Chapter 23

(Oechslin: 2.4)

Klein's Copernican clock in Prague (1752)

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.

23.1 Introduction

The clock described here was constructed in 1752 by Jan Klein (1684-1762) [1, p. 15].[1] This clock displays the Copernican system and belongs to a group of three similar clocks kept in the Clementinum in Prague.

This clock was first described in detail by Böhm in 1863 [1, 2]. It was again described by Oechslin in 1996, but Oechslin did not have the opportunity to disassemble the clock and based his description only on that published by Böhm.[2]

It is a table clock with two sides. One side of the clock shows the time on 12-hour and 24-hour dials. It also shows the sunrise, sunset, the Italic hours and the duration of day and night.

The other side shows the Copernican system, with the Sun at the center, and the planets Mercury, Venus, the Earth, Mars, Jupiter and Saturn revolving around it. Moreover, the Moon rotates around the Earth.

The clock is spring-driven (with two springs) and regulated by a pendulum, but the going work is not detailed by Oechslin. It is possibly that Oechslin only used Böhm's work, and did not have the opportunity to disassemble the clock.

I will describe each side of the clock separately.

[1]For biographical information on Klein, see the chapter on the geographic clock in Dresden.

[2]This clock was shown at the 1989 Hahn exhibition [19, p. 65]. See also Oechslin [9, p. 32-33, 49-50] and Michal [8].

Figure 23.1: Left: Portrait of Jan Klein with his geographic clock from 1753/1754. (source: [1]) Right: portrait in Pelcl's biographical notice [12].

23.2 Copernican system side

This side of the clock shows the Copernican system, with all the planets revolving around the Sun at the center, and the Moon revolving around the Earth. The various gears of this system are driven by the motion of arbor 1 which makes one turn clockwise in one day. All the motions are here expressed from the Copernican side.

$$\mathrm{V}_1^0 = -1 \tag{23.1}$$
$$\mathrm{P}_1^0 = -1 \tag{23.2}$$

This motion is first used to obtain that of the intermediate arbor 3:

$$\mathrm{V}_3^0 = \mathrm{V}_1^0 \times \frac{1}{5} \times \frac{1}{73} = \mathrm{V}_1^0 \times \frac{1}{365} = -\frac{1}{365} \tag{23.3}$$
$$\mathrm{P}_3^0 = -365 \text{ days} \tag{23.4}$$

Arbor 16 which is used in the other side of the clock gets the same motion:

$$\mathrm{V}_{16}^0 = \mathrm{V}_3^0 \times \left(-\frac{60}{60}\right) = -\mathrm{V}_3^0 \tag{23.5}$$

The arbor 3 thus makes a turn in 365 days.

23.2.1 The motion of the planets around the Sun

23.2.1.1 The motion of the Earth

The motion of arbor 3 is used to obtain the motion of the Earth on frame 9:

$$\mathrm{V}_9^0 = \mathrm{V}_3^0 \times \left(-\frac{60}{60}\right) = -\mathrm{V}_3^0 = \frac{1}{365} \tag{23.6}$$
$$\mathrm{P}_9^0 = 365 \text{ days} \tag{23.7}$$

The Earth/Moon system moves counterclockwise and makes a turn in 365 days. The same value is given by Oechslin. This is an approximation of the tropical year, but a very bad one, as the actual value is about 365.2422 days. Consequently, the Earth will quickly drift from its mean position.

The tube of frame 9 also carries a ring with the representation of stars, which does therefore also make a turn in one year [1, p. 20].

