Chapter 5 **(Oechslin: 6.2)**

Frater David's Schwarzenberg clock (1793)

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.

5.1 Introduction

The clock described here was commissioned by Joseph I Adam Prince of Schwarzenberg and is sometimes called the "Schwarzenberg clock." It was designed by David Ruetschmann (1726-1796), who went by the name Frater David a Sancto Cajetano.[1] The clock is probably located in the Schwarzenberg Palais in Vienna.

The clock was probably completed in 1793 by Frater David's nephew Joseph Ruetschmann (1755-1801) in Vienna.[2] For the mechanism of this clock, Joseph Ruetschmann was paid 2000 gulden in 1793 and the sculptor Adam Vogl 700 gulden.[3] In the past, there has been some confusion about the identity of this clock, when the 1769 clock was no longer in Vienna, or when it was at the Zwettl abbey.[4]

[1]For biographical information on Frater David, see the description of the 1769 clock in the previous chapter.

[2]The clock is illustrated in a number of articles and books, for instance [10] and more recently in the collective "*Himmlisches Räderwerk*" [31]. See also the 1989 exhibition catalogue [41, p. 67, pl. 24] where it is dated from 1786. It was also described by Oechslin in 1991, but I haven't seen his article [34]. About the authorship of the clock, see Oechslin [35, p. 218]. The same Joseph Ruetschmann has also built a clock with a small orrery on top of it [14, p. 127-128]. This orrery shows the planets up to Uranus and was made very compact. It uses a number of interior gearings [18]. Some accounts have listed Joseph Ruetschmann as Frater David's brother [5, p. 24].

[3]See [33], [6], [13], [5] and [35, p. 223].

[4]For instance, in 1896, Mörath [33] corrected Ilg [19] who thought that the Schwarzenberg clock was the same one as the 1769 clock.

The Schwarzenberg clock is the first clock by Frater David where he puts in practice his theory of epicyclic gears and achieves the precise ratios he aims at. This theory was then published in 1791 and 1793 [7, 8, 9]. Frater David wanted in particular to avoid using wheels with more than 100 teeth.

As observed by Oechslin, Frater David may have been influenced by Neßtfell's planetarium in Vienna, which he restored around 1785, and this may have brought him to develop his theory of epicyclic gears.[5] This connection was not put forward by Bertele when he wrote about this clock, and Bertele still viewed the origin of epicyclic gears in Frater David's clock as a mystery we would never be able to elucidate.[6]

The clock is a tall-case clock with ten dials. A description of the indications of the clock was given by Bertele.[7] The largest dial is the one for the time, but it also shows the motion of the Sun, the Moon, and the zodiac. This dial is set in a square whose corners contain four small dials showing the seconds, the day of the week, the synodic month, and the power reserve.

Above these dials, there is a sphere showing the phase of the Moon, and two dials, one left for the italic hours, and one right for the draconic month. On top of these dials, another dial shows the months on a four-year cycle. The day of the month is also shown on a circular arc.

5.2 The going work

The clock is spring-driven and regulated by a pendulum. However, Oechslin did not give the details of the going work train, and we only know that the arbor 5 is the central arbor of the main dial and that it makes a turn clockwise in one hour. We therefore have

$$\mathrm{V}_5^0 = -24 \tag{5.1}$$

$$\mathrm{P}_5^0 = -\frac{1}{24} = -1\ \mathrm{h} \tag{5.2}$$

5.3 The main dial

The main dial shows the time, but also the motion of the Sun, the Moon, the zodiac, the lunar nodes and the lunar apsides. The central arbor is the one making a turn in one hour, but in fact this arbor is connected by friction to a tube which is also named 5 by Oechslin. This tube therefore also makes a turn in one hour. It is the one carrying the minutes hand.

[5] [35, p. 227]
[6] [5, p. 24]
[7] [5, p. 25]

(Copyrighted image not shown)

Figure 5.1: The dials of the Schwarzenberg clock. (source: [10])

(Copyrighted image not shown)

Figure 5.2: A clock by Joseph Ruetschmann with almost the same dials as the Schwarzenberg clock, auctioned by Leonard Joel, 14 May 2017.

