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THE GDANSK PIONEERS IN METROLOGY

ANDRZEJ JANUSZAJTIS

Technical University of Gdansk,
Faculty of Technical Physics and Applied Mathematics,
Narutowicza 11/12, 80-952 Gdansk, Poland

Abstract: The paper deals with units and systems of measure used in old Gdansk and some particular achievements of its masters in the measuring technique. Special attention is paid to the unification work by M. Hanow (1747), the analytical balance of H. Kühn (1743), Fahrenheit's thermometers, and the astronomical clock dating from the year 1470 at St. Mary's Church.

Keywords: history of science, metrology

1. Introduction

Among the numerous works more or less significant related to the development of science and technology in old Gdansk, and particularly to the Gdansk scientists and their achievements there is a lack of more detailed discussion concerning the units of measure and the measuring instruments applied by them. As it occurs in every subject connected with the history of this unusual town, also in this sphere, sources are found in a great abundance. First of all, they are available in the local National Archives, or in the Municipal Library of Gdansk, functioning since 1596 (now a branch office of the Polish Academy of Sciences). There have even survived authentic metrological documents, although the war has seriously diminished their collection.

The paper deals only with some of the most interesting problems.

2. Peculiarities of the Gdansk measures

The oldest metrological relic found by archaeologists in the area of the old town of Gdansk is a pair of folding pan scales dating from the eleventh century [1]. The weights were in form of flat iron balls covered in brass sheet, which weighed 20 g. A similar weight from the years 1205-1255 weighs 24.68 g. The unit, that was currently used in Gdansk in those days, known as grzywna (mark) weighed 200 g, and was heavier than the Polish one grzywna being equal to 158.8 g [2]. If at that time that unit had already been divided into 16 lot (half-ounces), the smallest weight would have denoted 1 3/5 lot, while a larger one, two lot.

About the year 1227 [3] Gdansk was granted the first municipal rights. The acquisition of the rights was accompanied by spatial location, the lay out of streets and delimitation of the building lots. The remains of houses found under the Town Hall of the centre of Gdansk indicate that a unit measure used in the partition of the building lots was the so-called location rod reaching about 4.5 m [4] in length. Today it is hard to say whether the unit was effective in regional use, or brought by settlers coming in large numbers to Gdansk from the West.

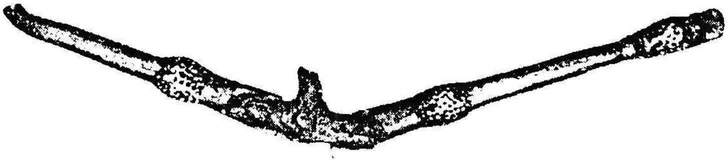

Figure 1. *The Gdansk pan scales of the eleventh century.*

At the beginning of the Teutonic Knights' rule the units of measure in use were multiple, Polish, German and Flemish, and this was inconvenient and likely to cause confusion. This state of events [5] was settled in 1335 or 1336 by an assembly of estates in Elblag (Elbing): "Following the nearest day of St. Martin (Nov. 10) in all our lands, uniform and equal measures and weights shall invariably and inviolably be obeyed... However, with respect to the quality of weight, let it be known that thirty-three pounds, generally known as mark pounds, and 17 scot of silver weight shall make one stone, while 12 stones — one talent, known as shippound, while 12 talents — one last...". To explain let us add that one pound was divided into two marks consisting of 24 scots. The Kulm mark was an essential unit of measure weighing 189.9 g, a little lighter than the Cracow grzywna (197.7 g) applied in Poland. The Kulm rod (4.35 m) was a linear measure the measurement standard of which is still hanging on the Town Hall of Chelmno (Kulm). The above unit of length was divided into 15 feet, and 1 ft. was 12 inches.

