HISTORICAL SURVEYING INSTRUMENTS FROM BOHEMIAN REGION

Pavel HÁNEK, Antonín ŠVEJDA

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1. INTRODUCTION

On the occasion of the FIG Working Week Prague 2000, „Exhibition of Historical Surveying Instruments from Bohemian Region" is taking place in the National Technical Museum in the period of 15.5. - 15.7.2000 within the action Prague 2000 – European City of Culture.

The authors of this contribution, who are also the authors of the exhibition topic, informed the scientific public about the history of manufacturing of surveying instruments in the Czech lands at the XXI. FIG Congress in Brighton (Hánek, Švejda 1993). The exhibition is complemented with a production of photogrammetric instruments and tools. The focus of the exhibition is – in accordance with the economic and political development of the Czech state – the time of the rule of Emperor Rudolph II and the turn of the 19. and 20. centuries. Besides the National Technical Museum, an organiser of the exhibition, the exhibits were borrowed also from collections of the Technical Museum Brno, the Technical University Ostrava – the Faculty of Mining, the Departments of Geodesy of the Faculty of Civil Engineering, CTU Prague, and also from the private collections.

The part of preparation was a verification of surveying instruments quality in accordance with the international standard CSN ISO 8322 (1996), with a completion of parameters, which have already been nearly forgotten. The verification was an objective of some diploma works conducted at the Department of Special Geodesy and defended at the Faculty of Civil Engineering, CTU Prague. The short review is listed in the conclusion of this contribution.

2. HISTORY OF PRODUCERS

2.1. THE RUDOLPHINE AGE

One of the peaks of the science flourishing, the part of which was also a surveying instruments production on our territory, is the period of the reign of the art-loving Renaissance ruler Rudolph II. (1552 – 1612). In 1583, he moved his seat to Prague, which became a significant European metropolis, attracting specialists of all fields. At the imperial court, the notable scientist and doctor Tadeáš Hájek from Hájek, known also as an author of the first triangulation of the Prague's area, was working. Due to him the renowned astronomers Tycho de Brahe and Johannes Kepler, who also cooperated on the instruments construction, came to Prague. Around 1610, Kepler designed his type of the so-called astronomic telescope, which is widely used even in geodesy. Besides these scientists, some significant European mechanics were also working at the imperial court. Many of their masterpieces soon spread out or were lost in the Thirty Years' War (1618-1648). All the collection from the aforesaid period comes from the collection of the National Technical Museum (Švejda 1997).

The famous Jost Bürgi (lat. Iost Byrgi, 1552-1632), Swiss by origin, worked on the Dukes of Hessen court, which belonged to one of the prominent European scientific centres. Since 1602 his works had been protected by the imperial privilege, a certain precursor of the patent protection. In 1604, he became the Emperor's watchmaker. An instrument for perspective drawing, working on the basis of a theodolite, is dated with the year 1604, too. In 1609, Jost Bürgi made for the Duke of Hessen a precise triangulation instrument, based on the triangles similarity, which is today a pride of the collection of the Museum in Kassel. In 1610, J. Bürgi
assembled, according to J. Kepler, who himself used them, logarithmic tables. Even if he surpassed John Napier, he was hesitating with the publishing for ten years, so that John Napier had published it before him. The Bürgi's type of ratio compasses from the 17. century is also presented at the exhibition.

Another eminent creator was Erasmus Habermel (?-1606). He is an author of theodolites, the levelling instrument, and the triangulation and artillery surveying instruments, which are mostly in foreign collections. A part of the world-renowned collection of gnomonic instruments installed in the National Technical Museum in Prague (NTM) is the functional and by its artistic manufacturing, perfect equatorial sundial clock with altimeter. The exhibited collection of mathematical instruments (ratio compasses, mason's levels, compasses and drawing instruments), fabricated for the Emperor's physician Franciscus Paduanius from Forli, also comes from Habermel's workshop.

