sciendo

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2018; 28 (4): 129-137

DOI: 10.2478/ceer-2018-0056

Original Research Article

TEST OF IMPACT OF VIBRATIONS FREQUENCY ON MEAN ERRORS OF THE PRECISE HEIGHT DIFFERENCES MEASUREMENT WITH ANALOGUE AUTOMATIC LEVELLER NI002

Marek KURNATOWSKI[1]

West Pomeranian University of Technology Szczecin, Poland

A b s t r a c t

The article describes the results of tests carried out to determine the measurable effect of vibrations on the accuracy of measurements with an automatic precise leveller. It contains specification of the research station created to examine the case and description of factors affecting the measurement results. The multi-frequency vibrations were forced on a leveller during measurements and calculated mean errors for each frequency analysed. The range of frequencies for which the measurement was possible was estimated. The obtained results can be helpful in the engineering measurements designing, especially in industrial areas, where vibrations are an inseparable element of the environment.

Keywords: vibrations, measurement accuracy, precise levelling

1. INTRODUCTION

Geodetic measurements of vertical displacements are very often carried out in specific conditions, characteristic for the examined objects. The measurement conditions, especially temperature changes, visibility as well as vibrations, should be taken into account during measurement technologies design. There is

[1] Corresponding author: Wydział Budownictwa i Architektury Katedra Budownictwa Wodnego al. Piastów 50, 70-311 Szczecin, e-mail: marek.kurnatowski@zut.edu.pl +48 914494540

no possibility for the technological processes taking place in industrial or power plants to be stopped for the duration of the measurement, in order to provide the surveyors with optimal conditions. The surveyors are the ones who must adapt their technologies to a specific object and its specific features. Very often, during the measurement, the work is hindered by vibrations caused by working machines, and commonly used automatic levellers equipped with compensators are very sensitive to shocks. The compensators are systems of prisms or mirrors suspended on pendulums which fix the horizontal line of sight using the direction of gravity force. However, when the compensator is subject to vibrations, the image in the eyepiece begins to vibrate and often causes staff reading errors; therefore, the accuracy of the measurement decreases or the measurement in certain places of the object becomes completely impossible

2. RESEARCH STATION AND MEASUREMENT CONDITIONS

In order to investigate how the change of the frequency of the leveller vibration affects the accuracy of single height difference measurement, an experiment was carried out. The analogue leveller Ni002 and a wooden tripod were used for the study. The instrument's vibrations were generated by placing an 80 watt modellers engine on the centre of one of the tripod legs, with an eccentrically mounted aluminium weight on its axle. Weight of the aluminium disc was 7 g, its diameter 25 mm, and the eccentricity 5 mm. The axle of the engine was directed perpendicular to the leg of the tripod, as shown in Fig. 1. The engine rotational speed was regulated by a potentiometer, so it was possible to maintain constant engine rotations with an accuracy of about 0.2 Hz. Neither the weight of the aluminium disc nor its eccentricity was changed; thus, the influence of the change in the vibration amplitude on the accuracy of the measurement was not studied. Measurement of the height difference between the two benchmarks took place in the main hall of the laboratory of the Faculty of Civil Engineering and Architecture of the West Pomeranian University of Technology in Szczecin, Poland. The indoor research station ensured the same measurement conditions - lighting and constant temperature, as well as isolation from external factors such as urban traffic or wind. The levelling staffs were set on two benchmarks and the position of the instrument was set at equal distances from the staffs - 17.2 m. It is an average target distance for precise levelling, assuming that the maximum distances should not exceed 35 m [1]. The station was placed on the line connecting the two benchmarks and the tripod leg equipped with the engine was placed on this line, so that the engine axle was perpendicular to the lines of sight. In this setting, the inclination of the engine axle to the line of sight of the leveller was identical for back sight and foresight staffs. Observations have shown that this angle affects the ability to read a staff and this ability is the poorest for the adopted setting – when engine axle is parallel to the line of sight, the compensator vibration is suppressed with this way of tremble enforcement. Other factors that influence the measurement station are the length of the tripod legs and their slenderness. The longer the tripod legs are, the more the rotating mass stimulates the compensator; the similar effect is obtained by setting the tripod legs very narrowly. The tripod was standing on a concrete floor, so the vibrations were muffled less than in case when he tripod legs are driven into the ground. In order to maintain equal conditions for all measurements, the height of the instrument was chosen for a man's average height (175 cm) and it was changed in the range of ± 5 cm only, without moving the legs of the tripod. The measurements were performed by one observer.