Although under the Teutonic Knights' rule the uniform Kulm units of measure were to be used, but in practice there were differences in the use, particularly in large towns. For instance, let us quote an excerpt taken from a document from 1428 [6]: "... of weights: four quarts make one scot, whilst two wiarduneks (vierdungs) make a quarter of a pound, whilst half a kromfunt (trade pound) is equal to one lotige mark. However, 16 kromfunts, that is, mark pounds, make one lyzfunt (Livonian pound). However, 24 mark pounds make one Torun (Thorn) stone, whilst 34 mark pounds make one Gdansk (Danzig) stone. However, 120 kromfunts make one centner (hundredweight). However, three centners make one shippound. However, 12 shippounds make one last. However, one barrel of butter (reading unclear) weighs 8 Gdansk stones, or 11 Torun stones, and 8 kromfunts, or 16 lyżfunts, or 128 kromfunts, or two centners one Toruń stone 48f (wiardunks). However, one Krolewiec (Königsberg) stone and one Braniewo (Braunsberg) stone are equal to 40f. However, one Elblag (Elbing) stone is 36f."

3. Calculations by Krüger

The return of Prussia to Poland as a result of the thirteen-year war did not eliminate the differences in measures. Some modifications were only made in the monetary system. As time passed the accuracy of the measurement standards became more reliable. The Gdansk system of measures and weights has been known to us with so many details owing to the work by the pioneers of metrology who lived in that town. One of them was a professor of the Academic Gymnasium, Piotr Krüger (1580-1636) a mathematician, an astronomer, a land-surveyor, and a poet, the author of a well-known arithmetic textbook, Rechenbüchlein, the first edition of which appeared in 1631 [7]. In the introduction to the book we find a description and comparison of various units used in it. Here are some examples [8]: "when it comes to weight, one last of flax, or hemp weighs 60 stones. One last of hop weighs 12 shippounds. There are 32 lots, or 48 scots in one pound. Four quarts, (or quintels) are equal to one lot at four pfennigs by weight". The calculations are followed by a table.

Ein Newes
Rechenbüchlein
Auff der Feder/
In ordentliche Capitel vnd ge-
wiſſe Regeln verfaſſet/ auch mit gnug-
ſamen dieſer Lande bräuchlichen Exempeln
erkläret vnd an Tag gegeben
Von
M. Petro Krüger/ Königl.
Stadt Dantzig Mathe-
matico.
Mit Königl. Privilegio.
16 31.
Dantzigk/
Gedruckt durch Andream Hüne-
feldt Buchhändler.

Figure 2. The front page of the textbook by P. Krüger (in the Gdansk Library PAS).

Big weight	Gdansk	Królewiec (Königsberg)
1 shippound	1 Livonian pound	1 shippound
1 quintel	1 stone of the big weight	1 stone of the small weight
20 Livonian pounds	16 mark pounds	320 pounds
120 pounds	34 pounds	24 pounds
20 Livonian pounds, i.e. 10 stones	20 mark pounds	400 pounds
128 pounds	40 pounds	25 pounds

The table is supplemented with information about conversion of units: "141 Gdansk pounds = 160 Königsberg pounds, 1 Cracow grzywna = 1 Prussian mark + Prussian scot".

Knowing that 1 Cracow grzywna was 197.7 g it is possible to find the mass of 1 Prussian grzywna being equal to 189.8 g. As can be seen it was, as a matter of fact, the Kulm grzywna.

There are some exercises taken from the book by Krüger: "Somebody buys in Vilnius 4 rings of wax weighing 33 stones and 28 pounds, 12 stones 22 pounds, 4 pounds subtracted from 15 stones, 14 pounds from 17 stones, one stone bought at 6 Polish zlotys.

The buyer dispatches the commodity to Gdansk. The freight and other costs are 56 zl. How much is a Gdansk stone of weight? A stone in Vilnius is equal to 36 pounds. Forty Vilnius stones make 37 3/4 Gdansk stones. The answer is 7fl 11gr 481/1881 pfennigs".