23.2.1.2 The motion of Mercury

The motion of arbor 3 is also used to obtain the motion of Mercury on tube 4:

$$\mathrm{V}_4^0 = \mathrm{V}_3^0 \times \left(-\frac{83}{20}\right) = \frac{1}{365} \times \frac{83}{20} = \frac{83}{7300} \tag{23.8}$$
$$\mathrm{P}_4^0 = \frac{7300}{83} = 87.9518\ldots \text{ days} \tag{23.9}$$

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

Figure 23.2: The Copernican system on Klein's clock. (source: [1])

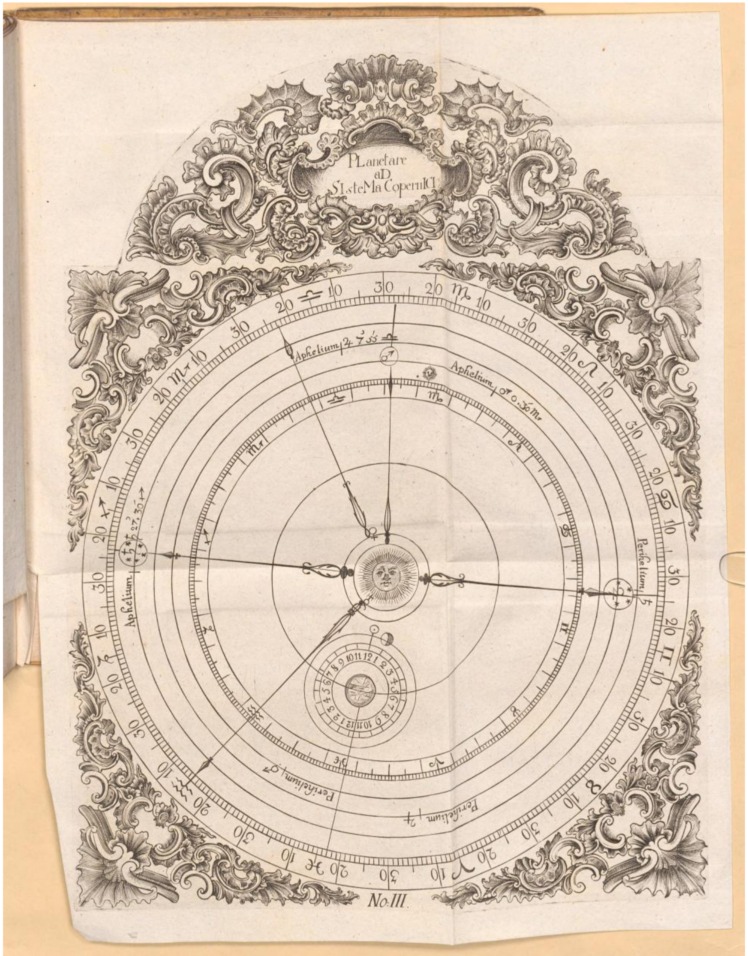


Figure 23.3: The Copernican system on Klein's clock. (source: [17])

