RESEARCH REGARDING THE SETTINGS OF SURVEYNG EDM INSTRUMENTS IN LABORATORY AND ON THE FIELD

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Abstract: *This paper presents some theoretical and practical aspects regarding different settings EDM instruments that are embedded in devices with multiple functions surveying. Measurements were carried away by this tool in laboratory and field taking into account introducing the atmospheric parameters for different settings EDM instrument. Was performed a comparation regarding EDM instrument setting out in a geodetic base inside the laboratory and outdoors. We aimed to show the influence of atmospheric parameters on the measurement of distance in terms of accuracy of measurement results.*

Keywords: *EDM, distance measurement, accuracy, precision.*

1. Introduction

EDM tool is an electronic device used to measure distances. These devices by construction type can be independent or be incorporated into a unit geodesic, specifically in its telescope. Measurement distances software is integrated in the geodesic unit.

An EDM instrument uses a pulse of electromagnetic energy (EM) to determine the distance measurement.

Power comes from an instrument positioned at one end along a distance and is sent to a " spotlight " on the other end, where it is returned to the original instrument. Nature of the " reflector " is dependent on the type of EM (electromagnetic energy). If energy is the type electro-optical (infrared or laser) EM is used when "reflector" which is usually a passive medium in which the signal bounces back. If EM is a "microwave " type, then the reflector is a second tool that captures energy input and instrument re- transiting back to originar instrument.

In any case measurement is the total distance from the instrument to the reflector and back to the instrument[1].

EDM instruments are used in surveying to determine the linear distance between two points or station. This tool is able to send an electronic pulse with a certain speed and its measured the time required for the impulse to travel distance from one point to another. Then, using the equation of distance = speed x time, interval length is calculated. EDM's are of two types:
1)electromagnetic-tools
2) electro-optical-instruments.

Before using EDM’s is very important to gather information on the operations of the instrument as described by the manufacturer[1], [3].

2. Electromagnetic EDM Tools

High-frequency radio waves are used in electromagnetic EDM. They were first developed as a tool in 1950. These are very accurate for measuring distances. They underwent several improvements over the years, and now the electromagnetic's EDM are available in small and portable sizes , and they have a special feature, direct reading of measurement. While using this tool, it is necessary to establish at both ends of the line we are going to measure, two identical and interchangeable tools for transmission and reception, so basically, a transmitter and receiver. Tool transmitter sends a series of modulated radio waves and they will be captured by the receiving instrument.

The instrument will return the receptor to the sender where the first transmission after processing and transmitting unit finally calculated the time required for radio waves to travel the travelled way from the transmitter to the receiver and the transmitter again. Atmospheric conditions affect the speed, which means the rate of travel of these radio waves.[1], [2].

3. Electro-optical EDM instruments

The tools that use the speed of light waves to determine the distance between two points are electro-optical instruments. The geodimeter was the early form of electromagnetic instruments. Instrument shall be fixed at one end of the measured distance and the other end is fixed to the reflector. The electromagnetic EDM can give accurate results if the distance measured is free without any obstacle. Unlike electromagnetic EDM, optical-electrical EDM require both ends of the measurement lines to be intervisible.

The EDM instrument sends a light beam to the reflector, which acts as a mirror and redirects the light pulse to the primary EDM instrument. Soon as EDM receives reflected light pulse, the values recorded in it are converted to linear distance between the EDM and the reflector[1], [2]. Correction must be based on atmosferic conditions. The method which is based on measurements by technique using electromagnetic phenomena in the radio and visible range.

Accuracies that can be obtained are millimeters or smaller and are practically independent of the measured length. Basically distance measurement is to measure the propagation time of electromagnetic waves between landmarks considered. The folowing formula underlies the basic principle of electro-optical EDM instruments:

$$D = v\tau, \quad (1)$$

where D-distance, τ - time measured, v-velocity of propagation of the electromagnetic wave. This speed *v*, is given by the formula:

$$v = \frac{c}{n}, \quad (2)$$

where c = 3 * 10^{-8} m/s and *n*- the index of refraction of the environment. Generally depends on a number of parameters (temperature, pressure, humidity, wavelength) and exact knowledge of this can improve the accuracy of measurements[1], [2].

