ANALYSIS OF THE ACCURACY AND PRECISION OF MAGNETIC AZIMUTHS MEASURED BY DIFFERENT CAVE SURVEYING INSTRUMENTS

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Abstract - **By cave surveying playing important roles those instruments, which are able to determine the direction of the magnetic meridian or the angle, between the line of sight and the magnetic north. The field surveying data, like the magnetic azimuths determine directly the accuracy of a cave map, so it is important to know exactly the precision and accuracy of a magnetic azimuth**

After testing four instruments (Süss-compass, Sokkia SET 230 R with a tubular-bussola, simple compass, Quechua C100 bussola with a dioptre), I involved in the precision and accuracy examinations two instruments: the Sokkia SET 230R mounted with a tubular-bussola and a Quechua C100 bussola. The precision of the tubular-bussola is 17'40", which is significantly worse, as given in the owner's manual (3-7'). The precision of the magnetic azimuth measured by the C100 bussola is 45', which is very good, when we take into account the non-precise setting up possibility of this instrument, and the disadvantages of the pointing with a dioptre. The circumstances in the caves rarely allowed to measure longer directions as 50 meters; in the most occasions the lengths of directions are between 0 and 15 meters. Take into account this distance-interval, the accuracy of magnetic azimuths, measured with the tubular-bussola will be between 0-8 cm, and measured with the Quechua C100 bussola will be between 0-20 cm.

I. INTRODUCTION

The most relevant documentation of a cave surveying campaign is the resulted map. By the field surveying we need to determine the angle between the line of sight and the magnetic north. For the determination of the magnetic azimuth we are using compasses and bussole (it is a compass, which has a sighting equipment, like a dioptre). Among the bussole we can find also some special instruments, like the tubular-bussola, which is an orientation bussola. It can be mount on the top of the alidade of a total station and is appropriate to show the direction of the magnetic meridian. When we set zero reading into this direction, we are able to measure directly magnetic azimuths on the field.

There are three different cave surveying methods, which are widely used: the chase-method, the TS (Total Station)-surveying and laser scanning [3]. By the chase-method and the TS-surveying we are using magnetic azimuths for the orientation of polygon lines. Only in rare occasions are we able to use points, with given coordinates in the national grid system (in Hungary this is the EOV) for the orientation. By laser scanning we are using pass points given in a local network or with coordinates given in the national grid system. Before the scanning we must determine the coordinates of the pass points, using some surveying methods, like TS-surveying or GNSS-measurements.

By cave surveying playing important roles those instruments, which are able to determine the direction of the magnetic meridian or the angle, between the line of sight and the magnetic north. The field surveying data, like the magnetic azimuths determine directly the accuracy of a cave map, so that is why it is important to know exactly the precision and accuracy of a magnetic azimuth.

II. THE STRUCTURE AND USE OF COMPASSES AND BUSSOLE

The bussola is a compass, which has a sighting equipment. In the surveying practice we are using circle bussole and orientation bussole. The most important part of a bussola is a wolfram or chrome-steel needle. The needle, and its pivot-point is built in a conic agate cup [4]. To ensure proper and prolonged operation of the needle, pivot point and cup, the needle can be fixed by pressing the cup to the glass with a catch. The magnetic needle must has a great magnetic remanency and a little coercitive force.

Due to the strength of the magnetic field of the Earth, the magnetic needle points to the magnetic north (N_M), which differs from the astronomical north (N_A) by the Δ magnetic declination (Fig.1). The declination is positive, when the magnetic north points to the east form the astronomical north. The magnetic needle deviates from the horizontal with an angle, called magnetic inclination.

The circle bussola contains counter-clockwise increasing graduations on its perimeter. When we rotate the bussola clockwise, the readings taken by the opposite ends of the needle are increasing, and are showing the magnetic azimuth of the collimation axis, which is parallel with the 0° - 180° graduations. By some bussola types the graduated circle and the needle are fastened, and are making rotation and swinging in a cup, which is full with shock absorber liquid, like oil. In this occasion the graduation of the circle is increasing clockwise, and the reading, taken on the index, mounted on the magnetic needle-house, shows directly the value of the magnetic azimuth. The tubular-bussola does not contain any graduations. The opposite ends of the needle are tend 90° upwards, and can be adjust in coincide with the help of a little mirror over the needle, using the small motion screw of the total station [4]. When the ends of the needle coincide, the collimation axis of the total station points to the magnetic north. When we store the reading for this direction, or set zero reading for it, than we record the direction of the magnetic meridian, as an orientation point for the further measurements and calculations. By some other types of tubular-bussole the free-swinging needle can bring into the centreline of two parallel, vertical index lines using the horizontal small motion screw of the instrument. When the needle coincide with the centreline, the line of sight points to the direction of the magnetic north.

