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WATER TUBE TILTMETER IN LOW SILESIAN GEOPHYSICAL OBSERVATORY. RESULTS OF ADJUSTMENT OF HALF YEARLY SERIES OF PLUMB LINE VARIATIONS

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ABSTRACT
In years 1996 to 2002 in Low Silesian Geophysical Observatory in Ksiaz there was built high sensitive tiltmeter (Kaczorowski, M. 1999a, 1999b). New instrument bases on phenomenon of hydrostatic equilibrium. It consists of two tens of meters long, perpendicular tubes partially filled with water. At the ends of the tubes interferometric gauges were installed. Luni-Solar forces produced tidal variations of water level in the tubes. Applied technique allowed us to measure these variations with accuracy 10^{-9} m. For hundred of meters long tube changes of water level of order 10^{-9} m correspond to plumb line variations of order 10^{-3} (msec) of arc. During the time of construction as well as during first years of exploitation of a new instrument there appeared unexpected problems. There were disturbances of free water surface caused by mechanical and organic origin. These problems significantly retard moment of initiation of permanent measurements. Therefore, the first time series of plumb line variations suitable for tidal analysis were obtained at the end of 2002. The tidal analysis basing on mean square method was applied to adjusted suitable data. The results of tidal analysis confirm high sensitivity of long water tube tiltmeter (Bower, D.R. 1973), (Ozawa, I. 1967), (Tsumura, K. 1960), (Takahasi, R. 1930) and indicate reasons of disturbances. We are still working to diminish ratio of noise to tidal signals. For this purpose special constructions in environment of long water tube like curtains and roofs were made. In water system low frequency filters was installed to slow down water level variations in measure chambers of interferometers and to reduce high frequency water waving. Organic disturbances have been fully eliminated by chemical method. System of registration and managing interference figures as well as their processing, bases on four programs written in Space Research Centre (SRC). All programs can be used in Windows 95, 98, 2000 and XP systems.

KEYWORDS: geodynamic, earth tides, tidal deformations, tilt effect, tiltmeters.

1. BASIS OF MEASUREMENTS OF THE LONG WATER TUBE TILTMETER AND PHENOMENAEFFECTING INSTRUMENT

In new tiltmeter, the momentary levels of water at the ends of tubes are measured values. Changes of difference of water levels divided by length of the tube are interpreted as angles of plumb line variations. In underground environment of instrument there are lot of reasons producing variations of water level. All phenomena causing variations of water levels order single nanometres are important. We are able to divide these phenomena on two groups.

First group consists of effects external in relation to instrument and its environment. To this group belong all geodynamic phenomena producing tilt effect like tidal deformations, direct and indirect effects, loading effects, free oscillation of the Earth as well as crust movements. For all these phenomena lengths of tilt waves are several orders greater than length of the tiltmeters tube. Therefore water level variations produced by these effects at both ends of tube are in opposite phases. The second group of phenomena producing water level variations originates from inside or environment of the instrument. To this group belong effects causing changes of water mass in hydrodynamic system of instrument like outflows, vaporization and condensation of water inside the tube. Similar effect appears after lifting or lowering any part of the tube. Mentioned effects give systematic or long period variations of water level. High frequency oscillations of water level are generated by drops dropping on the surface of tube and motions of the air in underground. Motions of the air in underground with velocity meter per dozen or so seconds were empirically proved. The reasons of air motions in corridors are convection and blasts from shafts. Air pressure changes of order 10^{-6} of [hPa] produced in our instrument measurable water level variations. Effects originating from inside instrument as well as from its environment generate water level variations at ends of tube in consistent phases. Comparison of the phases of water level variations allowed us to determine whether observed effect is geophysical or instrumental origin. This property of a new tiltmeter as well as high sensitivity allowed us to open new investigations of plumb line variations phenomena that were inaccessible with apply of old class of tiltmeters.

2. TECHNOLOGY OF MEASURING OF WATER LEVEL VARIATIONS

The measuring system of water level variations applied in new tiltmeter bases on interference technology. This technology allowed us to determine water level variations with accuracy close to single nanometres. At the ends of both tubes the interference gauges have been installed. Optic system of interferometers was maximally simplified to red colour lasers He-Ne, light separator plate, reflecting lens and CCD camera. We choose Newtonian interferometer in classic column architecture. Pictures of Newtonian interference rings are generated on CCD element like on a screen. All elements of interferometers have been adapted to conditions of work in high humidity. Water system of interferometers consists of two concentric chambers joint by several narrow tubes. This system suppresses high frequency oscillations of water level variations in internal chamber.