The second tube is tube 9 and it carries the hours hand. We have

$$V_9^0 = V_5^0 \times \left(-\frac{20}{40}\right) \times \left(-\frac{8}{48}\right) = V_5^0 \times \frac{1}{12} = -2 \quad (5.3)$$

$$P_9^0 = -\frac{1}{2} = -12 \text{ h} \quad (5.4)$$

The other motions (Sun, Moon, lines of nodes and apsides) are obtained using epicyclic (satellite) wheels, such that an input motion on a fixed arbor causes the motion of a satellite wheel, whose arbor moves around the initial fixed arbor, as a result of a constraint introduced by a fixed wheel. These constructions are much more elaborate than those used in Frater David's 1769 clock, and obviously the result of his research on gear ratios.

The reason for using these constructions is that the ratios that Frater David wanted to obtain cannot be obtained exactly with fixed arbors and teeth-counts smaller than 100. The sought ratios were

- for the Sun: $\frac{164359}{450}$ and 164359 contains the prime factor 269;
- for the Moon: $\frac{295073}{10800}$ and 295073 is prime;
- for the lunar apsides: $\frac{145951}{45}$ and 145951 contains the factors 103 and 109
- for the lunar nodes: $\frac{9789403}{1440}$ and 9789403 contains the prime factor 753031.

The use of epicyclic constructions makes it possible to use gears with smaller teeth-counts, smaller primes, and still obtain the same final ratios. Frater David also needed tables of primes, and he apparently used the unpublished work of Florian Ulbrich [37]. Of course, in most cases, constructors will use slightly different ratios, so that the gears can be cut. There is in fact little point trying to get some exact target ratio, first because these ratios are always approximations and will be improved over time, and second because astronomical clocks never work for ever without being stopped or restored, and therefore also reset.

Interestingly, the ratio $\frac{164359}{450}$ was also used by Jean-Baptiste Schwilgué in the Strasbourg astronomical clock [40], but Schwilgué resorted to 269-teeth and 270-teeth wheels, something he could have avoided, had he known about Frater David's work.

Frater David was however not the first one to use such constructions. In the 1750s, Neßtfell used the same constructions in his two planetary machines (Oechslin 3.1 and 3.2). Frater David may have taken his idea from Neßtfell's machine in Vienna, which he restored around 1785.[8] However, there is an important difference. Neßtfell's constructions were used because in his machines the planets are set on moving carriages. He didn't use them for the purpose of obtaining exact ratios, although one can be tempted to think so at first

[8] [35, p. 227-228]

sight. Frater David was probably the first one to use these constructions for the purpose of obtaining specific ratios with trains involving only small primes.

I will not go into the details of the theory of the epicyclic constructions here, and I refer the reader to the introduction of this book and to Frater David's writings [7, 8, 9] and those of Graham White [42, 43, 44]. See also Lunardi on this clock [30, p. 431-434].

5.3.1 The motion of the Sun

As a first application of the epicyclic layout of the gears, we can consider the motion of the Sun. The satellite wheels are located on frame 48, so that we first compute the motion with respect to this frame. There are two motions of special interest here, namely the input motion of arbor 42 (which is derived from tube 5), and the output motion of tube 47. The latter is in fact a fixed tube, and frame 48 rotates around it, but with respect to frame 48, tube 47 also rotates. And what we are interested in is how much frame 48 rotates with respect to tube 47 as a function of how much arbor 42 rotates with respect to the fixed frame. We therefore first seek the ratio between V_{47}^{48} and V_{42}^{48}:

$$\mathrm{V}_{47}^{48} = \mathrm{V}_{42}^{48} \times \left(-\frac{21}{21}\right) \times \left(-\frac{21}{71}\right) \times \left(-\frac{14}{74}\right) \times \left(-\frac{14}{75}\right) \times \left(-\frac{8}{80}\right) \quad (5.5)$$

$$= \mathrm{V}_{42}^{48} \times \left(-\frac{343}{328375}\right) = \left(\mathrm{V}_{42}^{47} + \mathrm{V}_{47}^{48}\right) \times \left(-\frac{343}{328375}\right) \quad (5.6)$$