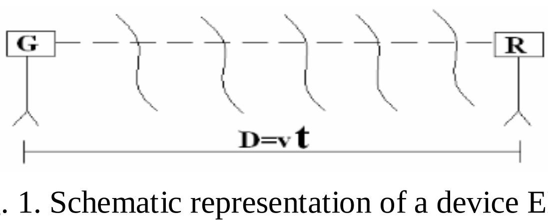

Fig. 1. Schematic representation of a device EDM

A generator G emits electromagnetic wave which propagates to the receiver R located at the end of the measured distance. When using waves in the visible R has a passive role, reflected wave without having to alter its appearance. In the case of radio wave undergoes certain changes before being reflected.

The general information is contained in a wave by introducing a time dependence of the quantity characterizing the wave. This process is called modulation, the reverse will bear the modulation. A wave expressed by an equation of the form: $y = A\cos(\acute{\omega}t + \varphi)$, do not carry any information. Its modulation is required.

Depending on the type size that do vary over time, we have the following types of modulation:

a) modulation amplitude $A = A(t)$, is used when using light waves.

b) frequency modulation $\acute{\omega} = \acute{\omega}(t)$, is used when using radio waves.

c) φ= phase modulation $\varphi(t)$ [1], [2], [3].

4. Experiments on the behavior of the EDM instruments on the temperature variation in the laboratory

Measuring distances using EDM instrument is done in the laboratory in a geodetic base that has a usable length of 50 m. The measuring interval on which is made calibration is between (0...50) m. Calibrations distance measured by the EDM tool is made from 10 m to 10 m, round trip (forward and back).

The geodetic reference atmospherical conditions on this base are: 20° C ± 0,5° C. The geodetic base has instruments used to monitor temperature, air humidity and atmospheric pressure. Readings provided by them is useful each time when these values are inserted in the device software to be able to perform geodetic instrument corrections, important to determine the precision of distance measurement.

The geodetic base in the laboratory Lengths, is used mainly for calibration calibration ribbons and measuring tapes.It is located in the basement, at level of -6 m geodetic base consists of the following main parts: floor foundation plate, the length of the base is 65 m and the cross-sectional dimensions are: 0,8mx0,55m, framework mounted on concrete foundation bearing two ways of measuring, steel plate measurement range (-10...10) mm (placed at equidistant intervals of 0.5 m), mobile trolley runway, trolley moving on the surface of the base geodetic measurement and microscope, laser interferometer measurement that records movement of the trolley [2].

Inside the laboratory are considered three atmospheric parameters, temperature, pressure and humidity of the ambient air, which have great influence in the process of measuring distances. Operating temperature range of these devices is (-20º C...+40 º C).

Were simulated in the laboratory different temperature conditions throughout the working range of this devices. Simulating these temperatures was achieved by manually entering these values EDM software tool. After entering the value of the ambient temperature in the machine, it has the ability to affect the temperature correction in the measurement of distances.

A second important parameter, is the atmospheric pressure that influences both the accuracy of the measurements. Basically, during the calibration process, it is desirable that the temperature remains constant, so that the measurement accuracy is not affected.

Were simulated (artificially) different environmental conditions values of all three atmospheric parameters when surveying equipment with multiple functions throughout their working range. Measurement errors distances vary depending on the operator's visual acuity, precision of the instrument and of course the correctness of the controller parameters introducing atmospheric read.

Therefore, after extensive research and extensive measurements in laboratory conditions, we can say that is not recommended using these devices range between minimum and maximum operating temperature as errors in measuring distances within a short distance (50 m), are important.

Basically, using the theory of error propagation, we can form an idea of what can happen over long distances. Below is the table containing the results of measuring distance with a geodesic device with multiple functions in the laboratory for a distance of 50 m in direct comparison with laser interferometer.

Table 1. Baseline values obtained in the laboratory using laser interferometer

Distance measurement range [m]	Laser interferometer's indication [m]	Geodetic base correction [mm]
0	0,011645	-0,011645
0÷0,5	0,497746	-0,002254
0÷1	1,045883	-0,045883
0÷2	1,999992	-0,000008
0÷3	2,999838	-0,000162
0÷4	3,999876	-0,000124
0÷5	5,076081	-0,076081
0÷10	10,181172	-0,181172
0÷15	14,999949	-0,000051
0÷20	19,999814	-0,000185
0÷25	24,999615	-0,000385
0÷30	29,999615	-0,000385
0÷35	35,105852	-0,105852
0÷40	40,023269	-0,023269
0÷45	44,999988	-0,000012
0÷50	49,998863	-0,001137