The angle between the N_A astronomical north and the N_G grid north is the μ convergence of the meridians. The meridian convergence is positive, when the grid north points to the east form the astronomical north.

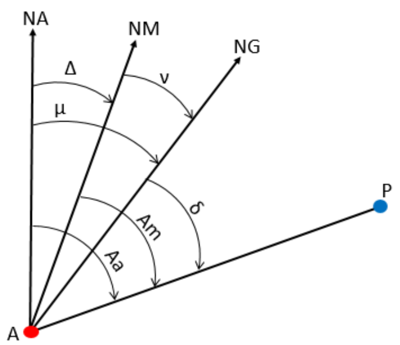

Figure 1. The relationship between the N_A astronomical, N_G grid and N_M magnetic norths

The angle between the N_M magnetic north and the N_G grid north is the ν magnetic orientation angle. It is positive, when the grid north points to the east form the magnetic north. For the mapping we need bearings (δ), also the angle between the line of sight and the grid north. To derivate astronomical azimuth from the magnetic azimuth we must reduce it using the magnetic declination, and the using meridian convergene we can derive from the astronomical azimuth bearing. When we know the value of the magnetic orientation angle, we can calculate directly the bearing from the magnetic azimuth:

$$\delta = A_m - \vartheta = A_m + \Delta - \mu \qquad (1)$$

The magnetic north at any particular place varies over a period of a century by tens of degrees, the complete cycle taking as much as for centuries or more. Such variation is referred to as the secular change. The annual change of the magnetic declination in Europe is on the average something like 5', westerly is currently diminishing while easterly declination is increasing [6]. There is also a diurnal variation which, in the middle latitudes of Hungary, may be as much as 15', in summer this value is greater than in winter and greater in the northern parts than in the southern parts of our country [8]. The magnetic declination may be also effected by magnetic disturbances or magnetic storms induced by different effects f.e. aurora borealis, solar activity etc. The magnetic needle's readings are also strongly influenced by the place of observation in areas of magnetic ore deposits. Such departures from the mean value of magnetic declination are described as magnetic anomalies. Great care should be taken not to work in areas where is a large amount of iron in the vicinity of a railway, ferroconcrete, fence or high-tension power line etc. The observers in the neighbourhood of the instrument could not have tools made of iron (hammer, axe, peg or penknife etc.) on them.

The magnetic declination varies in time and space. To calculate it, the plainest procedure is to use some free databases published on the Internet, like ngdc.noaa.gov; geomag.nrcan.gc.ca etc. The effect of the magnetic inclination is balanced with a weight, which is on the same offset situation on the magnetic needle, in the whole are of Hungary. The value of the meridian convergence does not varies in time, it depends only from the place and the used grid system. In Hungary, using the national grid system, the EOV, its value varies between -2° and +2°. His calculation is regulated by the A1 Grid Regulation (MÉM OFTH Surveying Department 63619/2/1975. direction).

III. TESTING OF A SURVEYOR'S COMPASS AND BUSSOLA

The surveyor's compass or bussola should meet the following requirements [5]:

1. the graduation of the horizontal circle must be adequately accurate,
2. the magnetic needle should be properly charged, the pivot point well sharpened, and the cup polished,
3. the magnetic needle should be straight,
4. the rotation axis of the magnetic needle should pass through the centre of the graduated circle.

The bussola in terms of the over mentioned points should be tested.

1. Let us pull an optional line on a paper, and let us fit always another graduate to this. If the readings agree within the range of the least count, than the graduations of the horizontal circle are adequate accurate.
2. To test this take readings on the graduated circle from the opposite ends of the needle when it has settled. Then place an iron object next to the needle and on removing it take a second reading once the needle has again settled. If the readings agree and the needle settles after a few swings (30") the requirement is met. If the needle settles quickly but the readings fail to agree, it shows that either the pivot point is dulled or the agate cup is badly polished. Should the needle swing

for a long time before it settles, this means that it is badly charged.