Then, we have:

$$\mathrm{V}_{47}^{48} \times \left(1 + \frac{343}{328375}\right) = \mathrm{V}_{42}^{47} \times \left(-\frac{343}{328375}\right) \quad (5.7)$$

$$\mathrm{V}_{47}^{48} \times \frac{328718}{328375} = \mathrm{V}_{42}^{47} \times \left(-\frac{343}{328375}\right) \quad (5.8)$$

$$\mathrm{V}_{47}^{48} = \mathrm{V}_{42}^{47} \times \left(-\frac{343}{328718}\right) \quad (5.9)$$

$$\mathrm{V}_{48}^{47} = \mathrm{V}_{48}^{0} = \mathrm{V}_{42}^{0} \times \frac{343}{328718} \quad (5.10)$$

Now, before going on, we need to compute the motion of arbor 42:

$$\mathrm{V}_{42}^{0} = \mathrm{V}_{5}^{0} \times \left(-\frac{20}{49}\right) \times \left(-\frac{15}{56}\right) \times \left(-\frac{42}{42}\right) = \mathrm{V}_{5}^{0} \times \left(-\frac{75}{686}\right) \quad (5.11)$$

$$= (-24) \times \left(-\frac{75}{686}\right) = \frac{900}{343} \quad (5.12)$$

Combining the two, we obtain

$$\mathrm{V}_{48}^{0} = \frac{900}{343} \times \frac{343}{328718} = \frac{450}{164359} \quad (5.13)$$

Now, the frame 48 carries a 94-teeth wheel meshing with another 94-teeth wheel on tube 49 carrying the solar hand. We have

$$V_{49}^{0} = V_{48}^{0} \times \left(-\frac{94}{94}\right) = -V_{48}^{0} = -\frac{450}{164359} \tag{5.14}$$

$$P_{49}^{0} = -\frac{164359}{450} = -365.2422\ldots \text{ days} \tag{5.15}$$

The same value is given by Oechslin. This is an excellent approximation of the tropical year, the same which was used in the Vienna clock constructed in 1769.

Since the above construction is used several times, we can also generalize it somewhat. There is an input motion x on arbor 42, a ratio y in the rotating frame, and a final ratio z to obtain. In the above case, we have

$$x = \frac{900}{343} \tag{5.16}$$

$$y = -\frac{343}{328375} \tag{5.17}$$

$$z = \frac{450}{164359} \tag{5.18}$$

The relationship between these three ratios is

$$z = x \times \frac{y}{y-1} \tag{5.19}$$

Now, in the special case where $x = a/b$ and $y = -b/c$, this reduces to

$$z = \frac{a}{b+c} = \frac{900}{343 + 328375} \tag{5.20}$$

How Frater David obtained these trains is explained in the introduction of this book. He took the tropical year to be 31556928 seconds, and introduced an input motion of 32928 seconds (P_{42}^{0} above), and thus came up with smaller primes.

5.3.2 The motion of the line of apsides

The motion of the line of apsides is obtained like that of the Sun. There is a rotating frame 38 with a number of gears and whose input is the motion of arbor 34. So, we first compute the motion of arbor 34. We have

$$V_{34}^{0} = V_{9}^{0} \times \left(-\frac{24}{51}\right) \times \left(-\frac{12}{52}\right) \times \left(-\frac{10}{64}\right) \times \left(-\frac{64}{24}\right) \times \left(-\frac{24}{64}\right) \tag{5.21}$$

$$= V_{9}^{0} \times \left(-\frac{15}{884}\right) = (-2) \times \left(-\frac{15}{884}\right) = \frac{15}{442} \tag{5.22}$$

This will be our x above.

Then,

$$\mathrm{V}_{37}^{38} = \mathrm{V}_{34}^{38} \times \left(-\frac{21}{50}\right) \times \left(-\frac{17}{70}\right) \times \left(-\frac{8}{89}\right) = \mathrm{V}_{34}^{38} \times \left(-\frac{102}{11125}\right) \tag{5.23}$$

The ratio $-\frac{102}{11125}$ is y.