A decoration of the exhibition is the gilded brass theodolite with the azimuthal sundial clock and an extensive set of mathematical functions (e.g. goniometric functions, lengths of triangles sides) coming from the years 1608-1613. The author is Heinrich Stolle, a co-operator of aforesaid J. Bürgi.

The mentioned instruments were, for their purpose, certainly rather exceptional. Nevertheless, the surveying practice itself reached excellent results, which is an evidence of the high level of the commonly used instruments. The construction of the unique water tunnel (the so-called Rudolph's Tunnel), finished after eleven-year-work in 1593, is an excellent example. The straight tunnel, with a diameter of (0.7-1.5) x (3-4) m approximately, traverses mostly natural rock, 43 m under the surface at maximum. It is 1.1 km long with an elevation of the ends of only 1.12 m. The tunnelling was performed from both ends simultaneously, on the route there were 4 vertical shafts, sunk from the surface. (Note: the tunnel is running near the building of NTM). Outstanding engineers of that age gathered at the tunnel construction. Just before the tunnel finishing, a clerk of the court office Issac Phendler drew for the Emperor's information a front view map at a scale of 1:540 (Hánek 1994). A modern copy is presented at the exhibition.

2.2. PRODUCTION OF THE 18. CENTURY

The events of the Thirty Years' War brought on our territory, little by little, an economic collapse, an emigration of many intellectuals and an overall decline into the provinciality, which also affected fine mechanics. In the following years only small surveying, mapping and drawing tools or unique pieces, manufactured on commission, were produced in small workshops. This period is at the exhibition represented by the mining instrument, the so-called schinzeug, the all-circle astrolabe, or the telescopic drawing board (sketching pad), designed by Reitzenstein.

It is good to remind at this place that it was just an imperial engineer Joseph Christian Willenberg (1676-1731), at whose initiative and request from 1705, the Estates School of Engineering in Prague was established. This institution, which was a precursor of today's Faculty of Civil Engineering, was founded on the basis of the Foundation Charter, issued by Emperor Joseph I and written in Czech. Two-years teaching included arithmetic, geometry, practical geometry, the so-called geodesy, and military engineering. A distinguished professor of Prague's Engineering School, František Linhart Herget (1741-1800), was the leading surveyor and the examiner of united estate cadastre, founded in 1785 by Emperor Joseph II (1741-1790). He also issued certificates for the designed surveying instruments.

2.3. DEVELOPMENT IN THE 19.CENTURY TO THE HALF OF THE 20. CENTURY

In the 19.century, connected with the industrial revolution and the Czech National Revival, a recovery of surveying instruments and tools arouse. It corresponded to the increasing economic influence and development of Bohemia within the Habsburg monarchy. The first mechanical workshop was founded in 1808 by Josef Božek (1782-1835), who had been since 1805 a watchmaker and mechanic of the Prague Polytechnic Institute. A successor in his function and the workshop became his son František (1809-1886), and also his second son Romuald manufactured instruments. They both continued in the manufacturing of individual, often unique scientific instruments, including surveying instruments. Above the average, in comparison with other European production, works signed by the name Spitra excelled. Three generations of the family (František, Václav Michal and Otakar) were working in Prague since 1820 till the end of the century. Roughly since 1840, another outstanding master, Mathias Richard Brandeis (-ys; 1818-1868), was manufacturing surveying instruments. After his death, the firm Haase & Wilhelm overtook his workshop. At the exhibition these very producers are represented by the extensive collection of angular and levelling instruments, topographic sets diopters and a heliotrope.

In 1890, there were in Prague, the centre of production, twenty-four workshops producing surveying instruments, at the end of the century there were even four dozens. As for the quality, the company Strejc & Dušek was the best among producers of drawing sets. From the designers and producers outside Prague, the most remarkable one was Karl Gangloff (1809-1879), a head forester in Rožmitál under Tremšín. He was an author of many tools and aids for the so-called forestry geodesy, various types of dendrometers and planimeters in particular. In the first half of the 20. century, the company Eichler, whose production is at the exhibition represented by a universal theodolite, had its seat in Ústí upon Labe.

