Study of electronic and optical-mechanical levels

Yu I Pimshin¹, Yu V Zayarov¹ and D M Arsenyev²

¹National Research Nuclear University "MEPhI"
²Don State Technical University DSTU

E-mail: YIPpimshin@mephi.ru, YVZayarov@mephi.ru, dima81-07@mail.ru.

Abstract. The article presents the study of electronic and optical-mechanical levels. It describes the vertical comparator and the method of its use in the study of levels. In addition, a variant of the universal comparator which improves stationary capabilities is proposed. In the study of levels the errors in measuring exceedances at specified working distances are determined, including a description of the procedure for determining errors of undercompensation of the level slope and the total error of the course correctness of the telescope focusing lens and the errors of applying divisions of the range poles for optical levels, and scales with Rab-code divisions for electronic ones. The article is written as part of the implementation of the NRNU MEPhI Competitiveness Enhancement Program.

1. Introduction

Describing the current state of the measuring equipment, it is necessary to note its rapid development. There is an update of measuring instruments, using new physical methods, principles of measurements, means of microelectronics and software every five, maximum ten years. However, a common feature of a new technology is its high cost compared to previous generations. Therefore, the update technology is somewhat behind the pace of its development. Production tasks are tightened in the requirements for accuracy of measuring, in its turn, without focusing on the difficulties, the complexity of the of new measuring equipment introduction. Under these conditions, there is a previously developed approach used for a long time to improve measurement accuracy. It is a study of existing equipment, the definition of achievable, accuracy-limiting characteristics and the use of the accuracy of devices at the limit when solving production problems. It almost always gives a positive result to solve high-precision measurement tasks and to provide some time to purchase new high-precision equipment when its cost is more affordable.

The levels are instruments designed to measure elevations. Today, this type of devices is widely used in geodesy, construction, installation, heavy mechanical engineering, etc. The problem of providing high and precise accuracy remains relevant for these devices [1–4].

The research carried out to increase the accuracy of measurements when leveling remains an urgent issue today.

2. Theoretical basis of the proposed method

The proposal of the technique is based on the use of a vertical comparator.

Figure 1 shows an example of a vertical comparator circuit, where S₁, S₂ is the distance from the instrument station to the first and last fixed point respectively, and S₁= S₂ in this comparator. There is
horizontal distance between the points of the comparator \( B_1, B_2, B_3, B_4, B_5, B_6, B_7, B_8 \) where \( B_1 = B_2 = B_3 = B_4 = B_5 = B_6 = B_7 = B_8 \). Accuracy of performance of all distances of the comparator is \( \pm 10 \) mm. Readings on the rail by level, installed at the lower station are \( A_{H1} \ldots A_{H9} \) and readings on the rail by level, installed at the top station are \( A_{B1} \ldots A_{B9} \). Moreover \( A_{H1} = a_{H1} + d_{H1}, \ldots, A_{H9} = a_{H9} + d_{H9}; \)
\[
\begin{cases}
A_{H1} = a_{H1} + d_{H1}, \ldots, A_{H9} = a_{H9} + d_{H9}; \\
A_{B9} = a_{B9} + d_{B9}, \ldots, A_{B1} = a_{B1} + d_{B1};
\end{cases}
\]
where \( a_{H1}, \ldots, a_{H9}; a_{B1}, \ldots, a_{B9} \) are values of theoretical readings on rails corresponding to the horizontal position of the sighting axis; \( d_{H1}, \ldots, d_{H9}; d_{B1}, \ldots, d_{B9} \) are errors caused by undercompensation of the angle of level inclination.

