Chapter 3 **(Oechslin: 5.1)**

Pater Aurelius's clock in Munich (1769)

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.

3.1 Introduction

The clock described in this chapter was constructed in 1769 by Michael Fras, who became a discalced Augustinian known as Pater Aurelius a San Daniele (1728-1782).

Very little is known of Michael Fras. According to Bertele, he was born in Shavers (sp.?) in Thuringia.[1] He entered the Mariabrunn Augustinian monastery near Vienna, the same that Frater David attended. We know that he constructed at least three clocks in the 1760s and 1770s. Pater Aurelius died in Vienna in 1782.

The present clock was an order from the former Cistercian abbey at Salem, near Konstanz, for which abbot Anselm II. Schwab paid 150 ducats to Pater Aurelius in 1771.[2] This clock was located in the Prelature of the abbey.

In 1938, Frischholz mentioned that a clockmaker had remade the escapement of Pater Aurelius' clock about 100 years before his article, so around 1830, and that the clock was restored by the clockmakers Anton and Karl Jagemann after it was donated to the museum.[3]

In any case, the ownership of the clock was forgotten until 1919, when it came in the possession of Ernst von Bassermann-Jordan who then bequeathed

[1]Most of this biographical notice is taken from Bertele [3]. I do unfortunately not know what Shavers refers to and the current spelling may be different. This location was first given by Bertele and repeated by a number of later authors. See also Lloyd [10], Maurice [14, v.1, p. 271, 276, 278] and Mattl-Wurm's short notice [13, p. 42-43].

[2]See the 1989 exhibition catalogue [17, p. 54-55] and Oechslin [15, p. 222].

[3]See [8, p. 198].

it to the *Bayerisches Nationalmuseum* in Munich in 1933.[4]

Another similar clock by Pater Aurelius is located in Innsbruck. It was completed in 1775 and was particularly described by Czermak.[5]

3.2 Description of the clock

Pater Aurelius' clock is a tall case clock, with a very ornate case made by Johann Georg Dirr (1723-1779).[6] There is a large dial surrounded by a number of smaller dials and spheres (figure 3.2). There are a number of calendrical indications, but they will only cursorily be described here. I will first describe the going work, then the main dial, the lunar sphere, the celestial sphere, and then the other dials.

3.2.1 The going work

The clock is weight-driven and regulated by a pendulum. The 30-teeth escapement wheel is on arbor 9 and makes a turn in one minute (all the motions are measured from the front).

$$\mathrm{V}_9^0 = -1440 \tag{3.1}$$

$$\mathrm{P}_9^0 = -\frac{1}{1440} \text{ days} = -1 \text{ m} \tag{3.2}$$

The pendulum thus makes a half-oscillation in one second.

This motion is then transferred to the central arbor 7 of the main dial:

$$\mathrm{V}_7^0 = \mathrm{V}_9^0 \times \left(-\frac{6}{60}\right) \times \left(-\frac{6}{72}\right) = \mathrm{V}_9^0 \times \frac{1}{120} = -12 \tag{3.3}$$

$$\mathrm{P}_7^0 = -\frac{1}{12} \tag{3.4}$$

[4] Cf. [16, p. 435] and [15, p. 233].

[5] See [4], [5], Bertele [3, p. 108-110] and [13, p. 116]. Fischer described the musical tunes of the clock [7]. As noted by Czermak, this clock was mistakenly attributed to Frater David by Luca [12, p. 86]. There are a number of other mentions in the 19th century, which I am not enumerating here. See more recently the account by Vrabec [18]. There is a third equation clock by Pater Aurelius, made in 1771 and kept in Vienna, see [3, p. 110-112], [1, p. 203], [11, p. 241] and [13, p. 115].

[6] When discussing Pater Aurelius' clock, Engelmann does illustrate another clock supposedly by Eberhart Camerhueber (or Camenhueber?) which has a case very similar to that of Pater Aurelius' clock, and dials which are somewhat simpler. This clock has a plate which gives Camerhueber's birth in 1749 [6], This clock was accompanied by a manuscript which seems to have been copied from the description of Pater Aurelius' clock [2]. It isn't clear who made the clockwork, and if Frater David was involved in the cases, as Engelmann believes. Oechslin mentions Camerhueber's clock, but doesn't have any information about it [15, p. 228]. According to a mention in the *Alt-Wien Kunst Chronik* from ca. 1948, p. 224, but which I wasn't able to check, Camerhueber's clock was previously in Dresden and its current (1948) location was not known. Perhaps it was destroyed during WWII.

Figure 3.1: Pater Aurelius' clock in Munich (photograph by the author).