3. The magnetic needle is straight, when the readings making from the opposite ends of the needle, differs exactly with 180°. The admissible variance should be 0.3° (18'), because it falls out by the diametral readings. If the difference is not 180°, the reason could be the eccentricity of the needle, too.
4. Rotate the horizontal circle within a range of 10° clockwise, and take readings from opposite ends of the needle from different parts of the graduated circle. If the difference of the readings is exactly 180°, the needle is straight and his axis pass through the centre of the graduated circle. If the differences are uniform, the axis of the needle pass through the centre of the graduated circle, but is not straight. When the axis of the needle is eccentric, the reading differs from 180° with different, but symmetric values on the different places. If the differences are not symmetric, than the needle is not straight and is eccentric. To rule out the effect of eccentricity and roundabout of the needle we have to calculate the arithmetical mean of the readings taken from both ends of the magnetic needle.

IV. THE INSTRUMENTS USED FOR THE EXAMINATION

I used four instruments for the examination: Sokkia SET 230R total station with a tubular-bussola, a compass manufactured by Süss, Quechua C100 bussola with a diopter, and a simple compass with an unknown trademark (Fig.2).

The angular measurement accuracy of the Sokkia SET 230R total station is 2", the magnification is 30°. The tubular-bussola can be mount on the alidade. The tubular-bussola is not a coincide-structured bussola. The free-swinging needle can bring into the centreline of two parallel, vertical index lines using the horizontal small motion screw of the instrument. When the needle coincide with the centreline, the line of sight points to the direction of the magnetic north. The precision of the tubular-bussola is 3-7' [7].

The compass, manufactured by Süss can be mount also on the top of the alidade of an instrument. It can be also use directly on the ground by the chase-method. It is graduated counter-clockwise from the South, the least count is 20'.

By Quechua C100 bussola the graduated circle and the needle are fastened, and are making rotation and swinging in a cup, which is full with shock absorber liquid. The graduation of the circle is increasing clockwise from the North, the least count is 5°. We should take the readings in ticks, then 64 ticks are equal with 360°. The least count is 0.2 tick, and we could estimate the reading by 0.1 tick. One tick is equal with 5°37'30", 0.1 is equal with 0°33'45". So when we take the reading in ticks, the least count is 0°33'45".

The graduation of the circle of the simple compass is increasing clockwise from the north, the least count is 2°.

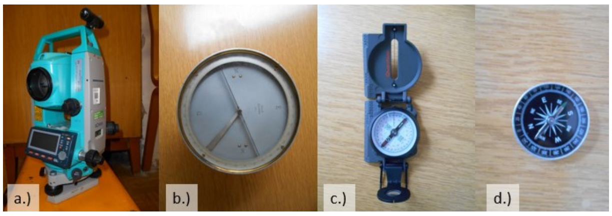

Figure 2. The Sokkia SET 230R total station with a tubular-bussola (a), the compass manufactured by Süss (b), Quechua C100 bussola (c) and the simple compass (d)

V. TESTING THE INSTRUMENTS USED FOR THE EXAMINATION

By the Süss-compass and by the simple compass it was possible to do the full examination process. By the Quechua C100 bussola it was possible to do the first and second examination steps, because the structure of the instrument does not allowed the third and the fourth steps. By this instrument we supposed, that the magnetic needle is centered and straight (it was insured in the course of the production process already). By the tubular-bussola is neither opportunity nor need for this kind of examination, because this instrument deals only for setting out the direction of the magnetic meridian. The Table 1. contains the results of the examination.

Table 1. Testing the instruments used for the examination

Instruments	Graduation accuracy	Charge		Straightness	Centring
		Settle time["]	RMSE [°]		
Compass (Süss)	good	14	1	yes	yes
Simple compass	good	4	2	yes	no
Quechua C100	good	11	0.3	-	-

The graduated circle of the Süss-compass does not have graduation errors, the magnetic needle is straight and centered, but the magnetic needle is badly charged and either the pivot point is dulled or the agate cup is badly polished. The age of this instrument is more than 100 years, so it can be explained, that the remanency of the needle decreased, and the pivot point dulled. The graduated circle of the simple compass does not have graduation errors, the needle is well charged, the pivot point is not dulled, the cup is well polished, the needle is straight but not centered. The readings taken from opposite ends of the needle differs symmetric, the root mean square error of the readings takes 4°. The graduated circle of the Quechua C100 bussola does not have graduation errors, the needle is well charged, the pivot point is not dulled, the cup is well polished, the needle is straight and centered.

Summarizing the results, from the further investigations I exclude the Süss-compass, because the badly charged magnetic needle, and the simple compass, because of its eccentric needle. Further reason is, that this type of instruments does not have any sighting equipment.