The chart below represents the variation of error provided by the laboratory reference values obtained using laser interferometer for distance useful laboratory (geodetic base).
These were made in 2013. Basically these changes are not very significant, are of the order $10^{-3} \div 10^{-2}$ mm. Below the graph are given the environmental conditions measurement was performed as well as other data on the precision and accuracy for measuring process itself (left column). As described above, the geodetic based has a useful length of 50 meters, with grade of steel plates are placed from 0.5 m to 0.5 m at measurement range (-10...10) mm. As can be seen from data , measuring distances on the geodetic base was performed in 16 points on distance useful base (50 m), round trip. This measurements were performed on different days, but in the same environmental condition. Were carried out a series of four

measurements points, basically what is shown in the graph and table above represents the average of these points. In the following measured values are further explained in table.

In the left column in the table is specified the distance measurement intervals. In the second column are the data shown the mean values of the laser interferometer measurement points. They are provided with the highest precision. It can also display the measurement results with a resolution of 7 digits . In the third column is given their correction, which is obtained from the difference between the standard (standard value) and the values given for the length (distance) measured.

This values are updated annually , their use as possible every year, and especially improving error correcting distance being made with interferometers laser. For diminish measurement errors is necessary that the environmental parameters (particularly temperature and humidity) are kept to a acceptable, namely:

•temperature:20°C±0,5°C.

• humidity: 40-45 %.

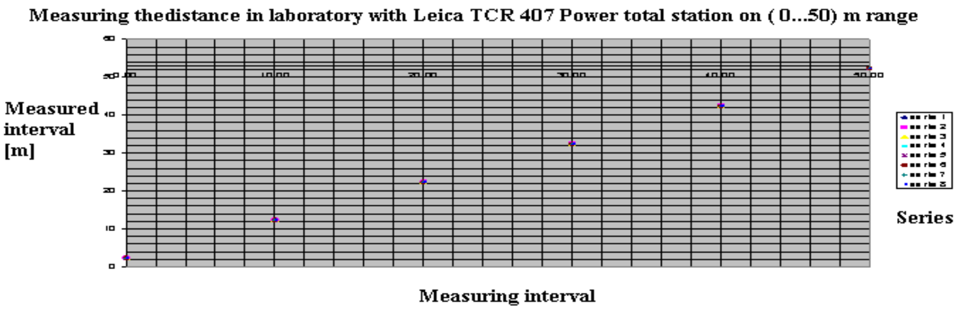

Fig. 2. Measuring distances in the laboratory in the range 0 m to 50 m using Leica TCR 407 Power at reference conditions

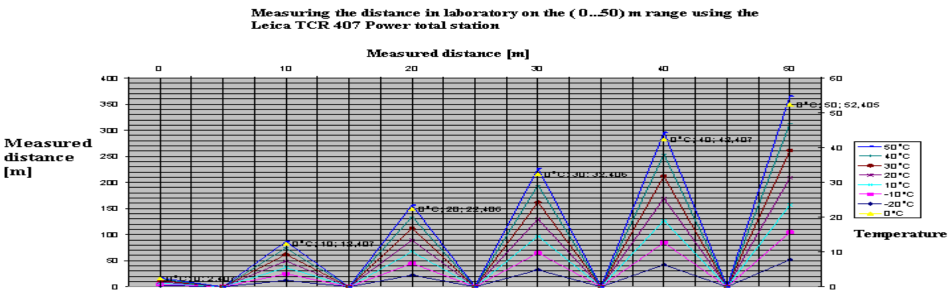

Fig. 3. Distance measurement laboratory TCR 407 total station Power (forward)

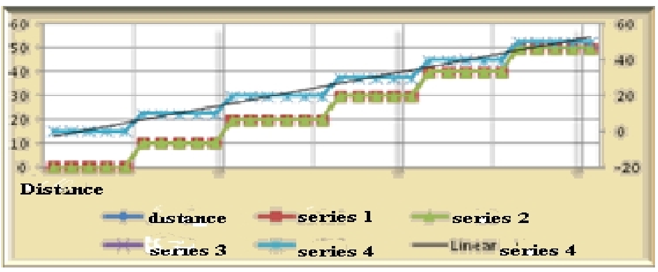

Fig. 4. Distance measurement in laboratory with Leica TCR 407 total station (back)

Table 2. Measuring the variation of distances on land using Leica TCR 407 Power device in the temperature range (-20° C÷50° C)