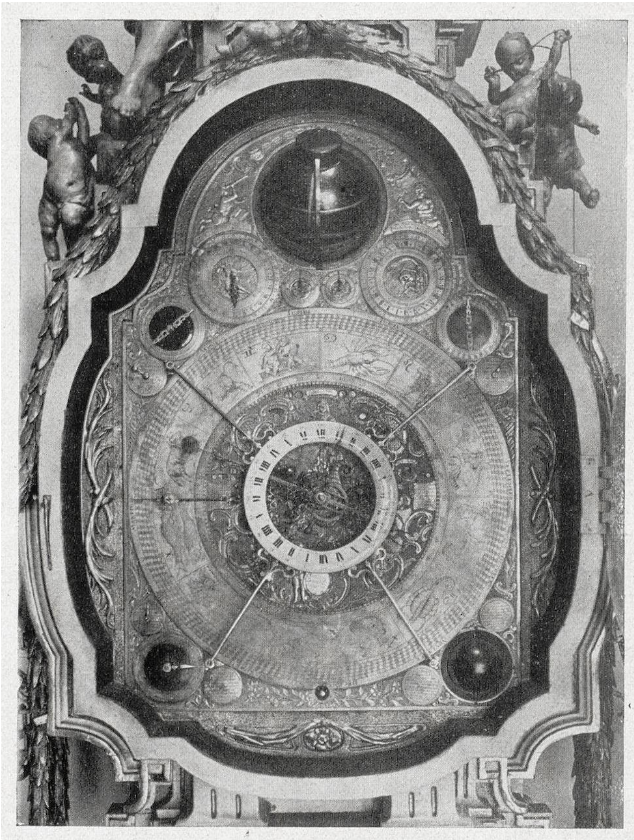

Figure 3.2: The dials of Pater Aurelius' clock in Munich. (source: [6])

Figure 3.3: The dials of Pater Aurelius' clock in Munich (source: https://www.bayerisches-nationalmuseum.de/sammlung/00070980, licence: CC BY-NC-ND 4.0).

Figure 3.4: The lower left part of the dials of Pater Aurelius' clock in Munich. (photograph by the author)

This arbor makes one turn clockwise in two hours.

The drum is on arbor 5 and its velocity is

$$V_5^0 = V_5^0 \times \left(-\frac{16}{76}\right) \times \left(-\frac{16}{80}\right) = V_5^0 \times \frac{4}{95} = -\frac{48}{95} \tag{3.5}$$

The drum thus makes a turn in a little less than two days. It can be rewound using a crank on arbor 1. The train rotates the winding wheel on arbor 4. The velocity of that arbor is

$$V_4^0 = V_5^0 \text{ (when the clock is not beeing rewound)} \tag{3.6}$$

and

$$V_1^0 = V_4^0 \times \left(-\frac{48}{35}\right) \times \left(-\frac{35}{35}\right) \times \left(-\frac{35}{35}\right) = V_5^0 \times \left(-\frac{48}{35}\right) \tag{3.7}$$

$$= \left(-\frac{48}{95}\right) \times \left(-\frac{48}{35}\right) = \frac{2304}{3325} \tag{3.8}$$

$$P_1^0 = \frac{3325}{2304} \text{ days} = 34.6354\ldots \text{ days} \tag{3.9}$$

One turn of the crank thus gets the clock working for almost 35 hours.

3.2.2 The main dial

The main dial has a wide ring with the signs of the zodiac and calendar rings. In the center, a smaller ring suspended by four arms shows the 24 hours. There are hands for the Sun, the Moon, the lunar apsides and the lunar nodes.

Inside the large ring, there are four small openings for the year, openings for the day, the month, the epact, the dominical letter, the golden number, the indiction, the day of the week and the regent of the day, as well as an indicator for the leap year.

These motions are all derived from that of the central arbor 7 which makes one turn in two hours.

3.2.2.1 The time

The time is shown by two hands, one for the hours (on twice 12 hours) and one for the minutes (on twice 60 minutes). The use of such a dial for the minutes is rather unusual, but the minute hand is carried on arbor 7 which makes a turn in two hours.

Figure 3.5: The 24-hour dial on Pater Aurelius' clock in Munich (photograph by the author).

The hour hand is carried by tube 11 whose velocity is obtain via the intermediate arbor 10:

$$\mathrm{V}_{10}^{0} = \mathrm{V}_{7}^{0} \times \left(-\frac{22}{88}\right) = \mathrm{V}_{7}^{0} \times \left(-\frac{1}{4}\right) = (-12) \times \left(-\frac{1}{4}\right) = 3 \tag{3.10}$$

$$\mathrm{V}_{11}^{0} = \mathrm{V}_{10}^{0} \times \left(-\frac{24}{72}\right) = 3 \times \frac{1}{3} = -1 \tag{3.11}$$

This hand thus makes a turn clockwise in one day.