Whereby
\[
\begin{align*}
\Delta d_{H1} &= d_{H2} - d_{H1}, \\
\Delta d_{B9} &= d_{B8} - d_{B9}.
\end{align*}
\]

**Figure 1.** Step vertical comparator diagram

Based on the constructive condition of the comparator \( B_1 = B_2 = B_3 = B_4 = B_5 = B_6 = B_7 = B_8 \) и \( S_1 = S_2 \) we have \( d_{H1} = d_{B9}, \Delta d_{H1} = \Delta d_{B9} \), then
\[
\begin{align*}
d_{H2} &= d_{H1} + \Delta d_{H1}, \quad d_{H3} = d_{H1} + 2 \cdot \Delta d_{H1}, \quad d_{H4} = d_{H1} + 3 \cdot \Delta d_{H1}, \ldots, \quad d_{H9} = d_{H1} + 8 \cdot \Delta d_{H1}; \\
d_{B8} &= d_{B9} + \Delta d_{B9}, \quad d_{B7} = d_{B9} + 2 \cdot \Delta d_{B9}, \quad d_{B6} = d_{B9} + 3 \cdot \Delta d_{B9}, \ldots, \quad d_{B1} = d_{B9} + 8 \cdot \Delta d_{B9}.
\end{align*}
\]

In this case, the readings by level \( A_{H1} \ldots A_{H9} \) and \( A_{B1} \ldots A_{B9} \) will be defined as:
\[
\begin{align*}
A_{H1} &= a_{H1} + d_{H1}, \quad A_{H2} = a_{H1} + d_{H1} + \Delta d_{H1}, \quad A_{H3} = a_{H1} + d_{H1} + 2 \cdot \Delta d_{H1}, \ldots, \quad A_{H9} = a_{H1} + d_{H1} + 8 \cdot \Delta d_{H1}; \\
A_{B9} &= a_{B9} + d_{B9} + 8 \cdot \Delta d_{B9}.
\end{align*}
\]
\[ A_{B1} = a_{B9} + d_{B9} + 8 \Delta dB, \ldots, A_{B7} = a_{B9} + d_{B9} + 2 \cdot \Delta dB, \ A_{B8} = a_{B9} + d_{B9} + \Delta dB, \ A_{B9} = a_{B9} + d_{B9}. \]

Then the total count at each point of the vertical comparator will be equal to:

\[
\begin{align*}
A_1 &= (a_{H1} + a_{B9}) + (d_{H1} + d_{B9} + 8 \Delta dB); \\
A_2 &= (a_{H1} + a_{B9}) + (d_{H1} + d_{B9} + \Delta dB); \\
A_3 &= (a_{H1} + a_{B9}) + (d_{H1} + d_{B9} + 2 \cdot \Delta dB); \\
A_4 &= (a_{H1} + a_{B9}) + (d_{H1} + d_{B9} + 3 \cdot \Delta dB); \\
A_5 &= (a_{H1} + a_{B9}) + (d_{H1} + d_{B9} + 4 \cdot \Delta dB); \\
A_6 &= (a_{H1} + a_{B9}) + (d_{H1} + d_{B9} + 5 \cdot \Delta dB); \\
A_7 &= (a_{H1} + a_{B9}) + (d_{H1} + d_{B9} + 6 \cdot \Delta dB); \\
A_8 &= (a_{H1} + a_{B9}) + (d_{H1} + d_{B9} + 7 \cdot \Delta dB); \\
A_9 &= (a_{H1} + a_{B9}) + (d_{H1} + d_{B9} + 8 \cdot \Delta dB).
\end{align*}
\]

The excess at each stage of the vertical comparator is determined from the expressions:

\[
h_{1-2} = (A_1 - A_2)/2, \ h_{2-3} = (A_2 - A_3)/2, \ldots, \ h_{7-8} = (A_7 - A_8)/2, \ h_{8-9} = (A_8 - A_9)/2.
\]

The component of undercompensation of the angle of level inclination installed at the lower station is determined by the formulas:

\[
\delta_{H1-2} = (A_{H2} + h_{1-2}) - A_{H1}, \ \delta_{H1-3} = (A_{H3} + h_{1-2} + h_{2-3}) - A_{H1}, ...,
\]

\[
\delta_{H1-9} = (A_{H9} + h_{1-2} + h_{2-3} + h_{3-4} + h_{4-5} + h_{5-6} + h_{6-7} + h_{7-8} + h_{8-9}) - A_{H1}.
\]