Many Czech specialists designed individual instruments – often for companies in Vienna. To name at least a few: the hypsometer designed by a distinguished professor at the Prague's Polytechnic, Karel František Edvard Knight Koristka (1825-1906), the instrument for graphic levelling by Professor František Müller (1835-1900) or the logarithmic tachymeter by an outstanding forester and railway surveyor Dipl. -Ing. Antonín Tichý (1843-1923).

Professor of Prague's Czech Polytechnic, František Müller and his successor, the professor and rector František Novotný (1864-1918), became authors of the first modern Czech textbook of geodesy (very quality four-parts unfinished Compendium of Higher and Lower Geodesy, Prague 1884-1923).

2.3.1. COMPANY J. & J. FRIC

In 1883, a turning point in the hitherto production of surveying instrument arouse, when brothers Josef (1861-1945) and Jan (1863-1897) Fric founded in Prague „the Shop for the Precise Mechanics". The area of interest and a creative invention of both brothers were very broad. Besides the designing and the production of manufacturing instruments for an equipment of their own shops, they also constructed a polarizer and an analyser, and also a bareoscope for the indication of the sugar juices density. They also designed machines for the division of circles of surveying instruments, for grinding of lenses, and many other constructions. Their participation at the General Land Exhibition in Prague in 1891 ended with a big success. After 1906 the enterprise J. & J. Fric produced a polarimeter for sugar content indication, which was accepted as the official standard in the USA.

The family led enterprise of the Fric Brothers was during its existence producing the whole assortment of surveying, mapping and cartographic instruments and tools, including the prestigious triangulation theodolite 6R with the screw micrometers and reading by estimation up to 2″, and special instruments for the measuring of the dam deformations and the tunnel constructions. The enterprise closed down after its nationalization at the beginning of 1950s', when it was within the national enterprise Metra switched to another production.

In 1884/1885, a small series of mine theodolites DUPLEX, in which for the first time in the world a divided ring of glass was utilized, was produced. The horizontal ring with 130 mm in diameter was made up from the 8 mm thick mirror glass. At the upper edge it was divided with diamond chisel by 1°, the numbering was engraved with the pantograph of Milanese type with 25x reduction. The engraving was filled with graphite powder. The ring was illuminated with a burner through a small window at the bottom of the ring cover. The angle minutes were read directly, by estimate 30″, by means of two opposite microscopes with 24x magnification, with the optical axis bent by a prism. The theodolite was universally usable for angular measurements (astronomic connections at the surface, and polygonization and steep measurements under the surface), but also for levelling. The Fric Brothers posed themselves 17 conditions for the construction of the repeating instrument with fine settings. Many of them are commonplace today (e.g. folding tripod, fixed and flexible fastening, nadir and zenith centering, reversible telescope with a visor illumination of a viewing field, covering of rings and other parts, and a possibility of the complete rectification of all mechanical axis relations). The Duplex had a height, including the setting level, of 28 cm and the width of 21 cm, which is roughly half of the usual sizes of that time. For easy targeting in vertical planes, two telescopes of variable lengths were chosen. The axis of the telescope for very steep measurements went through the concave turning axis of the top and insertion telescope with the reverse levelling tube and it was in the objective part (on the opposite side of the vertical metal ring with verniers) rectangular bent. A description of the construction was published in 1886 in the prestigious journal „Zeitschrift für Instrumentenkunde" (Fric J. & J. 1886).

At the exposition in Brussels in 1888, another remarkable novelty was presented, a hanging mining measuring compass of Kassel type with a vernier needle. Lateral oscillations of the knife needle were dumped with a friction mica disk so effectively that it might had been at the both ends equipped with verniers. The compass was divided into the traditional 24 hours, the smallest section of the ring had the value of 2^m, a section of the vernier 10^s, i.e. 2′ 30″ in the sexagesimal ring division into 360°.