3.2.2.2 The motion of the Sun

The Sun is carried by the tube 20 and its motion is derived from that of arbor 18, which is itself derived from that of arbor 10 seen above. We have

$$\mathrm{V}_{18}^{0} = \mathrm{V}_{10}^{0} \times \left(-\frac{16}{134}\right) = 3 \times \left(-\frac{8}{67}\right) = -\frac{24}{67} \tag{3.12}$$

$$\mathrm{V}_{20}^{0} = \mathrm{V}_{18}^{0} \times \left(-\frac{12}{80}\right) \times \left(-\frac{8}{157}\right) = \mathrm{V}_{18}^{0} \times \frac{6}{785} \tag{3.13}$$

$$= -\frac{24}{67} \times \frac{6}{785} = -\frac{144}{52595} \tag{3.14}$$

$$\mathrm{P}_{20}^{0} = -\frac{52595}{144} = -365.2430\ldots \text{ days} \tag{3.15}$$

This is a (not so good) approximation of the tropical year. The same value is given by Oechslin. The signs of the zodiac and the calendar are given clockwise and the Sun moves clockwise around the dial in one year.

3.2.2.3 The motion of the Moon

The mean motion of the Moon is given by frame 13 whose motion is derived from that of tube 11. We first obtain the velocity of arbor 12 which will be useful later:

$$\mathrm{V}_{12}^{0} = \mathrm{V}_{11}^{0} \times \left(-\frac{27}{73}\right) = \frac{27}{73} \tag{3.16}$$

$$\mathrm{V}_{13}^{0} = \mathrm{V}_{12}^{0} \times \left(-\frac{19}{192}\right) = \frac{27}{73} \times \left(-\frac{19}{192}\right) = -\frac{171}{4672} \tag{3.17}$$

$$\mathrm{P}_{13}^{0} = -\frac{4672}{171} = -27.3216\ldots \text{ days} \tag{3.18}$$

This is an approximation of the tropical month, but not the best one. The same value is given by Oechslin.

3.2.2.4 The motion of the lunar apsides

The hands of the lunar apsides are carried by tube 17. The motion of this tube is derived from that of arbor 16, which is itself derived from that of arbor 12 seen above. We have

$$\mathrm{V}_{16}^{0} = \mathrm{V}_{12}^{0} \times \left(-\frac{19}{44}\right) \times \left(-\frac{6}{72}\right) = \mathrm{V}_{12}^{0} \times \frac{19}{528} = \frac{27}{73} \times \frac{19}{528} = \frac{171}{12848} \tag{3.19}$$

$$\mathrm{V}_{17}^{0} = \mathrm{V}_{16}^{0} \times \left(-\frac{4}{172}\right) = \frac{171}{12848} \times \left(-\frac{1}{43}\right) = -\frac{171}{552464} \tag{3.20}$$

$$\mathrm{P}_{17}^{0} = -\frac{552464}{171} = -3230.7836\ldots \text{ days} \tag{3.21}$$

This is an approximation of the precession of the lunar apsides in about 8.85 years. The same value is given by Oechslin. The sign is negative, because the motion of the apsides is prograde and the signs of the zodiac are arranged clockwise.

3.2.2.5 The motion of the lunar nodes

The hands (dragon) of the lunar nodes are carried by tube 22. Their motion is derived from that of arbor 16:

$$\mathrm{V}_{22}^{0} = \mathrm{V}_{16}^{0} \times \left(-\frac{8}{52}\right) \times \left(-\frac{12}{167}\right) = \mathrm{V}_{16}^{0} \times \frac{24}{2171} \tag{3.22}$$

$$= \frac{171}{12848} \times \frac{24}{2171} = \frac{513}{3486626} \tag{3.23}$$

$$\mathrm{P}_{22}^{0} = \frac{3486626}{513} = 6796.5419\ldots \text{ days} \tag{3.24}$$

This is an approximation of the precession of the lunar nodes in about 18.6 years. The same value is given by Oechslin. The sign is positive because the nodes move counterclockwise on the zodiac which is arranged clockwise, but it is in fact a retrogradation.

3.2.2.6 The corrected motion of the Moon

The motion of the mean Moon is corrected in order to take into account its elliptic orbit. The Moon seems to be corrected as a function of the angle between the mean Moon and the line of apsides. The tube 17 carries an eccentric cam under it, and this cam moves the lunar hand back and forth. How exactly this is done is not entirely clear and Oechslin mentions a carriage with a rack.