Temperature introduced in the device	-20°C	-10°C	0°C	10°C	20°C	30°C	40°C	50°C
Corection made by the device	-36 ppm	-23 ppm	-12 ppm	-1 ppm	9 ppm	18 ppm	27 ppm	36 ppm
	Device indication[m]-forward							
0	2,406	2,407	2,407	2,406	2,407	2,407	2,407	2,408
10	12,407	12,407	12,407	12,407	12,407	12,407	12,407	12,408
20	22,407	22,406	22,407	22,407	22,408	22,408	22,408	22,408
30	32,406	32,406	32,407	32,407	32,407	32,407	32,408	32,408
40	42,405	42,406	42,406	42,407	42,408	42,408	42,408	42,409
50	52,404	52,404	52,405	52,406	52,406	52,408	52,407	52,408
	Device indication[m]-back							
50	52,404	52.404	52,405	52,406	52,406	52,407	52,407	52,408
40	42,405	42.406	42,407	42,407	42,407	42,408	42,408	42,409
30	32,406	32.406	32,406	32,407	32,407	32,407	32,408	32,408
20	22,407	22.406	22,407	22,407	22,407	22,408	22,408	22,408
10	12,407	12.407	12,407	12,407	12,407	12,407	12,407	12,408
0	2,406	2.407	2,407	2,406	2,407	2,407	2,407	2,408

The table above shows the calibration of geodetic Leica TCR 407 Power total station in the laboratory. The measurement of distance was performed on geodesic base useful distances on measuring range (0 to 50) m back and forward.

The geodesic devices was positioned on a tripod taking care to adjust the horizontal level leveling device. Measuring distances was performed on the interval (0...50) m. The points in which the measurement was made are given in the table.

Before starting the measurements, it was set the temperature of 20° C in the EDM instrument software tool. Was watched to see EDM instrument behavior in different temperature conditions in order to know how the variation of the distance measurement accuracy throughout the operation of the instrument.

Given that it is practically impossible and not recommended simulation in real conditions temperature range (-20° C to 50° C), here refer more to the temperature values given at the extreme limits of the range -20° C and +50° C, proceeded to artificially simulate them.

Fig. 5. Measurement trolley and support

All the distances have been measured at 20° C and then simulating the all temperature range (-10° C to 50° C). Basically have entered these values of temperature correction in the EDM instrument temperature program, and for every point measured these temperatures were simulated.

Distance measurement results can be seen in the table above. The concept of *ppm* (parts per million) is a term introduced in the software calculation error correction device provides precise distance measurement. Basically if it was far away on the range (0…100) m, 1 ppm represents 1 mm/1000 m error in distance measurement.

Many of the tools and software used in these areas requires an understanding of the concept ppm to use them properly. Parts per million can be used to express the probable error in a measurement as a tool specification EDM , "2mm + 3 ppm", or an error resulting from a measurement based on a comparison with other measurement or a value taken as certain, or even the average of a group of measurements of the same quantity. It should be noted that the notion of " parts per million " is not only related to EDM measurements [3], [5], [6].

I mention this here because topography is often referred to as " ppm " or the clearing system errors in a distance measurement EDM instrument, which are caused by fluctuations in the speed of light, ambient temperature, atmospheric pressure and content water vapor in the atmosphere through which the light passes[1], [3], [4].

One part per million is simply a fraction of 1/1.000.000. PPM is a superior way to assess the errors individually and combining them. For example, the EDM tool may determine that a 1° C variation in temperature produces a change in reading EDM as a 1 ppm. If the temperature increases, the impact on read a measured value greater than the actual value, so drop by 1 ppm could achieve a correction for this effect. It can also be measured as a change in air pressure of 0.1 inches of mercury will cause an error of 1 ppm reading EDM [2], [3], [4]. If the pressure increases to 0.1 inches of mercury, the impact on remote reading is to make smaller. Ppm thus, in the case where there are two conditions at the same time, it is easy to determine that the net effect is zero. By means of this factor can be calculated and other important parameters, such as the coefficient *k*,, which is the refractive coefficient of air.

In conclusion EDM instrument calibration is more accurate in laboratory than in the external environment, for the reasons stated above. EDM measurements with these instruments it is recommended to make the outdoor environment for several reasons, namely: -the possibility of measuring distances over a wide range (typically to measure distances on the minimum 1000 and maximum 3500 m to 5000 m depending on the type of prism/ reflector used or according to the technical specifications of the device [3], [5], [6].

