A test method and least-squares fitting have been used in algorithms for calibrating differential pressure gauges during use. The two methods provide good metrological characteristics in quantitative metering systems for oil products working over wide pressure difference ranges.

The hydrostatic method is the most widely used in measuring oil-product masses in vessels. One measures the hydrostatic pressure from the column of liquid and calculates the product mass from a calibration table.

A data-acquisition system (DAS) for determining liquid mass in a vessel from the hydrostatic pressure usually consists of pressure sensors (slot sensors) fitted with pneumatic channels located in the vessel, which convert the hydrostatic pressures into pneumatic pressures; there is also a differential pressure gauge which converts the measured pressure into a dc potential; and a pneumatic linking unit to connect the pneumatic line from a particular vessel to the differential gauge; a computing device; and a printer to document the recordings and mass and level measurements. A computer with VDU and printer is widely used at present as those devices.

Each vessel served by a system of that type is connected to the pneumatic switching unit by two tubes, one of which connects the unit to the gas space in the vessel and the other to the slot sensor. The differential pressure gauge receives these two pressures and measures the difference, which is equal to the hydrostatic pressure of the liquid column above the slot sensor.

Calibration tables define the product mass in the vessel without the measurement of level and density.

One does not attain the required measurement accuracy by the use of the direct hydrostatic method of determining oil product mass because of the considerable error in calibrating the vessel and the differential gauge.

In commercial operations, the relative error in measuring the liquid mass in a vessel should not exceed 0.5%, which error is made up in the main of errors in measuring the pressure and in calibrating the vessel (the other error components are small and may be neglected). On the existing method, a vessel can be calibrated with a relative error in determining the average area $\delta F_{av} = 0.2\%$. The confidence limits for the relative error in measuring the mass are defined by

$$\delta M = k_p \sqrt{(\delta F_{av})^2 + (\delta p)^2},$$

in which $k_p$ is dependent on the fiducial probability $P$, while $\delta p$ is the relative error in the pressure gauge.

From (1) we have $\delta M = 0.5\%$, $k_p = 1.1$, which corresponds to $P = 0.95$, and $\delta F_{av} = 0.2\%$, from which we determine the permissible relative error in a differential pressure gauge as $\delta p = 0.4\%$.

The metrological characteristics of means of measurement are unstable and vary throughout the working life, and there are errors in other parts of the system, so the inherent error in the pressure gauge should be even less.

It is fairly difficult and very expensive to make precision pressure gauges, so it is necessary to use algorithms for standard differential gauges to give the required accuracy over a wide range in conditions.

This involves some method of improving the measurement accuracy. Existing methods are usually based on obtaining additional information during the measurement that enables one to eliminate the effects of the errors on the result. Here we give results on improving the metrological characteristics of DAS for oil-product accounting.

There are two approaches to calibrating the differential gauges: a test method and least-squares fitting.

In the test method, the entire differential-pressure range is divided into three parts. During operation, such standard pressure sensors are used to calibrate the differential gauge in each part. In each of them the calibration characteristics are defined closely by a second-order polynomial.
In the test algorithm the measurement accuracy is raised by using the equation system [1]

\[
\begin{align*}
Y_1 &= a_0 + a_1 p_1 + a_2 p_1^2, \\
Y_2 &= a_0 + a_1 p_2 + a_2 p_2^2, \\
Y_3 &= a_0 + a_1 p_3 + a_2 p_3^2,
\end{align*}
\]

in which \( p_1, p_2, \) and \( p_3 \) are values reproduced by the standard gauges, which define the actual values of the parameters \( a_0, a_1, \) and \( a_2 \) (for each part), which define the conversion function, and then one uses the equation

\[
Y_i = a_0 + a_1 p_i + a_2 p_i^2
\]

and substitutes the calculated values of \( a_0, a_1, \) and \( a_2, \) together with the measurement \( Y_i \) from the differential gauge to derive \( p_{i1} \) and \( p_{i2} \) [Eq. (2) has two roots]:

\[
p_{i1,2} = \frac{-a_1 \pm \sqrt{a_1^2 - 4a_2(a_0 - y_i)}}{2a_2},
\]

and the value of \( p_i \) close to \( y_i \) is taken as the current pressure difference (the root

\[
p_{i2} = \frac{-a_1 - \sqrt{a_1^2 - 4a_2(a_0 - y_i)}}{2a_2}
\]

is either negative or too far from \( y_i \)).

Figure 1 and Table 1 give computer-processed results. The pressure gauge was a Sapfir-22 differential gauge with a relative error of 0.5% (measurement range 1.6 atm), while the standard gauges were Vozdukh-2.5 gauges with relative errors of 0.05%. These were used to reproduce the standard pressures 0, 0.2, 0.4, 0.6, 1, 1.2, and 1.6 atm, and the entire measurement range was divided into the three parts 0-0.4, 0.4-1, and 1-1.6 atm.

The test method gave the following coefficients in (2) for an environmental temperature of \( t = 23.2^\circ C \):

in part 0-0.4 atm, \( a_0 = 1.998, a_1 = 4.8217, \) and \( a_2 = 0.1348; \)
in part 0.4-1 atm, \( a_0 = 2.0301, a_1 = 4.7463, \) and \( a_2 = 0.1229; \)

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Figure 1}
\end{figure}