But on the front of the dial, the tube 17 also carries an eccentric ring (visible on photographs) which moves the lunar hand (of which the figure seems missing) farther or closer to the center. Pater Aurelius therefore both wanted to display the elliptic motion of the Moon, and to have the hand be ahead or behind the mean motion, depending on where the Moon is located with respect to the line of apsides.

This is interesting, but altering the distance of the Moon to the center seems to be a misunderstanding. Perhaps Pater Aurelius wanted to display the eclipses, but in that case, the lengthening of the lunar hand should have been a function of the line of nodes, not of the line of apsides, as it is for instance done in Schwilgué's astronomical clock in Strasbourg.

3.2.3 The lunar sphere

The lunar sphere is at the lower right of the main dial and it is carried by the arbor 47. Its motion is derived from that of arbor 12 seen above. We have

$$V^0_{47} = V^0_{12} \times \left(-\frac{73}{54}\right) \times \left(-\frac{28}{41}\right) \times \left(-\frac{24}{24}\right) \times \left(-\frac{24}{44}\right) \times \frac{44}{44} \times \left(-\frac{6}{33}\right) \tag{3.25}$$

$$= V^0_{12} \times \frac{4088}{44649} = \frac{27}{73} \times \frac{4088}{44649} = \frac{168}{4961} \tag{3.26}$$

$$P^0_{47} = \frac{4961}{168} = 29.5297\ldots \text{ days} \tag{3.27}$$

This is an approximation of the synodic month, but also a rather bad one. The same value is given by Oechslin.

Figure 3.6: The lower right part of the dials of Pater Aurelius' clock in Munich, with the lunar sphere. (photograph by the author)

This sphere has a vertical axis and moves counterclockwise as seen from above (assuming Oechslin's drawing is correct). This is rather counterintuitive, as it means that the lunar crescent after a New Moon appears at the left, whereas it should appear on the right.

3.2.4 The celestial sphere

The celestial sphere above the main dial shows the apparent clockwise motion (from above) of the sky in one sidereal day. It also shows the motion of the Sun on the sphere. Finally, a fixed cage carries the meridian and the 24-hour dial at the top.

This system obtains its motion from the arbor 55. This arbor was apparently missing, as Oechslin puts the number of the teeth of its two pinions in parentheses. The velocity of this arbor (measured from the left on Oechslin's drawing) is derived from that of arbor 10 seen above in the motion of the hour hand:

$$\mathrm{V}_{55}^{0} = \mathrm{V}_{10}^{0} \times \frac{88}{11} = \mathrm{V}_{10}^{0} \times 8 = 3 \times 8 = 24 \quad (3.28)$$

$$\mathrm{P}_{55}^{0} = \frac{1}{24} = 1 \text{ hour} \quad (3.29)$$

This arbor makes a turn clockwise (seen from above) in one hour.

The arbor 55 drives the central arbor 56 of the sphere, which goes through the dial on the top. Its velocity is

$$\mathrm{V}_{56}^{0} = \mathrm{V}_{55}^{0} \times \left(-\frac{5}{120}\right) = \mathrm{V}_{55}^{0} \times \left(-\frac{1}{24}\right) = -1 \quad (3.30)$$

This arbor makes one turn clockwise (seen from above) in a day.

The globe itself is carried by the tube 60 whose motion is obtained through epicyclic gears located on a 120-teeth wheel on the frame 56 and using a 24-teeth wheel on the fixed tube 57. We first compute the motion of the globe with respect to the moving frame 56. We have

$$\mathrm{V}_{60}^{56} = \mathrm{V}_{57}^{56} \times \left(-\frac{24}{67}\right) \times \left(-\frac{12}{40}\right) \times \left(-\frac{4}{157}\right) = \mathrm{V}_{57}^{60} \times \left(-\frac{144}{52595}\right) \quad (3.31)$$

$$= -\mathrm{V}_{56}^{57} \times \left(-\frac{144}{52595}\right) = -\mathrm{V}_{56}^{0} \times \left(-\frac{144}{52595}\right) \quad (3.32)$$

$$= -\frac{144}{52595} \quad (3.33)$$

$$\mathrm{P}_{60}^{56} = -\frac{52595}{144} = -365.2430\ldots \text{ days} \quad (3.34)$$

This is the same ratio as the one used for the motion of the Sun in the main dial. The same value is given by Oechslin.