In the external environment temperature varies significantly in a summer day, from morning to night, and these variations should be considered as useful for calculating future earth curvature correction constant, *(k=0,13)*, also temperature with the introduction of the controller device automatically that calculates the distance measurement accuracy in ppm (parts per million).

Calibration of these instruments is well to realize in to external geodetic bases, as the points where the measured distance spanned recognized are fixed and calibrated in turn by means of certificates. It is recommended to use an external geodetic basis which has pilasters. Now discussing this issue in general, it is recommended that before coming to any measurement of these three parameters into account air temperature, atmospheric pressure and sometimes moisture.

Generally before starting the calibration of the instrument EDM human operator must enter values for these parameters in the section "Setting the EDM instrument" because they contribute greatly to providing precision for distance measurement with the instrument. Of course when the data processed by the operator it can tell whether atmospheric parameters introduced in the wrong way or not, this is evident in the quality of measurements.

So it is advisable not to skip this step, it is essential to collect accurate data in both laboratory and field. The table above shows the EDM instrument calibration distances measured on the interval (0...50) m, measurement was performed in a summer day in the

09^{00}-12^{00} time frame, on the field, on the radius of Snagov, Ilfov county, the edge of the road, on county road number 108 B.

Adjacent location was chosen so as to meet the optimal conditions to the desired measurement which was not possible to perform measurements in the open field, for reason that is not recommended to expose the the device for a long time excessive to heat sunlight. Try as much as possible for the device to be positioned more time in the shade.

Although below the atmospheric parameters are passed to take measurements, it should be noted that throughout the measurement and their indications are corrected, by using appropriate tools. The measurement was performed under the following atmospheric conditions : temperature T=26° C, pressure P=762 mmHg, air humidity U = 50÷60 %.

Measuring distances covered the 6 point accuracy remote. In left column are data points in which the measurement was performed, and in columns two, three , four and five are given the results of measurements performed four series. They also indicate the average values of measurements. As can be seen from the results, the degree of variation in the accuracy of measurements is not high, we can talk about repeatability of measurements.

These variations are due to the fact that in the external environment are a number of factors which can influence the accuracy. One can speak and operator's visual accuracy and especially the precision with which the other operator crosses milestone in that point of measurement. Here you can discuss the many issues involved in determining the accuracy of measurements, but the purpose is to inform the user of these devices practicalities of measuring distances. Comparing the results obtained in the laboratory and the field can specify the following:

- on the ground can be measured easily mistaken because the factors stated above.
- on the ground, atmospheric parameters can not be kept constant, it would be preferable for them to be monitored at least every 10 to 10 minutes.
- In laboratory, distance measurement is made using certified reference for geodesic base calibrated, which in turn has a valid calibration certificate, restoring compliance of measurement accuracy. Laboratory atmospheric parameters being equal, this is a plus in increased confidence in providing measurement results.
- In the above table are given the results of distance measurement using EDM tool built into a multifunction device geodesic. The measurement was performed in a summer day on the ground, in the commune of Snagov, Ilfov county, on the edge of the county road number 108 B adjacent to the measuring range of distances was (0...1000) m, containing a number 12 measuring points.

Basically positioned the device on a tripod, taking arbitrary point" 0" m. Distance between points was determined by direct measurement. Straightness measured points was determined using the cross hairs of the geodesic telescope device.

The measuring of these points was performed under varying temperature practically have introduced actual temperature values, and whenever there was a notable change in its variation introduced program the EDM instrument program for temperature correction of the values obtained. The data collection was performed using a digital thermometer.

The length of the intervals measured distances specified in the table, return using the direct method, similarly as was done in complete laboratory. The results are given in table 4 and the graph in figure 6. From this chart, can be observed, there is a measurement repeatability between the specified intervals.