3. THE METHODS OF DECREASING LEVEL OF NOISE

At the beginning of our measurements it became clear that from point of view of nanometre surveying there are lot of sources of disturbances in underground. Unexpected high level of noise has been found in plumb line variations curve obtained on the base of first measurements. Very strong source of water level disturbances was connected with drops dropping on the surface of tube. The mechanical energy of these drops was transferred to the water causing waving. To stop these effects we built system of roofs one meter above the tubes. At the same time it became clear that problem with drops dropping was not solved definitely. In area where tubes cross central part of corridors we observed condensations of water under the roof causing secondary dropping water on the tube. Second roof was built ten centimetres above the tube. The energy of dropping drops was minimized but effect of water condensation under lower roof still exists. Second elements strongly reducing effects of shocks into the tube are separators of mechanical oscillations. High frequency oscillations are transporting not through the water but over the surface of plastic tubes. Separation of the measure modules from main water tubes caused decreasing of high frequency oscillations of water inside interferometers. Other reason of water level oscillations but little bit lower frequency is horizontal gradient of air pressure in underground corridors. In spite of our instrument records air pressure changes of the order 10^{-6} of [hPa] gradient of pressure along the tube 10^{-8} of [hPa/m] is important. Such a gradient can be produced by effect of compensation pressure in underground with momentary pressure at the Earth surface. Our goal is as much as possible slow down compensation process with special consideration of the environment of measure points. For this purpose we built hermetic curtains crossing corridors and separating elements of instrument from shafts and other parts of underground. Existence of horizontal pressure gradient has been proved by observations of rate of smog distribution. Observed by us extreme values of air velocity do not exceed quarter of meter per second.

Other phenomenon producing systematic motions of air is convection caused by relatively large geothermal gradient in Low Silesian area. We made experiment with sixteen-channel thermometer with resolution 0.01 degree. The results of half daily measurements of vertical temperature gradient confirm our conjecture about convection.

4. INFLUENCE OF MECHANICAL DISTURBANCES ON THE PROCESS OF MEASUREMENTS

Reasons of free water surface disturbances, mentioned in previous section, cause two kinds of effects in process of measurement. The first result of free water surface oscillations is that curve of tilt is not smooth but oscillates around the centre of momentary tide. These oscillations reached hundreds of nanometres maximally, which respond to half millisecond of arc of plumb line variations. The second result of free water surface oscillations is circle sleep effect. Circle sleep effect arrives when velocity of water level variation is greater than fifteen nanometres per second. In such a moment we lose the phase what is appeared as jump on the curve of tilt. Usually height of jump is equal to multiplicity of full phase. These effects are very characteristic and easy to eliminate.

5. THE LONG WATER TUBE TILTMETER SOFTWARE

Process of the plumb line curve calculation consists of few steps. During the first step we try to obtain sequence of images of Newtonian rings while in the second step we concentrate on the process of assigning time series of phases to sequence of images. Next we process time series of phases to determine time series of progressive phases. At the end of calculations the progressive phases are used to determine time series of plumb line variations. All the mentioned processes are administrated by four procedures. Process of determination and registration interference images on hard disk is realized by program “Recorder”. Program “Report” every day prepares information about conditions of measure system as well as quality of images to send daily report to Warsaw. Programs “Recorder” and “Report” work permanently in Ksiaz observatory making process of determination of the sequence of images of Newtonian rings fully automatic.

We present now in great summary list of steps in process of interference images analysis:

- Determination of light intensity sections for all interference images.

Table 1 The results of tidal analyze of time series of plumb line variations.

FINAL ADJUSTMENT OF TIDAL DATA
LEAST SQUARE ANALYSIS IN CLASSICAL MANNER (CHOJNICKI METHOD)

FINAL RESULTS OF COMPUTATIONS - ESTIMATION OF ACCURACY BASED ON RESIDUAL
FILTRATION OF OBSERVATIONS / FILTER 51 / 833
POTENTIAL CARTWRIGHT-EDDEN-(DOODSON) / COMPLETE EXPANSION
COMPUTATION IN SPACE RESEARCH CENTER, PAS - WARSAW

STATION 0906 KSIAZ
POLAND

50 51 N 16 18 E H 350 M P 50 M DISTANCE FROM THE SEA 370 KM
ARTIFICIAL UNDERGROUND CORRIDOR SEDIMENTARY ROCK PARTIALLY METAMORPHIC

DATA SOURCE - LONG WATER TUBE TILTMETER
AZIMUTH OF INSTRUMENT FROM NORTH TO EAST -121.4
CALIBRATION - ABSOLUTE
INSTALLATION - BY M. KACZOROWSKI
OPERATION - BY M. KACZOROWSKI