At that time 1 zl was 30 gr at 18 pfennigs. He who does not believe, let him count.

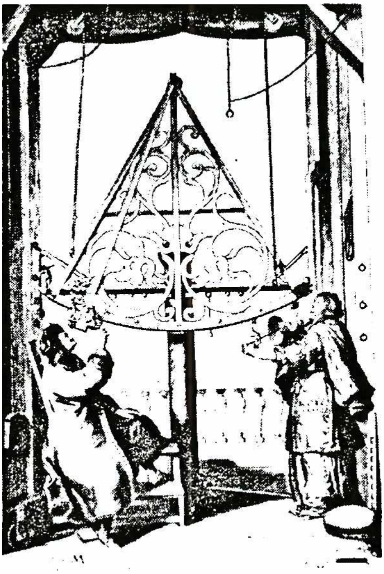

Figure 3*. Hevelius in course of carrying out his measurements.*

The greatest Gdansk astronomer, Johan Hevelius (1611-1687) [9] was also engaged in determining the values of the Gdansk measures and weights. In his estimation the ratio of the Gdansk foot to the Paris one was 914:1055, while the Gdansk foot to the Rhenish one 914:1000. Knowing that the Paris foot can be divided by 1000 scruples (1/10 of a line), Hevelius expressed the Gdansk foot as 1247 345/633 of a scruple. As a matter of fact, we know that the Paris foot measured 32.484 cm and 1 scruple was 0.02256 cm. Multiplying this by the above fractions, we shall have 28. 14 cm for Gdansk foot, while the Rhenish foot 28. 70 cm. These values are a little too small. The Paris foot measurement standard used by Hevelius due to its short length must have been inaccurate.

4. Hanow's measurement standards

The Gdansk units of measure were most accurately defined by Michael Hanow (1695-1779) [11].

In 1747 M. Hanow published his paper "Comparison of the Gdansk measures and weights with the Paris and London units of measurement" [11] in "Experiments and Treatises" of the Natural Society of Gdansk, where he was an active member. He noticed and corrected Hevelius's mistake defining the Gdansk foot length as 1271 1/2 part of the Paris scruple, that is, 28.68 cm. A similar calculation using an English foot (30.48 cm) gives the value of 28.70 cm. Making use of the above statements it was possible to determine the mean value, 28.69 cm. The measuring procedure was simple: "there was applied quite a new standard of the Royal foot made in Paris, which was acknowledged by the Royal Scientific Society as consistent with the measurement standard of the ell situated in Gdansk Town Hall. The ell (two feet) together with the standards of the foot and fathom (6 ft) hung till 1945 at the entrance to the Town Hall. Today it is possible to find some traces of a small semicircular roof that had been protecting the lost measurements standards. It is intended to reproduce the standards which in fact were of the same value as the Chelmno rod.

Figure 4. Portrait of M. Hanow.

Hanow described and also determined other measurement units. Owing to him we now know in detail, for instance, all the systems of weights, that is units of mass applied in trade and pharmacy in Gdansk in those days. One "commercial" pound corresponded to 434.4 g, while pharmaceutical one (12 ounces) was equal to 358.2 g. There were various measures used in retail and wholesale trade, and some cubic measures depended on the sort of goods measured. Special regulations defined also the way of striking off dry goods. To those people who were selling and buying, the measurement unit was equivalent with a material measure, a bar, a weight, or a measuring vessel. Today's approach is more abstract.

Figure 5. *Measurement standard at the entrance to the Gdansk Town Hall (pre-war photography in the author's collection).*

5. Kühn's scales

In the same first volume of "The Treatises" of the Gdansk Natural Society of the year 1747 including the work by Hanow, one can find an article by an Academic Gymnasium professor, Heinrich Kühn (1690-1769) [12] an eminent mathematician, member of the Petersburg Academy of Sciences, "A detailed description of a new, more improved type of balance of which it is possible to weigh quite precisely not only equal weights, but also different ones, and divide any weight in any proportion into smaller units" [13]. It was an extremely interesting prototype of an analytical balance supplied with so-called friction wheels.