VI. THE ACCURACY AND PRECISION OF THE MAGNETIC AZIMUTHS MEASURED BY THE DIFFERENT BUSSOLA TYPES

By the Sokkia SET 230 R total station, mounted with a tubular-bussola, and by the Quechua C100 bussola I investigated the accuracy and precision of the measured magnetic azimuths. I set out a 12 meters long reference line in the surveying practise room at the Alba Regia Technical Faculty of Óbuda University, Department of Geoinformatics. On one end of this line I set up the instrument, and on the other end I fixed a plastic surveying mark on the wall. I measured 15-th time the magnetic azimuth of this direction with the two instruments. Before each sighting I centered again and again the mark of the tubular-bussola, and I made also again and again a whole sighting process with the Quechua C100 bussola. By the tubular-bussola I set zero reading into this direction, and so I measured directly the magnetic azimuths. By the C100 bussola I was taken the readings in ticks, and then I convert these values to the 360° system. For the calculation of the precision of the azimuth I used the numerical method of the equally accurate measurements of the same quantity, for the calculation of the precision of the angle between the magnetic north and the line of sight I used the terms of error theory [1]. The results of the calculations contains the Table 2.

Table 2. The precision of the magnetic azimuths and the derived angles measured with the Sokkia SET 230 R total station, mounted with a tubular-bussola and with the Quechua C100 bussola

	RMSE	
Instruments	Azimuth	Angle
Tubular-bussola – Sokkia SET 230 R	±0°17’40”	±0°25’00”
Quechua C100	±0°45’08”	±1°03’50”

Based on the values of the Table 2. we can declare, that the precision of the tubular-bussola is significantly worse, as given in the owner’s manual (3-7’). The instrument has 2” reading precision from the horizontal circle; by magnetic azimuth measurements we can’t take advantage of this characteristic. Measured from the initial target point, the precision of the other directions will be equal with 2”, because without the initial direction, the further directions will be the part of a traditional round of directions. The precision of the magnetic azimuth measured by the C100 bussola is 45’, which is very good, when we take into account the non-precise setting up possibility of this instrument, and the disadvantages of the pointing with a dioptre.

I defined the accuracy with a viewing angle based on the value of the root mean square error of the magnetic azimuth and a linear bias, imagined at the correct point location. The value of the linear bias writes the accuracy down, which depends from the value of the viewing angle, and the distance between the station and the aimed point. Take into account the circumstances of cave surveying, I calculated the accuracy from 0 to 50 meters using 5 meters intervals. I based the calculation of the equation of the linear bias [2]. The Table 3. contains the results of the accuracy calculations.

Table 3. The accuracy of the magnetic azimuths measured with the Sokkia SET 230 R, mounted with a tubular-bussola, and with the Quechua C100 bussola

	Accuracy [cm]									
Instruments	5m	10m	15m	20m	25m	30m	35m	40m	45m	50m
Tubular-bussola – Sokkia SET 230 R	3	5	8	10	13	15	18	21	23	26
Quechua C100	7	13	20	26	33	39	46	53	59	66

Based on the values of the Table 3. we can declare, that both instrument is suitable for cave surveying. The circumstances in the caves rarely allowed to measure longer directions as 50 meters; in the most occasions the lengths of directions are between 0 and 15 meters. Take into account this distance-interval, the accuracy of magnetic azimuths, measured with the tubular-bussola will be between 0-8 cm, and measured with the Quechua C100 bussola will be between 0-20 cm.

REFERENCES

[1] Detrekői Á.: „*Kiegyenlítő számítások*”, Tankönyvkiadó, Budapest, p. 684., 1991

[2] Deumlich F., Sraiger R.: „*Instrumentenkunde der Vermessungstechnik*”, Wichmann Verlag, ISBN 10: 3879073058 ISBN 13: 9783879073054, Berlin, p. 426., 2002

[3] Eszterhás I., Tarsoly P.: „*Kisméretű barlangok térképezése*”, MKBT Vulkánszpeleológiai Kollektívájának évkönyve, Isztimér, pp. 39-62, 2015

[4] Fialovszky L.: „*Geodéziai műszerek*”, Műszaki Könyvkiadó, Budapest, pp. 181-186, 1979

[5] Hazay I. szerk.: „*Geodéziai kézikönyv*”, II. kötet, Közgazdasági és Jogi Kiadó, Budapest, pp. 409-412, 1957

[6] Maslov A.V., Gordeev A.V., Batrakov Yu. G.: „*Geodetic Surveying*”, MIR Publisher, Moscow, p.652., 1984

[7] Sokkia Operators Manual Series 30R: Sokkia B.V. European headoffice, 1300 BG Almere, Netherlands, p. 90., 2002

[8] Völgyesi L.: „*Geofizika*”, Műegyetemi Kiadó, Budapest, pp. 22-33., 2002