On the basis of the brilliant idea of Prof. F. Nušl, the construction of astronomic-geodetic circumzenithal instrument for definition of geographic coordinates by the method of the same heights was solved out. The advantage compared to astrolabes was, among others, a vertical division of the picture and a placement of the mercury horizon in the centre of the instrument. In 1932, the impersonal micrometer, according to the design of Prof. E. Buchar, was constructed. In 1970s, the construction was further improved by the Research Institute for Geodesy, Topography and Cartography (VÚGTK in Czech, now located in Zdiby), which is producing the instrument under the name 1000/100. The same staff constructed other astronomic instruments – the so-called diazenithal and radiozenithal instruments.

It is obvious that all mentioned surveying instruments are presented at our exhibition.

2.3.2. ENTERPRISES SRB & ŠTYS AND MEOPTA

In 1919, shortly after the formation of independent Czechoslovakia, the optical-mechanical enterprise Srb & Štys was founded in Prague. The company was rapidly developing mainly thanks to military commissions. The new enterprise introduced the modern system of factory production and gained a number of excellent mechanics from the Fric Brothers Company. Since 1923, the whole range of surveying instruments and tools (rods, planimeters, clinometers, pantographs, sets of drawing instruments) was being produced.

The instruments for special purposes, e.g. for the water level measuring, were also produced. Among the most successful constructions we can name the nice triangulation theodolite with screw microscopes with reading precision by estimation of 1″; the school theodolite Th Š; the theodolite TN 25; and the technical levelling instrument NN 25. A two-pictures distance-measuring adapter was also very popular.

After 1945, on the foundation of the geodetic department of the Srb & Štys Company, the national enterprise Meopta Košíre, which adopted the manufacturing programme, was established. A lot of designers from the old firm started to work in the newly established enterprise, e.g. A. Holý, Höger, A. Dvorák, who during the short time caught up a delay, caused by the war and reached a solid European standard. In the catalogue from 1961, the modernized version of theodolite TH 30 with metal rings and readings by verniers of 30″, but also a construction of the theodolite Meopta T1^{c} from 1955 with glass rings and reading by simple optical micrometer enabling estimation of 2 mgon (2^{cc}). For the army it was equipped with a periscope. In the catalogue there was also a balloon (meteorological) theodolite, a topographic set, a base-measuring bar, a construction levelling instrument NK 30x with a glass minute ring, an older small (the so-called pocket) instrument KNK 8.8x, and the novelty MN 10x. There were also a plotting cartographic set and plates there and a very popular triple pentagon.

In 1961, the Czechoslovakian professional public was acquainted with the development of a quite new series of theodolites with very good function and design. (Type MT 0, magnification 15x, reading of 5^{c}, MT 10, 28x, 1^{c}, MT 11 with an automatic index of vertical ring, MT 20, 28x, 10^{cc}, and MT 30, 34X, 1^{cc}). The series was complemented with school and compass theodolites and of course with a complete line of accessories. None of these instruments was used in practice, because already in 1963 the production was suddenly abolishes and delimited within the Council of Mutual Economic Help; the enterprise with the new production programme was incorporated into the enterprise ZPA. The situation in the production of levelling instruments was slightly better. The new type MN 20 with a micrometer, designed for the accurate levelling, and the building type MN 10 were developed and their production launched. The last produced model was elegant MNK 20 for the technical levelling with an automatic adjustment of measuring line by means of a compensator.

2.4. PHOTOGRAMMETRIC AND OTHER PRODUCTION

The tradition of photogrammetry is on the Bohemian territory, which was a part of Austrian-Hungarian monarchy, very rich. After the formation of Czechoslovakia, succesful civil firms were established; the Czechoslovakian Military Geographic Institute continued in work launched by the Military Geographic Institute in Vienna. The enterprise Koula in Prague produced quality photogrammetric and photoreproductive instruments. On commission of the army in 1930-1935, the enterprise supplied semiautomatic and automatic aerial cameras, types A-I-25 and A-II-30, with the size of 13 x 18 cm, a blind shutter and a focus length up to 500 mm. Besides, there were small instruments for a quick pictures evaluation: a sketch master, a mirror stereoscope, and a drawing stereoscope. Another Prague's firm Haager supplied the army with a hand aerial camera, e.g. type A-VII-38. The other Prague's companies A. Löschner and V. Kolár also designed and produced photogrammetric instruments before the II. World War. The Mahr-Kolár rectifier with a bent optical axis leading to the considerable height reduction was excellently designed, but it stayed only at the prototype level. The Zbrojovka Brno Company produced in 1933 stereoautograph for a terrestrial pictures evaluation in dimension of 6 x 9 cm.