Fig. 1. The tripod with engine generating vibrations

The frequencies were fixed by setting the appropriate number of engine rotations per minute with a potentiometer; next, the instrument's own vibrations were measured using the piezoelectric sensor. There were no differences between those two frequencies in post-processing comparison, therefore it can be assumed that the measurement of the engine frequency is sufficient to determine the natural frequency of the instrument.

3. EFFECT OF VIBRATIONS ON STAFF READINGS

Measurements were made for 13 cases for which the measurement was feasible. In the first case no vibrations were imposed at all, next measurements were made consecutively at the assumed frequencies in the ranges of 7 - 15 Hz and 37 - 43 Hz. This selection of frequencies results from the observed instrument's sensitivity to vibrations. In the range of 0 - 10 Hz, the instrument practically does not react to vibrations, which is confirmed by calculations of mean errors of measured height differences. The decrease in reading accuracy occurs between 10 and 11 Hz and progresses to 15 Hz. The image in the eyepiece starts to vibrate with increasing amplitude, but still slow enough that the observer can pick up the balanced reading. Engine rotations with a frequency above 15 Hz cause such a large blurring of the image in the eyepiece that the observer is unable to read. The situation changes at a frequency around 37 Hz, where the picture becomes blurred but stable. With a small amplitude, the image of lines on the staff changes into grey, fuzzy rectangles, and it is possible to set the cross hairs on the symmetry axis of the right staff rectangle [2]. In the case of vibrations imposed in the experiment, the amplitude of the trembling rectangles observed in the staff image decreased with higher frequencies and reading from the staff became possible. Above the frequency of 43 Hz the vibrations were so strong that the compensator went out of its range of work, which caused the need to re-level the instrument. It was also observed that at some high frequencies (around 30 Hz) the image of the fuzzy staff rectangle is reasonably stable and can be aimed with quite high accuracy, but as the vibrations were stopped, the cross hairs was aimed at a completely different place on the staff. This means that not only vision acuteness and image stability of the staff determine the possibility of measurement performance [3].

$$m_0 = \sqrt{\frac{[vv]}{n_{nadl}}} \tag{3.1}$$

where: m_0 – mean error of a single height difference in millimeters, $[vv]$ – sum of corrections squares, i.e. differences between averaged observation and the result of measurement, n_{nadl} – number of additional observations (number of degrees of freedom). The calculations confirmed the effects observed during the measurement. In the range of 0 - 10 Hz the vibrations do not affect the accuracy of the height difference determination. The error increases in the range of 11 - 15 Hz and reaches the peak value at the upper limit of this range. The peak value is about 4.5 times greater than the error calculated for the initial conditions (without vibrations). In the range of 37-43 Hz the error remains more or less at the same level, with the lowest value in the middle of the range (40 Hz). Table

1 presents the calculated mean errors and the values of the height difference calculated as an average from each of the observation samples. These values are also shown in Fig. 2 and 3. In the case of calculations of the height difference value, the attention is paid to two frequencies, 12 and 13 Hz, for which the averaged value clearly differs from the others. It can be assumed that for this range of frequencies the reading from the vibrating image of the staff is biased with a systematic error, which the observer is unable to compensate. This error is regularly repeated for every observation and is compensated for the mean error calculation, but it does have a significant impact on the measurement result.