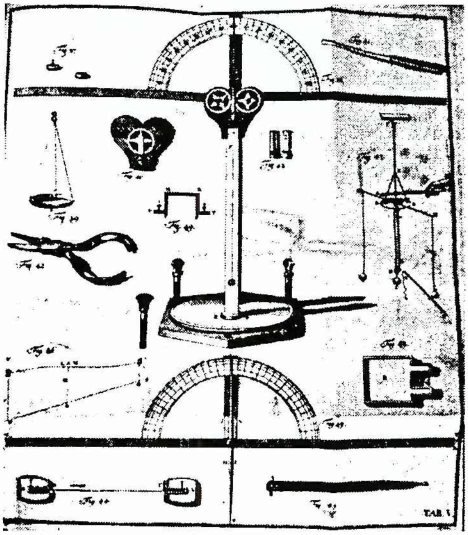

Figure 6. *A pair of scales by Kühn.*

Daniel Gralath

Figure 7. Portrait of D. Gralath.

The balance was made according to Kühn's instruction in 1743 by Drunckmüller, a wandering mechanic. The author of the treatise preceded his description of the balance with definitions of mass, the centre of gravity, and weighing. In the treatise we read "We shall demonstrate a better balance than the ordinary one, which (1) soon regains its equilibrium, and in which (2) neither the weight of beam, and the pointer (indicator), nor the scales with their accessories make the calculation of the weights difficult, which at a given deflection remain in equilibrium with each other, (3) the friction in the axis is significantly small, and by which (4) it is possible to determine easily by a given swing of the pointer the real relationship of the unequal weights which balance each other".

In 1747 using this unusual balance the founder of the Natural Society, Daniel Gralath (1708-1867), the future mayor of Gdansk, and the founder of the great avenue linking Gdansk with Wrzeszcz [14] measured, forty years before Coulomb!, the forces interacting between charged electrodes depending on distance. In this way Kühn's scales have become the first electrostatic balance in the world.

6. Fahrenheit's thermometers

Among the Gdansk masters of the measuring technique under review, it would be unfair not to include in it, Daniel Gabriel Fahrenheit (1686-1736) [15]. From an early age fated to leave the country at the expense of commercial career and family life, he devoted himself entirely to science. His greatest success was the construction of reliable and sensitive thermometers of comparable indications. It was an astonishment in those days that two different Fahrenheit's thermometers immersed in one vessel showed the same themperature! In the notes of his lectures that he gave in Amsterdam in 1718 we can find the following definitions of a good thermometer [16]:

"1. It must together with all others at any time and place indicate the same degree of cold, or heat, i.e. thermometers may not differ from one another.

2. It must react to changes occurring within certain limits of statements observed in nature.

3. Its changes must be noted as soon as possible, i. e. it must react to the slightest change occurring in the air and indicate it very quickly.

4. The fluid with which the thermometer is filled, must be open to the air.

5. The fluid must be dyed such a colour that does not change.„

By the expression "limits of statements observed in nature" Fahrenheit meant some constant limits applied by him, namely:

„1. The coldest possible temperature in the surrounding atmosphere can be obtained when certain quantities of water, ice, and salt are mixed (...).