We can now immediately compute the value of z:

$$\mathrm{V}_{38}^{0} = x \times \frac{y}{y-1} \tag{5.24}$$

$$= \frac{15}{442} \times \frac{-\frac{102}{11125}}{-\frac{102}{11125} - 1} = \frac{15}{442} \times \frac{102}{11227} = \frac{45}{145951} \tag{5.25}$$

A 90-teeth wheel on frame 38 meshes with an identical wheel on tube 39 carrying the hand of the lunar apsides. We therefore have

$$\mathrm{V}_{39}^{0} = \mathrm{V}_{38}^{0} \times \left(-\frac{90}{90}\right) = -\mathrm{V}_{38}^{0} = -\frac{45}{145951} \tag{5.26}$$

$$\mathrm{P}_{39}^{0} = -\frac{145951}{45} = -3243.3555\ldots \text{ days} \tag{5.27}$$

The same value is given by Oechslin.

5.3.3 The mean motion of the Moon

The mean motion of the Moon is obtained like those of the Sun and the line of apsides. There is a rotating frame 27 with a number of gears and whose input is the motion of arbor 21. We first compute the motions of arbor 20 (which is used later) and of arbor 21. We have

$$\mathrm{V}_{20}^{0} = \mathrm{V}_{5}^{0} \times \left(-\frac{20}{42}\right) \times \left(-\frac{30}{42}\right) = \mathrm{V}_{5}^{0} \times \frac{50}{147} \tag{5.28}$$

$$= (-24) \times \frac{50}{147} = -\frac{400}{49} \tag{5.29}$$

$$\mathrm{V}_{21}^{0} = \mathrm{V}_{20}^{0} \times \left(-\frac{42}{42}\right) = \frac{400}{49} \tag{5.30}$$

Likewise, within the frame 27, we have

$$\mathrm{V}_{26}^{27} = \mathrm{V}_{21}^{27} \times \left(-\frac{21}{21}\right) \times \left(-\frac{21}{40}\right) \times \left(-\frac{9}{47}\right) \times \left(-\frac{14}{50}\right) \times \left(-\frac{8}{50}\right) \tag{5.31}$$

$$= \mathrm{V}_{21}^{27} \times \left(-\frac{1323}{293750}\right) \tag{5.32}$$

Hence

$$\mathrm{V}_{27}^{0} = \frac{400}{49} \times \frac{-\frac{1323}{293750}}{-\frac{1323}{293750} - 1} = \frac{400}{49} \times \frac{1323}{295073} = \frac{10800}{295073} \tag{5.33}$$

A 88-teeth wheel on frame 27 meshes with an identical wheel on tube 28. We therefore have

$$V_{28}^{0} = V_{27}^{0} \times \left(-\frac{88}{88}\right) = -V_{27}^{0} = -\frac{10800}{295073} \tag{5.34}$$

$$P_{28}^{0} = -\frac{295073}{10800} = -27.3215\ldots \text{ days} \tag{5.35}$$

The same value is given by Oechslin. This is an approximation of the tropical month. This motion is then modified (see below) to obtain the corrected Moon.

We can also compute the synodic month:

$$V_{28}^{49} = V_{28}^{0} - V_{49}^{0} = -\frac{10800}{295073} + \frac{450}{164359} = -\frac{1642294350}{48497903207} \tag{5.36}$$

$$P_{28}^{49} = -\frac{48497903207}{1642294350} = -29.5305\ldots \text{ days} \tag{5.37}$$

5.3.4 The line of the nodes (dragon)

The motion of the nodes is obtained like those of the Sun, the line of apsides and the Moon. There is a rotating frame 18 with a number of gears and whose input is the motion of tube 12. So, we first compute the motion of arbor 12. We have

$$V_{12}^{0} = V_{9}^{0} \times \left(-\frac{24}{54}\right) \times \left(-\frac{10}{33}\right) \times \left(-\frac{12}{66}\right) = V_{9}^{0} \times \left(-\frac{80}{3267}\right) \tag{5.38}$$

$$= (-2) \times \left(-\frac{80}{3267}\right) = \frac{160}{3267} \tag{5.39}$$

Likewise, within the frame 18, we have

$$V_{17}^{18} = V_{12}^{18} \times \left(-\frac{27}{50}\right) \times \left(-\frac{11}{11}\right) \times \left(-\frac{11}{50}\right) \times \left(-\frac{11}{50}\right) \times \left(-\frac{11}{64}\right) \tag{5.40}$$