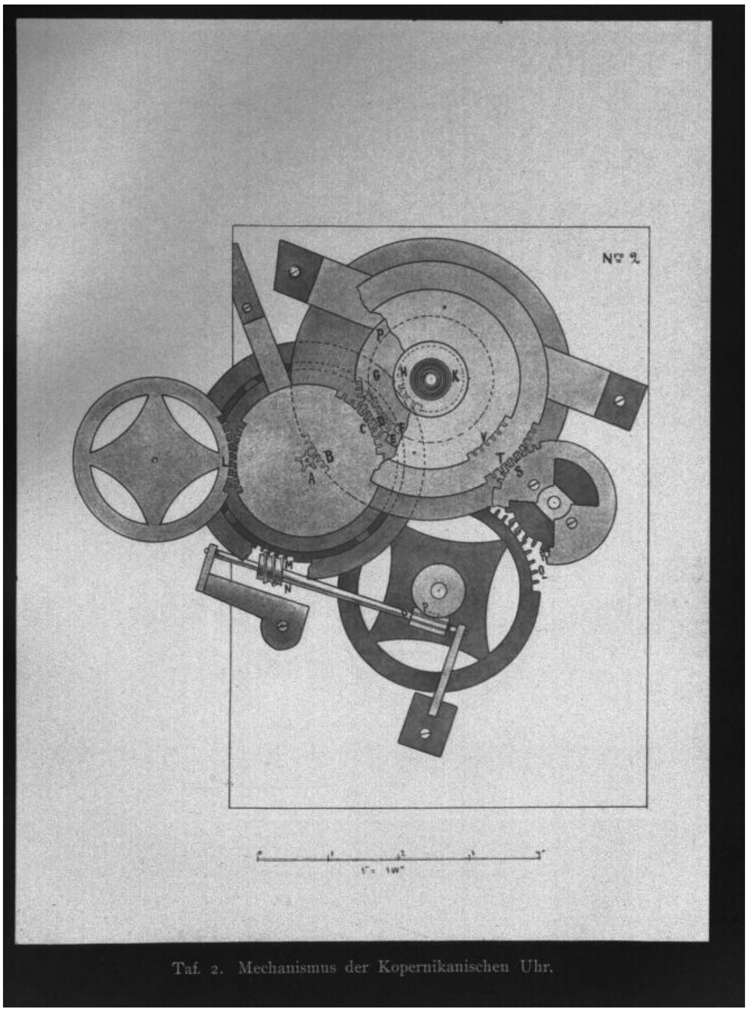


Figure 23.4: The gears of the Copernican system on Klein's clock. (source: [1])

23.2.1.3 The motion of Venus

The motion of arbor 3 is also used to obtain the motion of Venus on tube 5:

$$V_5^0 = V_3^0 \times \left(-\frac{92}{57}\right) = \frac{1}{365} \times \frac{92}{57} = \frac{92}{20805} \tag{23.10}$$

$$P_5^0 = \frac{20805}{92} = 226.1413\ldots \text{ days} \tag{23.11}$$

This is an approximation of the orbital period of Venus and the same value is given by Oechslin. Note that Oechslin's drawing mistakenly gives 52 teeth to the 57-teeth wheel of the train.

23.2.1.4 The motion of Mars

The motion of arbor 3 is also used to obtain the motion of Mars on tube 6:

$$V_6^0 = V_3^0 \times \left(-\frac{51}{96}\right) = \frac{1}{365} \times \frac{51}{96} = \frac{17}{11680} \tag{23.12}$$

$$P_6^0 = \frac{11680}{17} = 687.0588\ldots \text{ days} \tag{23.13}$$

This is an approximation of the orbital period of Mars and the same value is given by Oechslin.

23.2.1.5 The motion of Jupiter

The motion of arbor 3 is also used to obtain the motion of Jupiter on tube 7:

$$V_7^0 = V_3^0 \times \left(-\frac{12}{142}\right) = \frac{1}{365} \times \frac{12}{142} = \frac{6}{25915} \tag{23.14}$$

$$P_7^0 = \frac{25915}{6} = 4319.1666\ldots \text{ days} \tag{23.15}$$

This is an approximation of the orbital period of Jupiter and the same value is given by Oechslin.

23.2.1.6 The motion of Saturn

The motion of arbor 3 is also used to obtain the motion of Saturn on tube 8:

$$V_8^0 = V_3^0 \times \left(-\frac{5}{146}\right) = \frac{1}{365} \times \frac{5}{146} = \frac{1}{10658} \tag{23.16}$$

$$P_8^0 = 10658 \text{ days} \tag{23.17}$$

This is an approximation of the orbital period of Saturn and the same value is given by Oechslin.

23.2.2 The motions within the Earth-Moon system

At the position of the Earth, there is a planisphere on arbor 12, and the Moon on tube 15.

23.2.2.1 The rotation of the Earth

We can compute the motion of the Earth planisphere (arbor 12) with respect to frame 9 (direction of the Sun). This motion is based on the motion of frame 11, which replicates the motion of the central arbor 1:

$$\mathrm{V}_{11}^{0} = \mathrm{V}_{1}^{0} \times \left(-\frac{72}{36}\right) \times \left(-\frac{40}{80}\right) = \mathrm{V}_{1}^{0} \tag{23.18}$$

and then

$$\mathrm{V}_{12}^{9} = \mathrm{V}_{11}^{9} \times \left(-\frac{68}{68}\right) = -\mathrm{V}_{11}^{9} = \mathrm{V}_{9}^{11} = \mathrm{V}_{9}^{0} - \mathrm{V}_{11}^{0} = 1 + \mathrm{V}_{9}^{0} \tag{23.19}$$

However, the velocity of the Earth with respect to the Sun should be 1, and we should have a period of one day, which is not the case.