Table 4. Distance measurement on the field on (0...1000) m using Leica TCR 407 Power total

Distance (m)	Indication of the device-Mean value [m]	Standard deviation *S* [m]	Temperature inserted in the device [°C]	Temperature correction made by the device [ppm]
0	**0.020 ;0.195 ; 0.015; 0.0145**	0.002901	26	13.4
10	**10.016; 10.008; 10.006; 10.001**	0.006238	25.8	14.2
20	**19.976; 19.976; 19.976; 19.975**	0.0005	25.4	13.95
30	**29.995; 29.994; 29.989; 29.990**	0.002945	25.3	13.77
40	**40.024; 40.022; 40.025; 40.025**	0.001414	25.4	13.86
50	**50.000; 49.999; 50.000; 50.000**	0.0005	25.6	14.04
100	**100.024; 100.024; 100.022; 100.025**	0.001258	25.4	13.86
200	**199.991; 199.994; 199.994; 199.992**	0.0015	25.6	14.04
400	**400.012; 400.009; 400.015; 400.010**	0.00264	25.2	13.68
500	**500.017; 500.016; 500.018; 500.018**	0.00095	25	13.5
600	**600.005; 600.008; 600.009; 600.006**	0.000182	24.8	13.32
800	**800.016; 800.009; 800.008; 800.010**	0.000359	25	13.5
1000	**1000.019; 1000.20; 1000.015; 1000.015**	0.002629	25.2	13.68

station

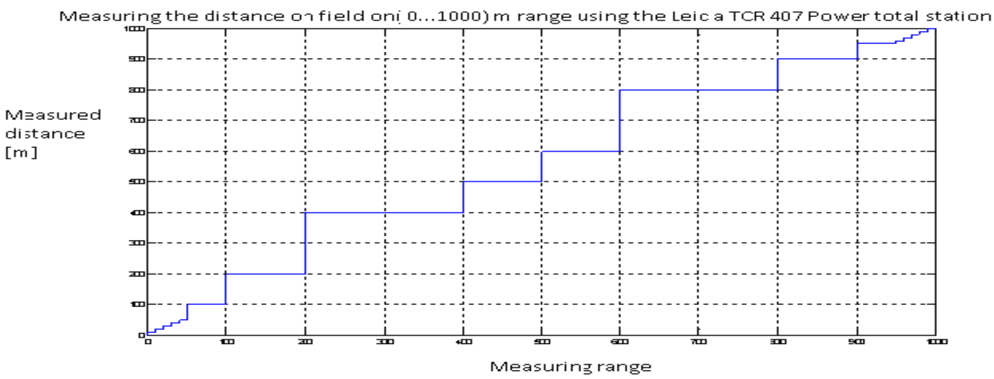

Figure.5. Distance measurement field on (0...1000) m using Leica TCR 407 Power total station

5. Conclusions

This article was written to highlight the importance to be given to the correct use of these tools in terms of their use. Were noted some important issues relating to the operation of these instruments, which should be considered before starting the measuring process, which involves making device adjustements on the field and in to the laboratory.

Measurements for distances were performed in laboratory and on land, and have found the following: on the ground the distances can be measured easily mistaken because the factors stated above, and on the ground, atmospheric parameters can not be kept constant, it would be the measurement process itself, which involves performing unit adjustments both on the field and in the laboratory at least 10 to 10 minutes.

In laboratory,distance measurement is made using certified reference base geodesic calibrated, which in turn has a valid calibration certificate certifying compliance of measurements.

In conclusion we can say that the measurement range of up to 1000 m measurement accuracy is within specification of the instrument. Interesting was to measure the distance to a higher range (1000...3500) m or higher than 3500 m.

Depending by the type of prism used and how EDM instrument measurement will achieve results that will be conclusive in terms of distance measurement errors, that is given by these devices. Unfortunately landform not allowed this.

It is recommended to perform these distances measurements for distances exceeding 1000 m because the results will show that with increasing distance and accuracy measurements will decrease if the topographic accessories which are used for that (prisms, reflectors) are appropriate.

6. References

1. *Albota Michael Gabriel, Atudorei Mircea, Balea Victor, Oprescu Nicholas Engineer surveyor's Handbook, vol 1,2,3, Technical Publishing House, Bucharest, 1972.*
2. *Atudorei Mircea, Geodetic measurements waves, Technical Publishing House, Bucharest, 1981.*
3. *Measuring instruments: Part 10: Making Accuracy in Distances – Professional, Surveyor Magazine* **-** *September 1998 Dr. Ben Buckner, LS, PE,PS.*
4. *Pop, Nicholas., M. Ortelecan, 2005, Surveying engineering, AcademicPres Publishing House, Cluj-Napoca.*
5. *Cosarca, C., 2003, Surveying Engineering, Ed MatrixRom.*
6. *Cristescu, N.,1978, Surveying Engineering, Didactic and Pedagogical.*