2. The melting and freezing limits that are obtained by mixing water and ice (...).

3. The limit of blood of living creatures, which after all (...) is not reliable.

4. The limit of boiling water (...).„

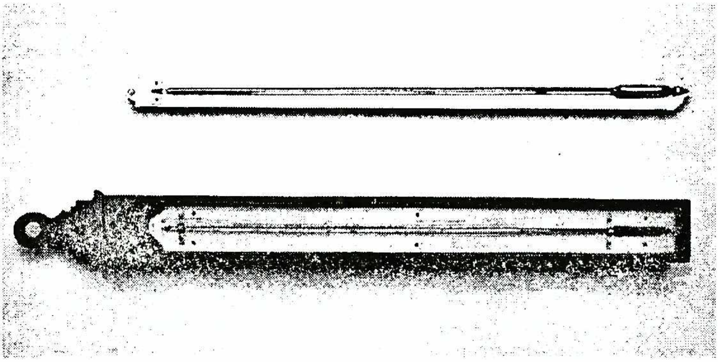

Figure 8. Fahrenheit's thermometers (The Boerhaave Museum in Leiden).

An increase of the response rate was possible by making use of a cylindrical bulb: "This sort of thermometer was invented for the first time by Fahrenheit and it was him who on the 25th of March (1718) explained to us clearly the difference between them in the following way: He took two identically operating thermometers. One of them was provided with a spherical bulb, and the other one with a cylindrical bulb. He put both of them at the same height near the flame of a candle (...): it was evident that the one with the cylindrical bulb reacted much faster than the one with the ball, due to the fact that the thermometer bulb (being exactly the same size as the ball) and for this reason was activated faster by the air. And because of its smaller diameter, it was easy to penetrate it."

It is worth explaining that Fahrenheit's thermometers measuring identically, which enchanted Christian Wolf in Leipzig, were provided with small vessels of 3.7, and 4.2 cm in length, and 0.66 and 0.5 cm in diameter, respectively. The scale length was the same — 17.4 cm. Some later thermometers made by Fahrenheit which are exhibited at the Leiden Museum are much longer.

7. Fahrenheit's scale

In 1724 [17] Fahrenheit informed us himself about scaling his thermometers, in the five treaties qualifying him for a fellowship of the Royal Society in London:

"The scale of thermometers used entirely for meteorological observations begins at the bottom from zero and runs up to 96 degrees. The marking on this scale is based on three constant points which can be reproduced artificially; the first of them situated at the extreme end, or at the starting-point of the scale, which is obtained by mixing ice water and ammonium chloride, or also sea salt. When the thermometer is immersed in such a mixture, the fluid falls as low as the point denoted as zero (...). The second point is obtained „when water and ice are mixed without salts with a thermometer in it. The fluid will then reach degree 32, called by me the beginning of freezing (...). The third point is situated at 96 degrees, namely spirit expands up to the point when thermometer is placed in the mouth, or the armpit of a healthy man as long as it reaches the exact temperature of human body (...).

The scale of thermometers, by means of which the boiling points of a fluid are measured, starts from zero and has 600 degrees, because at this degrees the mercury with which the thermometer is filled, starts boiling."

In the year 1717 Fahrenheit begin to use his scale. Before that time he applied Olaf Römer's scale modified by him in 1713. Fahrenheit co-operated with Römer while he was in Copenhagen in 1708. By determining the boiling point of water he discovered the connection between the boiling point and air pressure: "... water does not always boil at the same degree of heat, as Mr Amontons and many others, not excluding me, always used to think. But it boils at the higher degree of heat in heavier atmosphere and at lower degree in lighter atmosphere (...). On the other hand the degree at which water boils, is constant for every particular atmospheric weight [18]. "This dependence has become the reason for the construction of an original thermo-barometer enabling to carry out the measurement of the atmospheric pressure, and the heights of mountains and depths of mines. However, the dependence made it difficult to calibrate the thermometers. An additional problem was caused by the thermal expansion of glass used for their manufacture. In consequence the boiling point determined by Fahrenheit oscillated between 205 and 213 degrees. It was not till 1777 that the Henry Cavendish commission set up by the Royal Society declared the boiling point to be 212 degrees at the pressure of 29. 8 inches, i. e. 756 mm of mercury column (simultaneously retaining 32 degrees as the freezing point). Later, when the pressure of 760 mm Hg was accepted as the measurement standard, an appropriate correction was made [19].