Table 1. Height differences values and their mean errors

frequency [Hz]	m_0 [mm]	height difference Δh [mm]	$\Delta h+m_0$ [mm]	$\Delta h-m_0$ [mm]
0	0.034	64.69	64.73	64.66
7	0.033	64.71	64.74	64.67
10	0.038	64.69	64.73	64.66
11	0.067	64.67	64.74	64.60
12	0.091	64.76	64.85	64.67
13	0.094	64.78	64.88	64.69
14	0.097	64.70	64.80	64.60
15	0.154	64.71	64.86	64.55
37	0.111	64.69	64.80	64.58
38.5	0.121	64.67	64.79	64.55
40	0.099	64.67	64.77	64.57
41.5	0.124	64.68	64.81	64.56
43	0.12	64.69	64.81	64.57

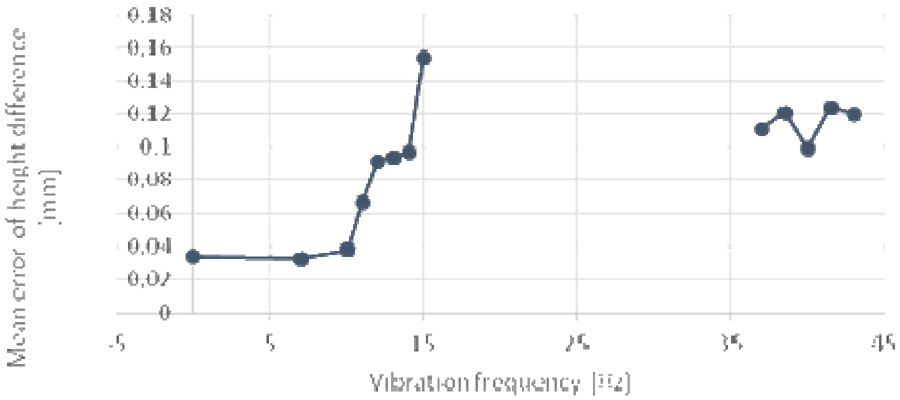

Fig. 2. The relation between mean errors and the vibration frequency

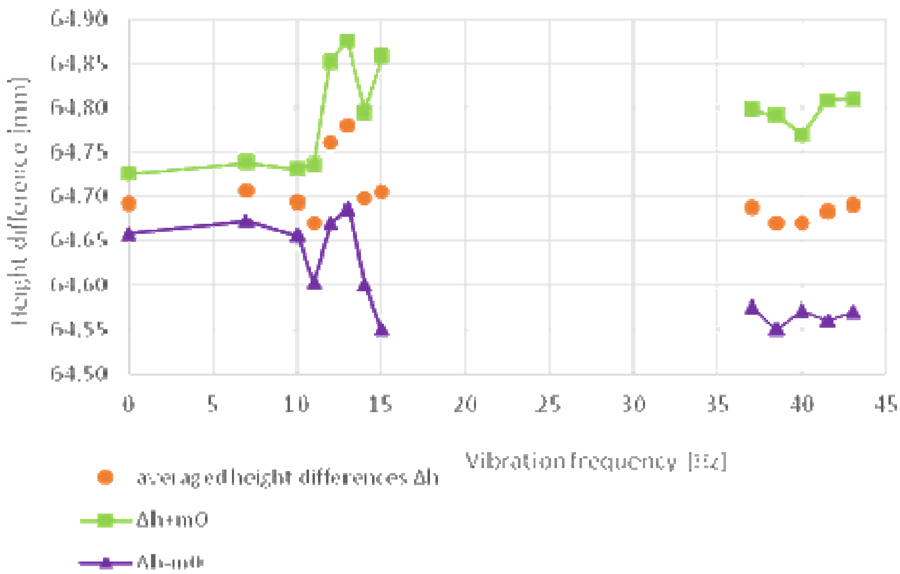

Fig. 3. Relation between average results of height differences measurement and the vibration frequency