Then, in the absolute frame

$$\mathrm{V}_{60}^{0} = \mathrm{V}_{60}^{56} + \mathrm{V}_{56}^{0} = -\frac{144}{52595} - 1 = -\frac{52739}{52595} \quad (3.35)$$

$$\mathrm{P}_{60}^{0} = -\frac{52595}{52739} = -0.9972\ldots \text{ days} = -23 \text{ h } 56 \text{ m } 4.0910\ldots \text{ s} \quad (3.36)$$

This is the sidereal day and the globe thus makes one turn clockwise (from above) in one sidereal day.

The figure of the Sun moves on the sphere as it is carried by a ring with an internal gearing of 183 teeth on arbor 66. This ring presumably moves in the ecliptic. This motion is also obtained by an epicyclic gearing using another 24-teeth on the fixed tube 61. We can compute the motion of the Sun (ring 66) with respect to the globe (frame 60) (beware of the last fraction which is positive):

$$V_{66}^{60} = V_{61}^{60} \times \left(-\frac{24}{36}\right) \times \left(-\frac{20}{40}\right) \times \left(-\frac{10}{40}\right) \times \left(-\frac{24}{24}\right) \times \frac{6}{183} \quad (3.37)$$

$$= V_{61}^{60} \times \frac{1}{366} = -V_{60}^{61} \times \frac{1}{366} = -V_{60}^{0} \times \frac{1}{366} = \frac{52739}{52595} \times \frac{1}{366} \quad (3.38)$$

$$= \frac{52739}{19249770} \quad (3.39)$$

$$P_{66}^{60} = \frac{19249770}{52739} = 365.0006\ldots \text{ days} \quad (3.40)$$

The Sun thus moves counterclockwise with respect to the celestial sphere and makes a turn in slightly more than 365 days. The Sun should indeed move counterclockwise, but the motion should take place in a tropical year, and the value found here (not given by Oechslin) is extremely bad.

3.2.5 The other dials

All the other dials and indications derive their motion from the motion of arbor 7 which makes one turn clockwise in two hours.

3.2.5.1 The oscillating indications

Six of the dials show indications with oscillate during the year. For instance, at our latitudes, the sunrise varies between about 4 a.m. in Summer and 8 a.m. in Winter. These motions are all based on the motion of an annual cam.

3.2.5.1.1 The Italic and Babylonian hours

The two medium-sized dials at the lower left and lower right of the celestial globe give the Italic and Babylonian hours, that is the number of hours since the last sunset and since the last sunrise. I believe that the Italic hours are shown on the dial left, and the Babylonian hours on the dial right.

There is only one hand on each dial and these hands make a turn in 24 hours. The hand of the dial on the left is carried by arbor 32, whereas the hand of the dial on the right is carried by arbor 30. The motion of these two arbors is derived from arbor 18, via arbor 23:

$$\mathrm{V}^0_{23} = \mathrm{V}^0_{18} \times \left(-\frac{134}{48}\right) = -\frac{24}{67} \times \left(-\frac{134}{48}\right) = 1 \tag{3.41}$$

$$\mathrm{V}^0_{30} = \mathrm{V}^0_{23} \times \left(-\frac{48}{48}\right) \times \left(-\frac{48}{48}\right) \times \left(-\frac{45}{45}\right) = -\mathrm{V}^0_{23} = -1 \tag{3.42}$$

$$\mathrm{V}^0_{32} = \mathrm{V}^0_{30} \times \frac{45}{24} \times \frac{24}{45} = \mathrm{V}^0_{30} = -1 \tag{3.43}$$

The dial on the left shows the astronomical hours from 1 to 24, presumably counted from noon. The dial on the right shows the common hours on a twice 12 hours dial. The Italic and Babylonian hours are shown using outer moving rings which have an oscillating motion. This is similar to the construction used by Frater David a Sancto Cajetano in the two clocks described in this volume.

The oscillation of the Italic and Babylonian hours is controlled by a cam located on arbor 33. This arbor makes a turn in one tropical year:

$$\mathrm{V}^0_{33} = \mathrm{V}^0_{20} \times \left(-\frac{157}{157}\right) = -\mathrm{V}^0_{20} = \frac{144}{52595} \tag{3.44}$$

$$\mathrm{P}^0_{33} = \frac{52595}{144} = 365.2430\ldots \text{ days} \tag{3.45}$$

This cam is used to move the tube 49 on the axis of the Babylonian hours, this causing the oscillation of the outer ring.