The component of undercompensation of the angle of level inclination installed at the top station is determined by the formulas:

\[
\delta_{B9-8} = (A_{B9} + h_{8-9}) - A_{B8}, \ \delta_{B9-7} = (A_{B9} + h_{7-8} + h_{8-9}) - A_{B7}, ...,
\]

\[
\delta_{B9-1} = (A_{B9} + h_{1-2} + h_{2-3} + h_{3-4} + h_{4-5} + h_{5-6} + h_{6-7} + h_{7-8} + h_{8-9}) - A_{B1}.
\]

The analysis of the total error of the course correctness of the focusing lens and the errors of applying divisions of the range poles for optical levels, and scales with Rab-code divisions for electronic ones, are carried out by examining for equality of values \(\Delta_{H2,3}, \ldots, \Delta_{H8,9}\) and \(\Delta_{B7,8}, \ldots, \Delta_{B8,9}\).

\[
\Delta_{H2,3} = \delta_{H1-2} - \delta_{H1-3}, \ \Delta_{H3,4} = \delta_{H1-3} - \delta_{H1-4}, \ \Delta_{H4,5} = \delta_{H1-4} - \delta_{H1-5}, \ \Delta_{H5,6} = \delta_{H1-5} - \delta_{H1-6}, \ldots, \ \Delta_{H8,9} = \delta_{H1-8} - \delta_{H1-9}.
\]

\[
\Delta_{B7,8} = \delta_{B9-8} - \delta_{B9-7}, \ \Delta_{B8,9} = \delta_{B9-7} - \delta_{B9-6}, \ldots.
\]

Thus, the levels are studied with the definition of corrections to the values of readings at given distances. The introduction of amendments allows increasing the accuracy of measurements. At the same time, it is possible to examine levels at different working distances by changing \(S_1\) and \(S_2\).

The vertical comparator can be made in a universal version, see Fig.2. The design of the comparator can be represented as the main frame of the comparator (1) on which the frame (2) is installed, with the possibility of lifting it. The steps (3) are permanently fixed on the frame (2), with a uniform pitch (\(B_1 = B_2 = B_3 = B_4 = B_5 = B_6 = B_7 = B_8 = B_9\)). Using the stop (4) and the universal ram pin (6), the length of which is determined by the sum of the lengths of the parts of its components, the frame (2) can be rotated relative to the frame of the comparator (1) at a given angle. The main frame of the comparator (1) is adjusted to a horizontal position with the help of lifting screws (5). The total height \(h\) of the triangle frame of the comparator is equal to

\[
h^2 = H_b^2 + \Delta^2,
\]

where

\[
\Delta = \frac{H_b^2 - B^2 + L_b^2}{2 \cdot L_b^2}
\]

\(H_b\) is the total length of universal ram pin;

\(L_b\) is the length of the triangle base of the comparator frame;

\[B = \sum_{i=1}^{9} B_i\]

Then the \(h\) excess will be equal to \(h_i(i+1) = (B/9)\) at each step of the comparator.
All other stages of the implementation of research levels correspond to the above.

Figure 2. Universal step vertical comparator: 1 – Main Comparator frame; 2 – Frame steps; 3 – Steps of the comparator; 4 – Stop; 5 – Lifting screws; 6 – Stacked stock

3. Conclusion
The use of vertical comparators in the study of optomechanical and electronic levels provides a definition of the limiting instrumental accuracy at given working distances. A reliable knowledge of instrumental accuracy allows providing a reliable solution to production issues for determining exceedances or for controlling the horizontal position of elements of controlled objects. At the same time the implementation of the described methodology and the means of ensuring it do not require significant capital investments of the organization using them.

References
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