Worthy of notice is that even for frequencies with low measurement accuracy, the values of the measured height differences are very close to those measured without the impact of vibrations, despite the fact that their mean error is much

higher. Unfortunately, achieving such a result would in practice involve multiple measurements of the same quantities, which is economically unjustified.
The measurement with the piezoelectric sensor was performed in two directions of vibration - along the vertical line and along the line of sight. In each case the influence of vibrations is greater for the direction along the vertical, which is confirmed in Fig. 4. These graphs show the deviation of the tested object from the balance at 43Hz vibration. The graph on the left shows the deviation of the object along the line of sight, on the right - along the vertical line. The values in both figures are absolute values of the amplitude.

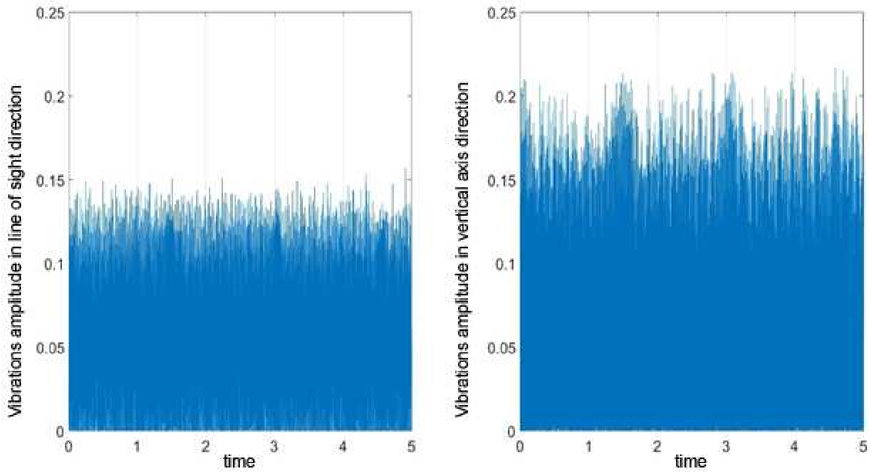

Fig. 4. Comparison of vibration amplitude absolute value in time, along the line of sight and along the vertical axis of the instrument at the 43Hz oscillation frequency

The graph shows that the amplitude of vibrations in the vertical direction is greater by about 40% in relation to the vibrations in the direction of the line of sight. There was also an increase in the amplitude measured by the sensor along with the increase in frequency. Fig. 5 shows a comparison of the vibration amplitudes measured at 14 Hz (left graph) and 40 Hz (right graph) in the vertical direction. Although the deflections at 40 Hz are greater than the deflections at 14 Hz over three times, the mean error value of the measured height difference is similar - 0.097 mm and 0.099 mm respectively. This can mean that the amplitude of vibrations does not have such a significant influence on the accuracy of measurements as the frequency has.

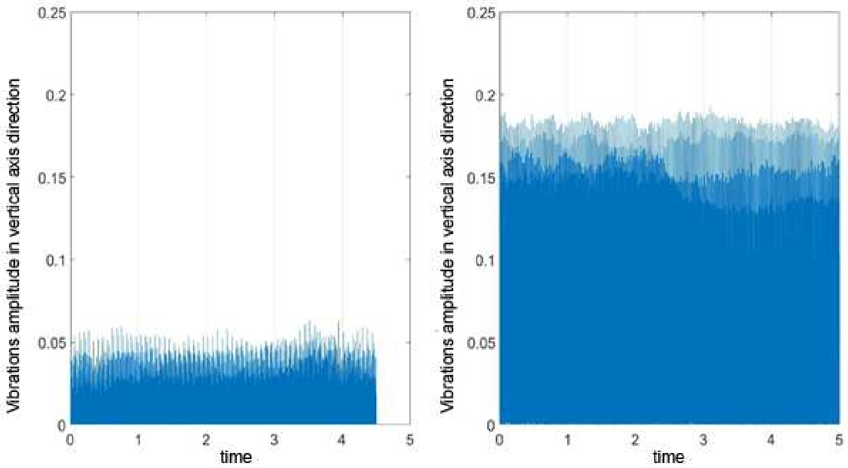

Fig. 5. Comparison of amplitude absolute values in time in the vertical axis of the instrument at 14Hz and 40Hz vibrations