3.2.5.1.2 The other oscillating motions

This oscillating motion of the Babylonian hour ring is also transferred to five other dials: the Italic hours (frame 53), the hour of sunrise (arbor 51), the hour of sunset (arbor 52), the lengths of day and night (arbor 50), and the declination of the Sun (arbor 54). During the year, all of these indications oscillate between two values. However, the amplitude of the oscillation varies. The small dials for the sunset (left) and sunrise (right), which are located under the celestial sphere, show variations of ± 2 hours around a median value, and this amplitude of four hours represents about 150 degrees, so that there would be only about ten hours on each dial. More precisely, the ratio between the wheels controlling the Babylonian hours and the sunrise is such as to adapt the amplitude of the Babylonian hours to the amplitude of the sunrise. In his clock, Pater Aurelius took the ratio 68/160. This means that the dials for the sunrise and sunset are virtually on $\frac{68}{160} \times 24$ hours, that is 10 hours and 12 minutes. This is a matter of choice, and Pater Aurelius could have chosen a different ratio. Only the small dials would have had to be changed.

The dial for the lengths of the day and night is located at the right of the dial for the Babylonian hours. It has one hand (arbor 50) of which the upper part gives the length of the night and the lower part the length of the day. The sum of the two lengths is always equal to 24. This dial seems to be divided in about 32 hours. Unfortunately, Oechslin didn't give the exact ratio between these two dials, he only stated that behind the dial for the lengths of the day and night there is a 27-teeth sector. However, whenener the Babylonian hour changes by one hour, the length of the day or night should change by two hours. Since there are about 32 hours in the day/night lengths dial, this corresponds to about 16 hours in the Babylonian hours dial. Hence, there should be a ratio of about 24/16 between the two dials. The full wheel should be about 240 teeth. More precise measurements should be made to obtain the exact value.

The same applies to the dial for the solar declination which is located at the left of the dial for the Italic hours. But here only the upper part of the hand (on arbor 54) is used to read the declination which varies between $-23.5°$ and $+23.5°$.

3.2.5.2 The calendrical indications

A number of calendrical indications are shown between the wide zodiac ring and the 24-hour suspended dial (figure 3.7). These are the four digits of the year, the day of the month, the day of the week, the month, whether the year is a leap year or not, the day ruler (planet associated to the day), the indiction the dominical letter, the epact, and the golden number.

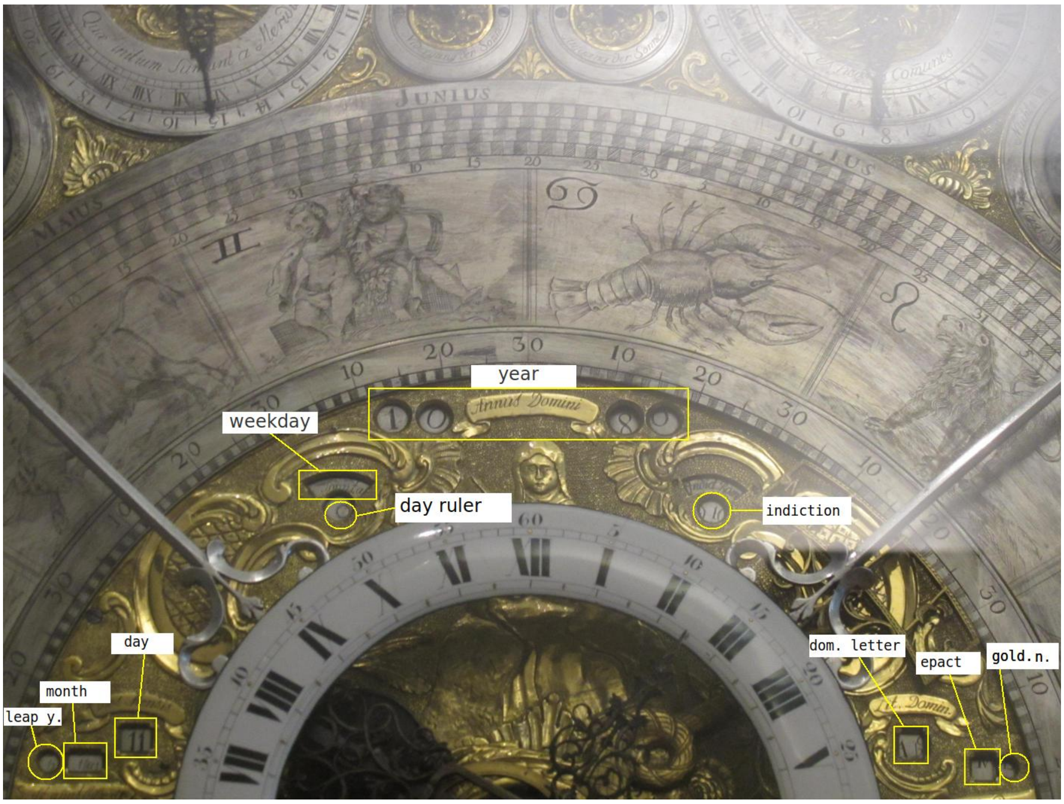

Figure 3.7: Detail of the signs of the zodiac and the openings for the year and other indications (photograph by the author).