Oechslin doesn't obtain the same result and he finds $\mathrm{V}_{12}^{9} = 1$. His conclusion may be based on Böhm's analysis [1, p. 20] which is incorrect. Surprisingly, Böhm concludes that arbor 12 makes a turn in 24 hours, but this would only be true if the Earth were not rotating around the Sun.

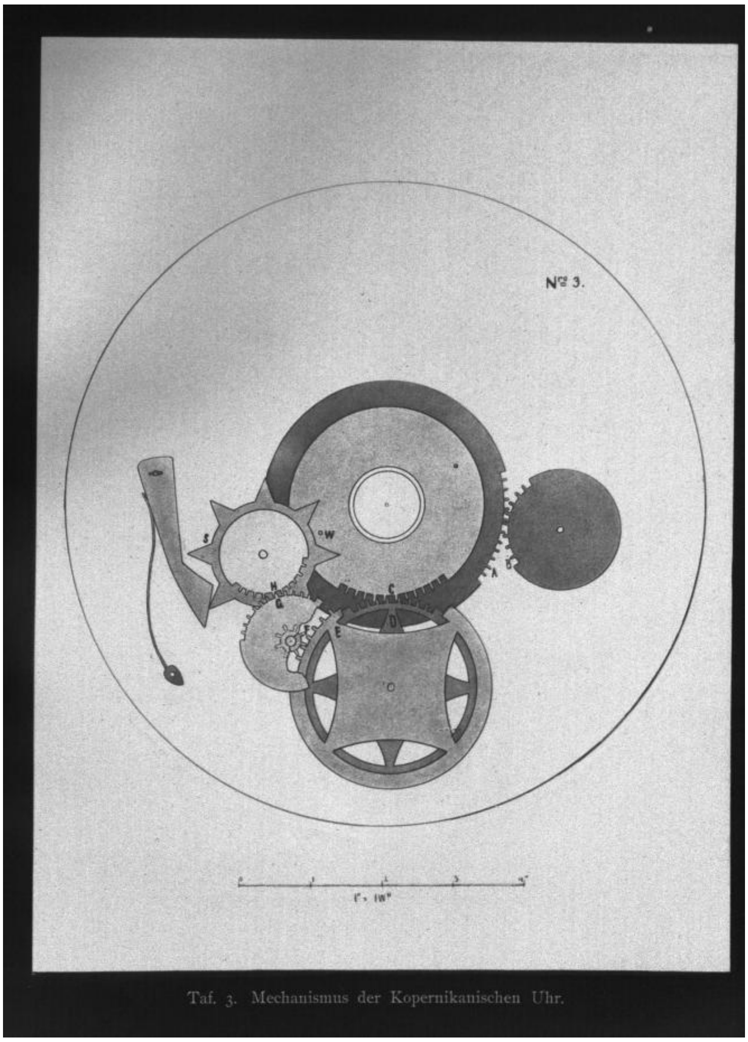
23.2.2.2 The revolution of the Moon

The motion of the Moon (tube 15) is obtained using 2 pins on frame 11, and these pins move a 8-pointed starl whose arbor 13 is located on frame 9 (Oechslin doesn't show the construction clearly, but it is more explicit in Böhm's drawing, see figure 23.5). Another wheel on this arbor meshes with a wheel on arbor 14 which also seems to be located on frame 9. We thus have

$$\mathrm{V}_{15}^{9} = \mathrm{V}_{11}^{9} \times \left(-\frac{2}{8}\right) \times \left(-\frac{36}{36}\right) \times \left(-\frac{8}{59}\right) = \mathrm{V}_{11}^{9} \times \left(-\frac{2}{59}\right) \tag{23.20}$$

If $\mathrm{V}_{11}^{9} = -1$, then we would obtain a period of 29.5 days and the Moon would move couterclockwise on frame 9, which is what it should.

However, as we have seen above, we do not have $\mathrm{V}_{11}^{9} = -1$ and the synodic month is slightly different and worse than the value 29.5.



Taf. 3. Mechanismus der Kopernikanischen Uhr.