TOTAL NUMBER OF DAYS 182 **2659 READINGS**

WAVE GROUP			ESTIM.AMPL.		AMPLITUDE COEFFICIENTS		PHASE DIFFERENCE		RESIDUALS	
ARG.	**N**	**NAME**	**VALUE**	**R.M.S.**	**VALUE**	**R.M.S.**	**VALUE**	**R.M.S**	**AMPL.**	**PHASE**
105.-39.	65	Q1	.74	.04	.78543	.04613	-17.077	3.361	.23	-74.7
143.-149.	26	**O1**	**3.44**	**.04**	**.75974**	**.00949**	**-14.064**	**.718**	**.86**	**-75.2**
152.-158.	22	M1	.46	.05	.77480	.07856	-.563	5.802	.05	-5.1
161.-168.	33	**PSK1**	**4.36**	**.04**	**.81149**	**.00666**	**-17.179**	**.471**	**1.31**	**-79.9**
172.-177.	22	J1	.41	.05	.98869	.11265	-7.607	6.514	.14	-23.8
181.-1E3.	37	OO1	.20	.05	.61402	.14818	13.678	13.767	.05	121.4
207.-23X.	41	2N2	.34	.04	.77181	.08517	-21.080	6.302	.12	-83.1
243.-248.	24	**N2**	**1.28**	**.04**	**.64921**	**.01881**	**-11.620**	**1.664**	**.28**	**-111.1**
252.-258.	26	**M2**	**5.69**	**.04**	**.60786**	**.00374**	**-15.725**	**.352**	**1.81**	**-121.6**
262.-267.	17	L2	.16	.04	.70506	.17033	-35.423	13.867	.09	-105.3
271.-2X5.	47	**S2K2**	**2.87**	**.04**	**.53366**	**.00697**	**-14.948**	**.745**	**1.18**	**-141.1**
327.-375.	17	M3	.06	.01	.52236	.07378	9.170	8.103	.03	163.9
382.-382.	1	S3	.02	.01	.15737	.08731	73.840	31.767	.08	168.8

ROOT-MEAN-SQUARE ERROR (R.M.S.) M-ZERO 0.4674 MILLISEC

- Partition on classes of identity of all interference images and determination of the representatives of the classes.
- Determination of the phases of representatives of classes.
- Attribution of the phases of representatives to other images and calculation of progressive phase.
- Determination of the time series of water level variations as well as time series of plumb line variations.
- Interpolation time series of plumb line variations in hour interval to adapt data format to tidal analysis program.

Two programs realize all above jobs: "Analysis of interference images" and "Phases processing and determination of plumb line variations".

Applied programs have been written in programmer's environment –"Visual Studio" and can be used in systems Windows 95, 98, 2000 or XP.

6. TIDAL ADJUSTMENT OF PLUMB LINE VARIATIONS SERIES.

The observations of plumb line variations obtained from long water tube tiltmeter in second part of 2002 were elaborated with help of tidal analysis method. From whole measure period we could obtain 2659 interpolated hourly data. Before interpolation plumb line variations time series were processed to remove jumps and discontinuities. Because density of measurements of long water tube tiltmeter is equal to one data per 10 seconds and tidal analysis program needs hourly series, it was necessary to interpolate observations. Tidal adjustment basing on least square method was applied (Chojnicki, T., 1970). In the process of analyze we used expansion of tidal series by Cartwright-Edden-Doodson considering 511 tidal waves.

Mean square error of observations obtained from analyze is less than 0.4674 (msec) of arc (Tab. 1). Taking into account quality of first data series, high level of noise and great number of discontinuities we are able to expect that upper limit of sensitivity of a new tiltmeter is essentially higher than 0.4674 (msec) of arc. This expectation is confirmed by small errors of determination of amplitudes coefficients indicated on good adjustment of observations to theoretical tidal curve. We are able to expect also that the temperature wave S1 effects on the long water tube observations weaker than on horizontal pendulums. The amplitude coefficient of PSK1 group, disturbed by Sun temperature wave S1, is equal 0.81. For horizontal pendulums coefficient of PSK1 group is greater than 1. According to theory phase shifts of tidal waves are negative except weak waves OO1, S3 and M3. In the case of horizontal pendulums we obtained positive phase shifts also for strong waves. It is result of problems with determination of momentum azimuths of pendulums. This problem does not exist in a case of long water tube tiltmeter.

7. CONCLUSIONS

Progress with plumb line measurements in Low Silesian Geophysical Observatory in Ksiaz was obtained with help of a new instrument - long water tube tiltmeter. The results of tidal analysis confirm high sensitivity of new instrument. Mean square error of data series of plumb line variations is 0.4674 (msec) of arc. For comparison the mean square error of observations of many years long data series from horizontal pendulums is close to 1 (msec) of arc. For the present, our activity is concentrated on diminishing level of noise. We test frequency filters to diminish amplitude of high frequency water waving. Most of the reasons of noises were eliminated till now. Some of mechanical sources of noises were eliminated with help of special roofs and curtains. We expect that of actually assembled time series of plumb line variations accuracy overhead 0.4674 (msec). Additional increase of accuracy of plumb line variations will be obtained after employment of the coherence method in process of determination of the difference signal of water variations from both ends of tubes.

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Fig. 1 The interferometer on measure platform.

Fig. 2 Great curtain shields measure platform.