$$= V_{12}^{18} \times \left(-\frac{35937}{8000000}\right) \tag{5.41}$$

Hence

$$V_{18}^{0} = \frac{160}{3267} \times \frac{-\frac{35937}{8000000}}{-\frac{35937}{8000000} - 1} = \frac{160}{3267} \times \frac{35937}{8035937} = \frac{1760}{8035937} \tag{5.42}$$

$$P_{18}^{0} = \frac{8035937}{1760} = 4565.8732\ldots \text{ days} \tag{5.43}$$

This value is wrong, but Oechslin found the same one. However, Oechslin suggested that one of the ratios 11/50 should be replaced by 9/61.[9] In that

[9]See [35, p. 205] on this error.

case, we obtain

$$V(h)_{17}^{18} = V_{12}^{18} \times \left(-\frac{27}{50}\right) \times \left(-\frac{11}{11}\right) \times \left(-\frac{11}{50}\right) \times \left(-\frac{9}{61}\right) \times \left(-\frac{11}{64}\right) \quad (5.44)$$

$$= V_{12}^{18} \times \left(-\frac{29403}{9760000}\right) \quad (5.45)$$

Hence

$$V(h)_{18}^{0} = \frac{160}{3267} \times \frac{-\frac{29403}{9760000}}{-\frac{29403}{9760000} - 1} = \frac{160}{3267} \times \frac{29403}{9789403} = \frac{1440}{9789403} \quad (5.46)$$

$$P(h)_{18}^{0} = \frac{9789403}{1440} = 6798.1965\ldots \text{ days} \quad (5.47)$$

The same value is given by Oechslin.

The sign of the velocity is positive, because there is a retrogradation of the nodes (which is here a counterclockwise motion, since the signs of the zodiac are given clockwise).

5.3.5 The corrected motion of the Moon

The frame 39, which has the motion of the line of apsides, also carries an eccentric cam which is used to correct the motion of the Moon. The mean Moon corresponds to frame 28, and the corrected Moon to frame 29. The period of this correction is that of the motion of frame 28 with respect to frame 39, that is the draconic month:

$$V_{28}^{39} = V_{28}^{0} - V_{39}^{0} = -\frac{10800}{295073} + \frac{45}{145951} = -\frac{1562992515}{43066199423} \quad (5.48)$$

$$P_{28}^{39} = -\frac{43066199423}{1562992515} = -27.5536\ldots \text{ days} \quad (5.49)$$

5.4 The other dials

5.4.1 The italic hours

The medium-sized dial at the left of the Moon sphere gives the mean time as well as the italic hours. These hours are counted from the last sunset, and the difference between the two is about six hours on average. The dial has an outside fixed ring of twice 12 hours (in Arabic numerals), and an inner moving ring of also twice 12 hours (in Roman numerals). The inner ring oscillates and its motion is obtained like on Frater David's 1769 clock (Oechslin 6.1). The ring has a back-and-forth motion controlled by a cam. This cam makes a turn in one year and is located on arbor 51. The motion of this cam is derived from that of frame 48 which also makes a turn in a year:

$$V_{51}^{0} = V_{48}^{0} \times \left(-\frac{94}{26}\right) \times \left(-\frac{26}{94}\right) = V_{48}^{0} \quad (5.50)$$

The cam on arbor 51 moves a rack meshing with a toothed circular segment on the italic hours ring 52. Since I do not have the dimensions of the cam and the lever, I will not go further into this description, but the shape of the cam could be recomputed and the motion of the ring could be obtained from the dimensions of the various parts. However, like in 1769 clock, this also raises the question of whether the actual cam takes the equation of time into account.

The italic hours are also shown on Pater Aurelius' clock in Munich (Oechslin 5.1).