3.2.5.2.1 The day and the derived indications

The day is updated through arbor 25 which makes a turn in a day:

$$\mathrm{V}_{25}^{0} = \mathrm{V}_{23}^{0} \times \left(-\frac{48}{48}\right) = -1 \tag{3.46}$$

A lever on this arbor moves the day of the month and there is a 4-year wheel for the lengths of the months. I will not describe this part in more details here.

The day of the week is on arbor 24 and its motion is also derived from arbor 23:

$$V_{24}^0 = V_{23}^0 \times \left(-\frac{1}{7}\right) = -\frac{1}{7} \tag{3.47}$$

$$P_{24}^0 = -7 \text{ days} \tag{3.48}$$

This arbor makes a turn clockwise in seven days. The dial with the names of the day probably also carries the planets ruling the days.

3.2.5.2.2 The yearly indications

All the other indications only change when the year changes. They are derived from the motion of arbor 33 which makes a turn in one tropical year.

The arbor 33 carries a finger which moves a 7-teeth wheel on arbor 34 by one tooth every year. This arbor thus makes a turn in seven years:

$$V_{34}^0 = V_{33}^0 \times \left(-\frac{1}{7}\right) \tag{3.49}$$

$$P_{34}^0 = -7 \text{ years} \tag{3.50}$$

Next, we obtain the motions of the arbors for the dominical letter (one turn in 28 years), the epact and golden number (one turn in 19 years) and the indiction (one turn in 15 years):

$$V_{35}^0 = V_{34}^0 \times \left(-\frac{21}{84}\right) = V_{33}^0 \times \frac{1}{28} \tag{3.51}$$

$$P_{35}^0 = 28 \text{ years} \tag{3.52}$$

$$V_{36}^0 = V_{35}^0 \times \left(-\frac{84}{57}\right) = V_{33}^0 \times \left(-\frac{1}{19}\right) \tag{3.53}$$

$$P_{36}^0 = -19 \text{ years} \tag{3.54}$$

$$V_{37}^0 = V_{34}^0 \times \left(-\frac{21}{45}\right) = V_{33}^0 \times \frac{1}{15} \tag{3.55}$$

$$P_{37}^0 = 15 \text{ years} \tag{3.56}$$

The arbor 37 is used to derive the motion of arbor 39:

$$V_{39}^0 = V_{37}^0 \times \left(-\frac{45}{30}\right) \times \left(-\frac{30}{30}\right) = V_{37}^0 \times \frac{3}{2} = V_{33}^0 \times \frac{1}{10} \tag{3.57}$$

$$P_{39}^0 = 10 \text{ years} \tag{3.58}$$

This arbor carries the units of the year and makes a turn in 10 years.

It also carries a finger which moves a 10-teeth wheel on arbor 40 by one tooth every 10 years:

$$V_{40}^0 = V_{39}^0 \times \left(-\frac{1}{10}\right) = V_{33}^0 \times \frac{1}{10} \times \left(-\frac{1}{10}\right) = V_{33}^0 \times \left(-\frac{1}{100}\right) \tag{3.59}$$

$$P_{40}^0 = -100 \text{ years} \tag{3.60}$$

This arbor carries the tens of the year and makes a turn in 100 years.

This arbor also carries a finger which moves a 10-teeth wheel on arbor 41 by one tooth every 100 years:

$$V_{41}^{0} = V_{40}^{0} \times \left(-\frac{1}{10}\right) = V_{33}^{0} \times \left(-\frac{1}{100}\right) \times \left(-\frac{1}{10}\right) = V_{33}^{0} \times \frac{1}{1000} \tag{3.61}$$

$$P_{41}^{0} = 1000 \text{ years} \tag{3.62}$$

This arbor carries the hundreds of the year and makes a turn in 1000 years.

It isn't clear if there is a wheel for the thousands of the year, or if other digits than 1 are possible.

3.3 Conclusion

Compared to other clocks in this volume, Pater Aurelius' clock is not as complex as it seems. The most surprising, though, is that many of the periods used in this clock (for instance the motion of the Sun on the celestial sphere) are not very accurate.