Fahrenheit is also known as the designer of the first mercury thermometers (starting in 1713), and small clinical thermometers (before 1733), which he sold at the price of two ducats apiece [20].

8. Measurement of Time

Let us now proceed to the measurement of time. The first mechanical clock in Gdansk was at St. Mary's Church — it was a mechanism striking hours. The clock bell of 1. 33 m diameter and 1400 kg mass had hung in the central roof turret [21] before the church was destroyed in 1945. Indirect premises indicate that it was made by 1389 at the latest.

Its flattened shape testifies that from the onset it was a clock bell. The clock was maintained by the town. Some mechanical clocks had appeared in other parts of Poland before the Gdansk clock, e. g. in Malbork (presumably in 1330), in Wroclaw (1367), in Brzeg and Owidnica (1370), in Szczecin and Kamien Pomorski (1380), in Elblag (1383), in Chelmno (1385), in Torun (1386), in Cracow (1387), in Miechow and Kolobrzeg (1388). In 1637 the bell was connected to a mechanism called, the Dam clock (on the side of the Dam street) with a dial of 5. 12 m diameter, which is the largest in Poland. The second clock was installed by the Teutonic Knights in the Gdansk castle in 1401. The third one functioned on the Town Hall since 1418. The dials currently in use date from 1560. It is worthy to mention that the dials had already been divided into 12 hours, before the clock at the Town Hall in Wroclaw (1580) considered to be the oldest half clock in our country.

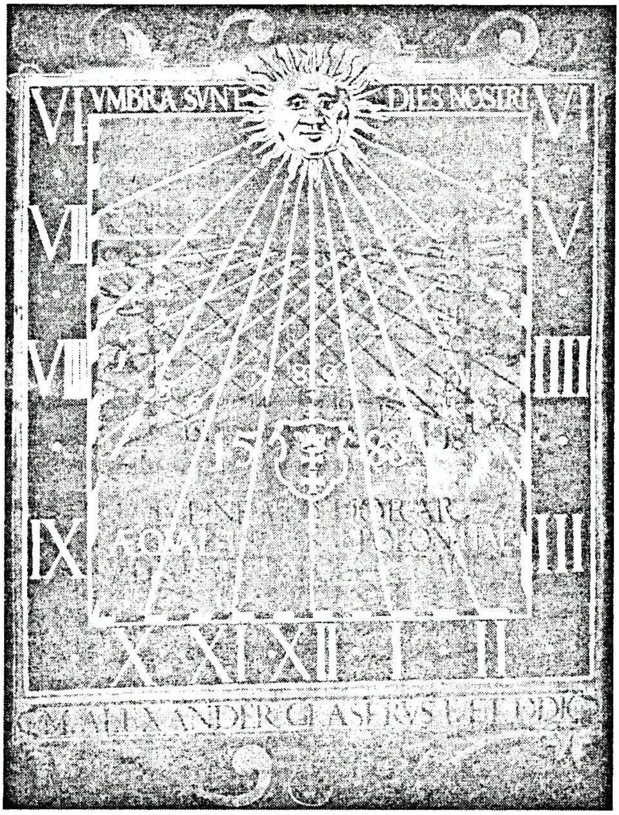

Figure 9. Project of a sundial by Alexander Glaser (kept in the National Archives in Gdansk).

Various hour systems can be best noted on the sundial, situated on the corner of the Town Hall. The sundial was founded in 1588 by St. Barbara's minister, Alexander Glaser [22]. On the coloured project of the dial kept by the archives office of Gdansk it is possible to find lines of hours defined as equal, unequal, Polish and Italian.