4. CONCLUSIONS

The conducted experiment shows that in the presence of vibrations the measurements with precise leveling characteristics are possible to be performed under specific conditions. The maximum value of the mean error of a single height difference is estimated at approx. 0.15 mm, taking into account only the range of vibration frequencies at which analogue level measurement is possible. This is a value that is still much lower than the errors encountered in technical levelers. It turns out that the measurement is possible not only at low frequencies (up to 15 Hz), but also at higher frequencies to some extent. For the constructed test station this range included frequencies from 37 to 43 Hz, however, it may be different for other conditions - the influence of the change in amplitude or the influence of vibrations on another type of the leveler was not studied. Research will be extended to include these aspects, primarily with the use of code levels, which are widely used in engineering surveys nowadays.

At the 12 Hz and 13 Hz frequencies, compared to the other tested frequencies, a difference of approximately 0.08 mm was observed in the obtained value of height difference. At the remaining frequencies, differences in the values did not exceed 0.04 mm. Although the error calculated at 12 and 13 Hz was lower than at higher frequencies, there was probably some effect introducing a systematic error that caused readings errors on staffs.

There is also a possibility that the amplitude has smaller impact on the accuracy of the measurement than the frequency. To confirm this, it is necessary to carry out tests with variable amplitude, e.g. changing the mass of the weight or its eccentricity. When analyzing the results of measurements, it should be considered that the reading from the staff with an analogue leveler is a subjective issue of the observer. Despite providing the same external conditions, such as lighting or temperature, factors like the observer's experience, his sense of sight or even his temporary disposition may be decisive when determining specific values of errors.

REFERENCES

1. *Niwelacja precyzyjna*, Warszawa, Polskie Przedsiębiorstwo Wydawnictw Kartograficznych im. E. Romera 1993.
2. Hermanowski A.: *Pomiary przemieszczeń pionowych*, Warszawa, Instytut Geodezji i Kartografii 1993.
3. Adamczewski Z.: *Rachunek wyrównawczy w 15 wykładach*, Warszawa, Oficyna Wydawnicza Politechniki Warszawskiej 2004.

BADANIE WPŁYWU CZĘSTOTLIWOŚCI DRGAŃ NA ŚREDNIE BŁĘDY POMIARU PRZEWYŻSZEŃ W PRECYZYJNYM NIWELATORZE ANALOGOWYM NI 002

S t r e s z c z e n i e

Artykuł opisuje wyniki badań przeprowadzonych w celu określenia wymiernego wpływu drgań na dokładności pomiaru analogowym niwelatorem precyzyjnym pojedynczego przewyższenia. Opisano stanowisko badań oraz generator wstrząsów, jakie stworzono na potrzeby zbadania problemu oraz czynniki wpływające na wyniki pomiarów. Porównano wartości błędów średnich uzyskanych w wyniku pomiarów przeprowadzonych niwelatorem pobudzonym do drgań o różnych częstotliwościach i oszacowano przedziały tych częstotliwości, dla których pomiar był możliwy. Analizie poddano również otrzymane wartości przewyższeń, zmierzone przy różnych częstotliwościach drgań. Otrzymane wyniki mogą być pomocne przy projektowaniu pomiarów inżynierskich w warunkach przemysłowych, gdzie wstrząsy są nieodłącznym elementem środowiska.

Keywords in Polish: drgania, dokładność pomiaru, niwelacja precyzyjna

Editor received the manuscript 17.10.2018