Prof. F. Svoboda designed and with his co-operators constructed the series of geodetic-astronomic instruments at the astronomic observatory of CTU Prague. The mirror instrument, the so-called almukantar for geographic latitude measuring from 1937, is the most known.

After the II. World War there were, besides the enterprise Meopta, other small manufacturers. The aforesaid Research Institute of Geodesy, Topography and Cartography constructed electronic hydrostatic levelling sets HYNI, controlled by computer, and produced one of the first prototype of luminous distance meters, supplied invar steel bands, and it has produced an adapted construction of the so-called cirkumzenithal till now. Ring tachymetric rules Cirta, polar coordinatographs and orthogonal plotting sets were also produced in the enterprise Meopta. Currently, reflecting prisms of distance meters and other small tools are being produced in the Czech republic.

3. VERIFICATION OF QUALITY AND PARAMETERS OF HISTORIC INSTRUMENTS

In years 1996-2000, six diploma theses dealing with a verification and completion of parameters of the Czech production instruments, mainly from the turn of the 19. and 20. centuries, as well as with a determination of their quality in accordance with the Czech International Standard (CSN ISO 8322/1996) were defended at the Department of Special Geodesy of the Faculty of Civil Engineering, CTU Prague. Even if such a verification of exhibits does not give a precise picture of their properties in the time of their practical usage, we presume that they can considerably contribute to the classification of collection or to the study and analysis of older engineering works yet.

The prerequisite of the verification, according to the CSN ISO Standard, is measuring with the tested instrument in two different days, always in one series. Regarding theodolites, a series consists of measurements of 4 horizontal directions, placed on the whole ring in 3 groups without a closure, or a measurement of 4 vertical angles measured on points with various elevations, respectively. The result are standard deviations s_f of a horizontal direction and vertical (or zenith) angle $s_?$, always for measurement in two positions. For theodolites equipped only with the segment of a vertical ring, the value $s_?$ relates to the measuring only in one position. Levelling instruments are for a determination of the standard kilometre deviation s_{km} of double levelling tested on the path, long 240 m with stabilized lengths, sight line 20 m. One series consists of 5 two-ways measuring. The non-typical instruments, e.g. tubular liquid clinometer or levelling diopter, were also tested by this procedure. The magnification of telescope was determined in the laboratories of the Department of Higher Geodesy. The constant of a cross-wires distance meter and its addition constant were determined from the levelling of measurement on the bases of the known lengths. The accuracy ranges from 0.1-0.2 of the unit, 1-2 cm respectively.

In depositaries of NTM, the basic set of angular and levelling instruments and the so-called universal levelling instruments, nowadays called rather tachymeters (theodolites) with a sensitive levelling tube, was chosen. The basic parameters of some instruments, chosen from the whole set to characterize the given designed group, are shown in

Tables 1, 2, 3 (Hánek 1999). Dimensions, mass weight, index levels sensitivity, telescope lengths in the edge positions of focusing etc. are stated in diploma theses.

Instruments were before the measuring carefully cleaned and rectified, according to the original procedures. Because of the shortage of original statives, the adapters on Zeiss statives were made. The common bars with E division were used for levelling instruments. They were for tubular clinometer and levelling diopters complemented with sliding circular target, horizontally divided with a contrast colour. The level sensitivity was determined from repeated measurements on the rectified rule with accuracy of 1″ approximately. At the cross alidade levels, the level sensitivity perpendicular to the sight line is given at the first place, after the slash a sensitivity of a longitudinal level or a level placed on the telescope fork, follows. The sensitivity of striding levels or levelling bubbles of theodolites is in Table 1 given with an abbreviation of location in a column „other levels". In Table 2, there are levelling instruments with a fixed telescope. The exception is the Spitra's instrument, equipped with the free telescope.