5.4.2 The phase of the Moon

The phase of the Moon, the synodic month and the draconic months are derived from the motion of arbor 54, which is itself derived from the motion of arbor 20. We therefore first compute the motion of arbor 54:

$$V^0_{54} = V^0_{20} \times \left(-\frac{14}{32}\right) \times \left(-\frac{14}{50}\right) = V^0_{20} \times \frac{49}{400} = -\frac{400}{49} \times \frac{49}{400} = -1 \quad (5.51)$$

This arbor makes one turn clockwise per day.

Now, this motion is used to derive the motion of arbor 58:

$$V^0_{58} = V^0_{54} \times \left(-\frac{12}{31}\right) \times \left(-\frac{16}{31}\right) \times \left(-\frac{10}{59}\right) \times \left(-\frac{59}{59}\right) \quad (5.52)$$

$$= V^0_{54} \times \frac{1920}{56699} = -\frac{1920}{56699} \quad (5.53)$$

$$P^0_{58} = -\frac{56699}{1920} = -29.5307\ldots \text{ days} \quad (5.54)$$

The same value is given by Oechslin. This is also an approximation of the synodic month, but not the same that was used above.

The motion of arbor 58 is transferred to the vertical arbor 59 through two 25-teeth wheels and this arbor carries the lunar sphere which is located in the center and above the main dial. The sphere rotates clockwise as seen from above (from the right on the drawing).

5.4.3 The synodic month

This dial is located in the upper left corner of the main dial and shows the number of days since the last new moon. Its period is therefore the synodic month. The hand is on arbor 63. Its motion is derived from that of arbor 58. We have

$$V^0_{63} = V^0_{58} \times \left(-\frac{59}{59}\right) \times \left(-\frac{59}{30}\right) \times \left(-\frac{30}{59}\right) \times \left(-\frac{59}{59}\right) = V^0_{58} \quad (5.55)$$

5.4.4 The draconic month

This dial is located in the upper right corner of the main dial. The hand is on arbor 68 and makes a turn in a draconic month. Its motion is also derived from the motion of arbor 54. We have

$$\mathrm{V}^0_{68} = \mathrm{V}^0_{54} \times \left(-\frac{12}{41}\right) \times \left(-\frac{25}{32}\right) \times \left(-\frac{9}{28}\right) \times \frac{28}{22} \times \left(-\frac{22}{56}\right) \tag{5.56}$$

$$= \mathrm{V}^0_{54} \times \frac{675}{18368} = -\frac{675}{18368} \tag{5.57}$$

$$\mathrm{P}^0_{68} = -\frac{18368}{675} = -27.2118\ldots \text{ days} \tag{5.58}$$

The same value is given by Oechslin.

5.4.5 The day of the week

This dial is located in the lower left corner of the main dial. The hand for the day of the week is on arbor 72 and its motion is derived from arbor 54 seen above. We first obtain the motions of arbor 70 and 71:

$$\mathrm{V}^0_{70} = \mathrm{V}^0_{54} \times \left(-\frac{50}{50}\right) \times \frac{50}{25} = \mathrm{V}^0_{54} \times (-2) = 2 \tag{5.59}$$

$$\mathrm{V}^0_{71} = \mathrm{V}^0_{70} \times \left(-\frac{20}{40}\right) = 2 \times \left(-\frac{1}{2}\right) = -1 \tag{5.60}$$

The arbor 71 makes on turn in a day and carries a finger which moves a wheel on arbor 72 by a 7th at each turn. The hand on arbor 72 therefore makes a turn clockwise in seven days.

5.4.6 The calendar dial

The calendar dial derives its motion from arbor 73 which makes a turn in 24 hours:

$$\mathrm{V}^0_{73} = \mathrm{V}^0_{70} \times \left(-\frac{25}{50}\right) = 2 \times \left(-\frac{1}{2}\right) = -1 \tag{5.61}$$

This arbor is used to move the arbor 75 also in one day. The latter carries a finger which moves the day of the month on arbor 76 by one unit every day. The length of the month is taken into account on the basis of a 4-year cycle. I am not detailing this here, as I do not have sufficient information to do so. But when the day returns to 1, a 48-teeth wheel on arbor 77 advances by one tooth, and the motion of this arbor is transferred using two 60-teeth wheels to the tube 78 which carries the hand of the month. This hand therefore makes a turn in 48 months, that is four years.

5.5 References

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