Unequal hours are a relic of the mediaeval times when the day and the night were divided into 12 hours, from the sunrise to the sunset and from the sunset to the sunrise. The lengths of hours defined in this way depended on the season of the year. Polish hours were equal hours, counted from the sunrise. Italian hours were equal hours, counted from the sunset of the previous day. On the sundial completed, and repainted in 1647/48 according to the instruction by Wolfgang Günter, a clockmaker co-operating with Johan Hevelius, equal hours are denoted as astronomical hours, while unequal hours as the old ones, and Polish hours as Babylonian ones. The gnomon of the sundial is provided with a ball the shade of which shows the position of the sun in the zodiac. This unusual sundial proves a high level of knowledge of astronomy among the inhabitants of Gdansk in those days.

9. The astronomical clock

The famous astronomical clock, a wonderful chronological monument of Gdansk, was constructed by Hans Düringer [23] at St. Mary's Church in 1470. It was the largest clock in Europe in the Middle Ages. Its total height with its figures is 14 m. The lower storey is taken by calendar, the middle one by orrery, and the upper one by a theatre of figures. Two dials of the calendar are designated for reading the date, the day of the week, dates of new Moon (calculated accurately to the minute!), liturgical calendar, solar cycle, a golden number, Roman indict (the data were used in the Middle Ages for stressing datation), interval between Christmas and the last Sunday of carnival, etc.

Twenty-two circles of a large dial and nine circles of a small dial contain a total of 3584 data. The data refer to the years 1463-1538, but owing to a 532-year period of repetition in the Julian calendar (the so-called Platonian year) it is possible to apply them to the years 1995-2070, with a 13-day shift. The pointers and the dials in the orrery enable to read out the time on the 24-hour dial (twice twelve hours), phases of the moon, and positions of the Sun and the Moon with respect to the zodiac. In the orrery windows there appeared scenes of Annunciation and Homage of the Three Magis. In the hemispherical scenes of the theatre of figures there appear the twelve Apostles and four Evangelists. At the top of the clock Adam and Eva strike the hours and the quarters. The decorations are an evident allegory of human Transition.

10. The End

The paper is far from being complete. Certain curious facts have been omitted, among them, measurements of magnetic declination initiated in 1539 by Joachim Rheticus, and continued by Krüger and Hevelius, discoverer of its historic changes.

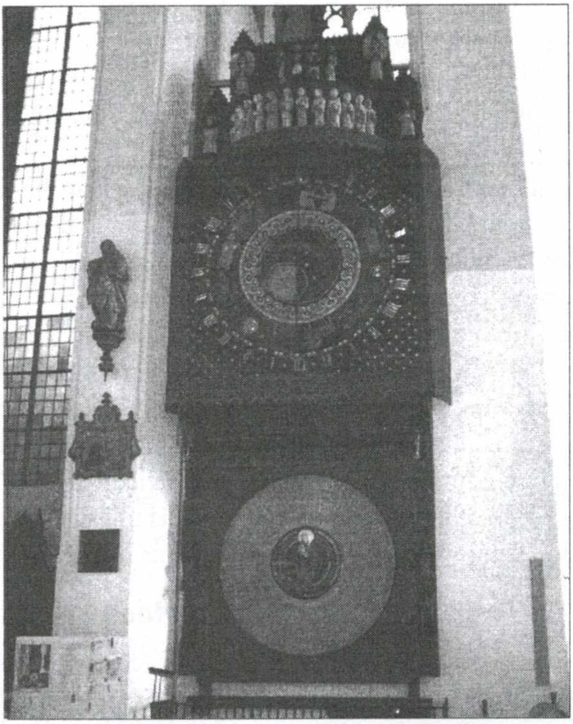

Figure 10. *The astronomical clock at St. Mary's Church.*

Hevelius was also the first one to use micrometer screw to increase the accuracy in setting a telescope. There has also been omitted a prototype of a marine chronometer operating by gravity, and constructed in 1716 by an anonymous watchmaker from Gdansk. Many, many other interesting facts have also been left out. The historical development of the Gdansk metrology is a fascinating sphere of investigation for a historian interested in science.

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Translation: Stanisław Lipecki