm{P}_{22}^{26} = \mathrm{P}_{13}^{26} \times 3232 \approx 3232 \text{ days} \tag{6.31}$$

This is an approximation of the period of precession of the lunar apsides and the value is positive because the motion is prograde. The same value is given by Oechslin.

The frame 22 is not used to change the motion of the Moon, but rather to change the position of the Earth with respect to the Moon. The shortest distance between the Moon and the Earth, that is the perigee, moves like frame 22.

6.8.4 The rotation of the Earth

Within the lunar system, the Earth would have been on arbor 14, but it is now missing. The motion of arbor 14 is derived from that of arbor 13, but the arbor 14 is located on frame 22. So, we first compute the motion of arbor 14 with respect to frame 22:

$$\mathrm{V}_{14}^{22} = \mathrm{V}_{13}^{22} \times \left(-\frac{6}{6}\right) = -\mathrm{V}_{13}^{22} \tag{6.32}$$

then

$$\begin{aligned}
\mathrm{V}_{14}^{26} &= \mathrm{V}_{14}^{22} + \mathrm{V}_{22}^{26} = -\mathrm{V}_{13}^{22} + \mathrm{V}_{22}^{26} = -\left(\mathrm{V}_{13}^{26} + \mathrm{V}_{26}^{22}\right) + \mathrm{V}_{22}^{26} && (6.33)\\
&= -\mathrm{V}_{13}^{26} + 2\mathrm{V}_{22}^{26} = -\mathrm{V}_{13}^{26} + 2\mathrm{V}_{13}^{26} \times \frac{1}{3232} && (6.34)\\
&= -\mathrm{V}_{13}^{26} \times \left(1 - 2 \times \frac{1}{3232}\right) = -\mathrm{V}_{13}^{26} \times \frac{1615}{1616} && (6.35)\\
&= -\frac{80779335}{80779376} \times \frac{1615}{1616} = -\frac{7674036825}{7678792448} \approx -1 && (6.36)
\end{aligned}$$

So, the Earth makes a turn clockwise in about one day. This motion is however wrong, as the Earth should move counterclockwise with respect to frame 26, as it does on arbor 12.

6.9 References

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