Figure 23.5: Detail of the motion of the Moon in Klein's clock. (source: [1])

23.3 Time side

This side of the clock shows the time on 12-hour and 24-hour dials. It also shows the sunrise, sunset, the Italic hours and the duration of day and night.

The central arbor 18 of the dial carries the hand of the minutes and makes a turn clockwise in one hour. Seen from the front of the side, we have

$$\mathrm{V}^0_{18} = -24 \tag{23.21}$$

$$\mathrm{P}^0_{18} = -\frac{1}{24} = -1 \text{ h} \tag{23.22}$$

This arbor carries a 30-teeth wheel which meshes on the one hand with a similar wheel on arbor 19, and with a 60-teeth wheel on arbor 21. The former is used to derive the motion of the 12-hour hand (tube 20), the latter the motion of the 24-hour hand (tube 22):

$$\mathrm{V}^0_{20} = \mathrm{V}^0_{18} \times \left(-\frac{30}{30}\right) \times \left(-\frac{6}{72}\right) = \mathrm{V}^0_{18} \times \frac{1}{12} = -2 \tag{23.23}$$

$$\mathrm{P}^0_{20} = -\frac{1}{2} = -12 \text{ h} \tag{23.24}$$

$$\mathrm{V}^0_{22} = \mathrm{V}^0_{18} \times \left(-\frac{30}{60}\right) \times \left(-\frac{6}{72}\right) = \mathrm{V}^0_{18} \times \frac{1}{24} = -1 \tag{23.25}$$

$$\mathrm{P}^0_{22} = -1 \text{ day} \tag{23.26}$$

This side also obtains an input through arbor 16 which was seen earlier. This motion is transferred to that of arbor 17 (measured from this side):

$$\mathrm{V}^0_{17} = \mathrm{V}^0_{16} \times \frac{56}{56} = \mathrm{V}^0_{16} \tag{23.27}$$

The velocity of arbor 16 is measured from the Copernican side, and the velocity of arbor 17 from the time side, this explains why the sign is not changed.

Arbor 17 makes a turn in 365 days, this is an approximation of the tropical year, but not a very good one.

Arbor 17 carries a cam which is used to modify the Italic hour, the sunrise, the sunset, and the durations of day and night. This cam moves a moving 24-hour dial with four sector openings. This moving dial carries the 24 hours in Arabic numerals and is used for the Italic hours. The left and right openings are meant for the sunrise and sunset, an index on the moving dial being used to read the value which is on the fixed back (see figure 23.7). The moving 24-hour dial can also be used to read the times of sunrise and sunset, as these times correspond to the 12 and 24-hour marks of the moving dial.

The upper and lower openings are for the durations of the day and night. The values 12 are at the top and bottom, and when the moving dial moves, its index will show longer or shorter days and nights. Of course, these durations could also be deduced from the times of sunrise and sunset.

Figure 23.6: The time side of Klein's clock. (source: [1])