Table 1: Theodolites

Producer	Type	Year	Purpose	Magnification	Standard deviation [“]		Level sensitivity [“]		Note: Multiplic. constant
					s_φ	s_ζ	alidade	others	
J.& J. Fric	6R	1907	Triang.	30x	5.8	-	19.6/93.5	striding level not measured.	Screw microscope
				40x	4.0	-			
				60x	5.8	-			
J. & J. Fric	9R	1910	Polyg.	30.0x	8.5	8.9	30.6/50.0	15.0 levelling bubble	100.2±0.2
J. & J. Fric	13RN	1911	Tach.	undetected	31.8	not measured	22.4/4.1	-	100.2±0.1
Srb & Štys	No. 256	1927	Triang.	26.1x	3.6	-	17.9/16.2	5.0 strid.	Screw micr.
Srb & Štys	THN	1939	Polyg.	23.3x	10.3	7.2	34.7/37.8	22.0 lev.b.	100.4±0.1
Srb & Štys	THN	1947	Tach.	20.0x	14.6	8.2	53.3/40.6	23.6 lev.b.	100.0±0.1

Table 2: Instruments for determination of elevation

Producer	Construction	Year of Production	Sensitivity of levelling bubble [“]	Rule [mm]	Magnification	Standard Deviation. s_{km} [mm]
Spitra	Tabular Liquid.	2.half of the 19.cent.	-	800	-	44.5
Božek	Levelling diopter	1838	90	860	-	11.9
Spitra	Levelling diopter	1.half of the 19.cent.	150	320	-	19.0
Haase & W.	Levelling diopter	1880-98	46	310	-	18.5
J. & J. Fric	Levelling diopter, No 597	1899	34	315	-	10.7
Spitra	Levelling diopter	The half of the 19.cent.	25	-	10x	4.3
Haase & W.	Levelling diopter	2.half of the 19.cent.	16	-	8x	6.3
J. & J. Fric	Levelling diopter, No 866	1902	16	-	44x	1.8
J. & J. Fric	Levelling instrument No.1541	1908	21	-	17x	2.9
J. & J. Fric	Levelling instrument, No.3630	1918-25	20	-	28x	2,6

Table 3: Universal tachymetres (with a sensitive levelling bubble)

Instrument	No.	Year	Alidade Level/ Levelling Bubble [“]		Magnification	Standard Deviation			Multiplic. constant
			alidade l.	lev. bubb.		s_{φ} [“]	s_{ζ} [“]	s_{km} [mm]	
Brandeis	40314	1860-70	102	damaged	18x	126	30	not meas.	100.07
J. a J. Fric	260	19./20. century	58/65	17	19.2x	60	45	12.7	99.94
J. a J. Fric	4179	1925-30	129/142	13	25.7x	10	17	1.6	no
Haase & W.	35658	1881-98	55/56	17	11.2x	102	90	23.4	100.20
Haase & W.	8964	1881-98	162/162	10	21.8x	90	36	7.9	99.98
Haase & W.	8965	1881-98	32	23	15.8x	84	60	5.0	99.50

Instruments of the Haase & Wilhelm production do not have production numbers; an inventory number of NTM is quoted

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Contact:

Ass. Prof. Pavel Hánek, PhD,

Czech Technical University of Prague - Faculty of Civil Engineering, Department of Special Geodesy, Thákurova 7, 16629 Praha 6, Czech Republic.

E-mail: hanek@fsv.cvut.cz

Dipl. Ing. Antonín Švejda

NTM Praha, vedoucí odd. exaktních ved, Kostelní 42, 17000 Praha 7, Czech Republic

E-mail: antonin.svejda@ntm.cz