3.4 References

[1] Jürgen Abeler. Die Gebrüder Johann, Augustinerpatres und Uhrmacher. Bericht über eine Forschung des Wuppertaler Uhrenmuseums. *Mainzer Zeitschrift*, 69:197–205, 1974.

[2] Pater Aurelius a San Daniele. *Gründliche Erklärung eines astronomisch- und systematischen Uhrwerks, welches P. Aurelius a S. Daniele, Augustiner Baarfüßer in dem k. k. Hofkloster zu Wien, dermaliger Lehrer der mathematischen Wissenschaften erfunden, und eigenhändig verfertiget hat. im Jahr 1770.* Wien: Van Ghelen.

[3] Hans von Bertele. Zur Geschichte der Äquationsuhren-Entwicklung. *Blätter für Technikgeschichte*, 19:78–121, 1957.

[4] Paul Czermak. Die astronomische Standuhr des physikal. Institutes der Universität Innsbruck. *Berichte des naturwissenschaftliche-medizinischen Vereines in Innsbruck*, 24:195–217 + 3 plates, 1899.

[5] Paul Czermak. Nachtrag zur astronomischen Standuhr des physikalischen Institutes der Universität Innsbruck. *Berichte des naturwissenschaftliche-medizinischen Vereines in Innsbruck*, 27:3–4, 1902.

[6] Max Engelmann. Werke der letzten Blüte klösterlicher Uhrmacherei. *Der Kunstwanderer*, 5(1):193–197, 1923. [on Pater Aurelius, Frater David, Neßtfell and Hahn].

[7] Wilhelm Fischer. Die Spielstücke einer Innsbrucker astronomischen Uhr von 1775. In *Mozart-Jahrbuch 1957*, pages 7–14. Salzburg: Zentralinstitut für Mozartforschung der Internationalen Stiftung Mozarteum, 1958. [on Pater Aurelius' clock].

[8] Gustav Frischholz. Kunstvolle Uhren aus Österreichs vergangenen Tagen. *Deutsche Uhrmacher-Zeitung*, 62(15):196–200, 1938.

[9] Ulrich Knapp and Ludwig Oechslin. Die astronomische Uhr des P. Aurelius a S. Daniele, c1989. [unpublished, not seen].

[10] Herbert Alan Lloyd. *Some outstanding clocks over seven hundred years, 1250-1950.* London: Leonard Hill Limited, 1958. [p. 116-118 on Pater Aurelius and p. 118-120 on Frater David].

[11] Anton Lübke. *Das große Uhrenbuch — Von der Sonnenuhr zur Atomuhr.* Tübingen: Ernst Wasmuth, 1977.

[12] Ignaz de Luca. Versuch einer akademischen gelehrten Geschichte von der kaiserl. königl. Leopoldinischen Universität zu Insbruck. *Journal der Literatur und Statistik*, 1:1–116, 1782. [see p. 86 for Pater Aurelius' clock].

[13] Sylvia Mattl-Wurm, Heinrich Lunardi, and Ludwig Oechslin. *Himmlisches Räderwerk — Die astronomische Kunstuhr des Frater Cajetano 1726-1796.* Wien: Historisches Museum, 1996.

[14] Klaus Maurice. *Die deutsche Räderuhr — Zur Kunst und Technik des mechanischen Zeitmessers im deutschen Sprachraum.* München: C. H. Beck, 1976. [2 volumes].

[15] Ludwig Oechslin. *Astronomische Uhren und Welt-Modelle der Priestermechaniker im 18. Jahrhundert.* Neuchâtel: Antoine Simonin, 1996. [2 volumes and portfolio of plates].

[16] Lorenz Seelig. Uhren und wissenschaftliche Instrumente. In Ingolf Bauer, Birgitta Heid, and Lorenz Seelig, editors, *Das Bayerische Nationalmuseum 1855-2005 — 150 Jahre Sammeln, Forschen, Ausstellen*, pages 433–447. München: Hirmer, 2006.

[17] Christian Väterlein, editor. *Philipp Matthäus Hahn 1739-1790 — Pfarrer, Astronom, Ingenieur, Unternehmer. Teil 1: Katalog*, volume 6 of *Quellen und Schriften zu Philipp Matthäus Hahn.* Stuttgart: Württembergisches Landesmuseum, 1989.

[18] Franz Vrabec. Eine astronomische Kunstuhr von Pater Aurelius a San Daniele (die auch für Sonnenuhrfreunde von Interesse ist). *Rundschreiben*, 14:2–4, 1997. [Arbeitsgruppe Sonnenuhren. Gnomonicæ Societas Austriaca (GSA). Österreichischer Astronomischer Verein].