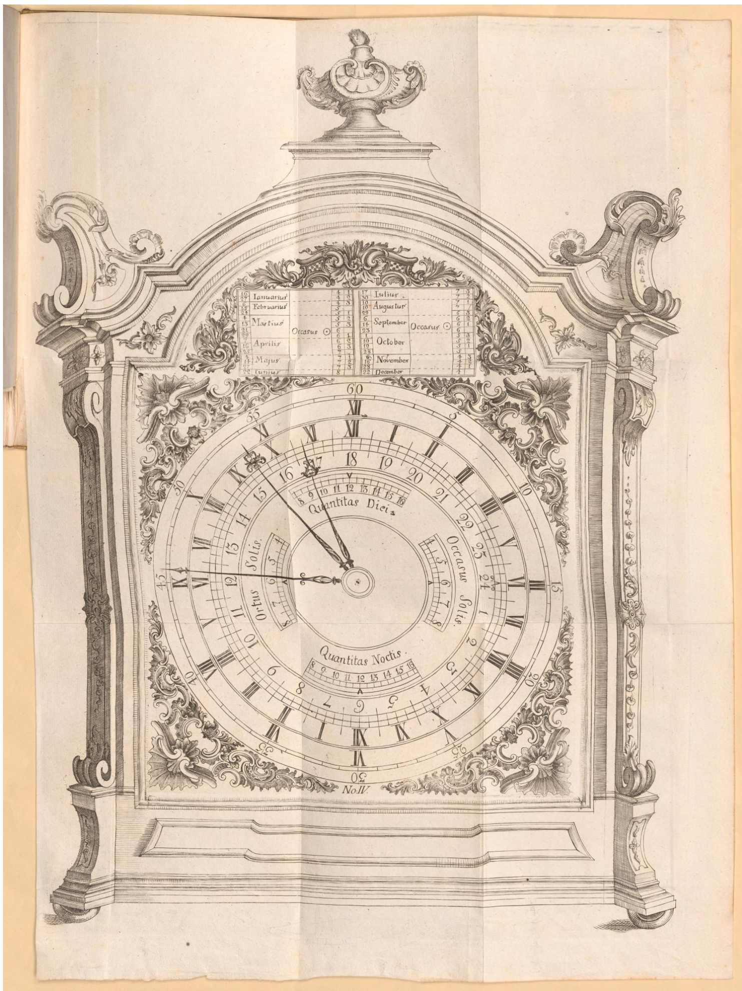


Figure 23.7: The time side on Klein's clock. (source: [17])

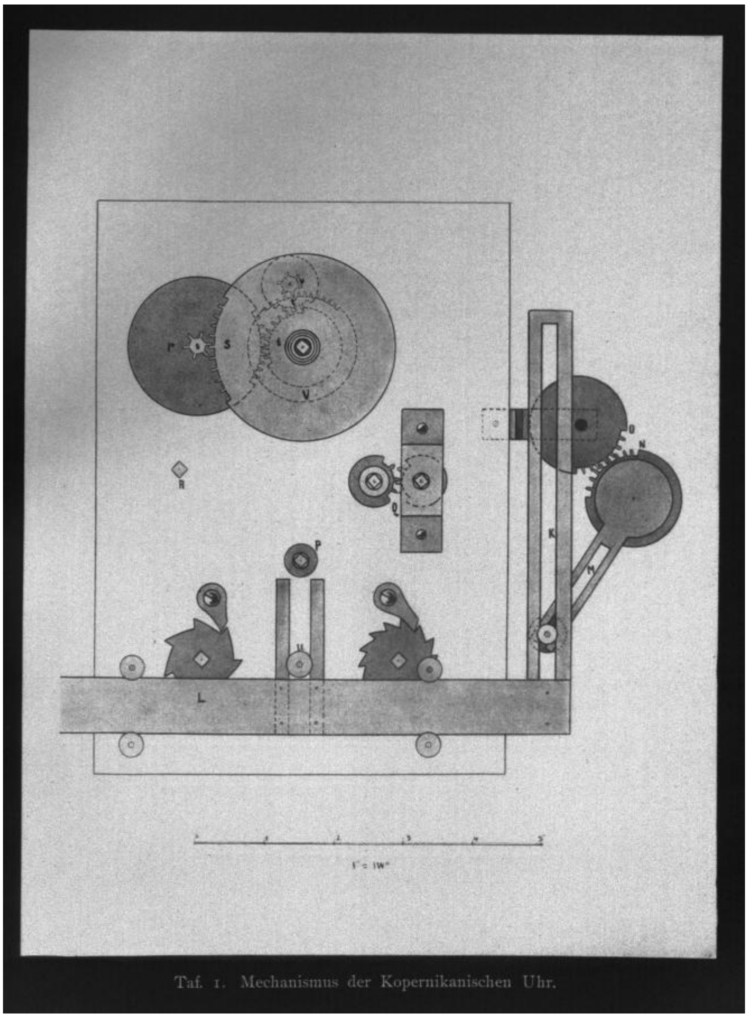


Figure 23.8: The gears of the time side of Klein's clock. (source: [1])

23.4 Conclusion

The study of Klein's clock has been rather disappointing, with surprisingly bad values for the periods of the different motions, including those of the planets and the Earth around the Sun.

23.5 References

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