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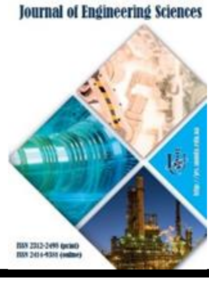

Ensuring Accurate Characteristics of the Pipe-Piston Installation

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Abstract. The study aims to increase the efficiency of the use of the pipe-piston unit by ensuring the reliability of the measurement results based on the development of calibrating technique for the pipe-piston installation. Theoretical research is based on using the principles of system and process approaches. To solve the scientific problem, the fundamental provisions of statistical methods and experimental methods were used; methods of mathematical modeling of estimation of measurement uncertainties. Based on the results of the work, the normative document "Metrology. Installations of a standard pipe-piston. Calibration technique". The approach to controlling metrological characteristics of the pipe-piston installation, based on estimating the uncertainty of measurements during its calibration, was further developed. Application of the proposed approach allows one to control the metrological characteristics directly on site without disrupting the working product's accounting process and increasing the pipe-piston installation's efficiency by an increase in the reliability of measurements and ensuring repeatability.

Keywords: methods, calibration, pipe-piston installation, uncertainty, verification.

1 Introduction

The economies of many countries, including Ukraine, are based mainly on natural resources. Available natural resources are the key to the country's competitiveness in the world market. Therefore, a reliable system of accounting and control of the use of such resources is an essential factor in the efficient and economical use of nature.

Today in our area, the pipe-piston test installation (production of "Energoinvest. Measuring systems") is designed to control the characteristics and verification of measuring instruments of volume and mass at the place of operation without violating the process of accounting for the working product.

Legislation of Ukraine in the field of metrology has changed in recent years. According to the Resolution of the Cabinet of Ministers of 04.06.2015 № 374 [2], the pipe-piston installation was not included in the List of categories of legally regulated measuring equipment subject to periodic verification, so it belongs to the gages. According to the procedure for calibration of legally regulated measuring equipment in operation and registration of its results (Order of the Ministry of Economy of 08.02.2016 № 193), the gages used during the verification must be calibrated.

The purpose of the work is to increase the efficiency of the pipe-piston installation by ensuring the reliability of measurement results based on the development of calibration techniques for the pipe-piston installation.

2 Literature Review

Consumption - the amount of liquid, gas, or bulk (mass, volume, or weight) transported or supplied per unit time across the cross-section [3].

When measuring the volume of liquid (gas) flowing through the cross-section, determine the volume consumption when measuring mass flow.

Volume flow rate is the volume of liquid that passes through a given area per unit of time.

Usually, the liquid (gas) consumption is measured by a flowmeter and to measure the amount of a substance – by a quantity counter (counter).

For verification, calibration, and control of measuring equipment's characteristics of volume and weight on a place of operation without disturbance of process of the account of a working product, the pipe-piston installation (further PPI) is used.

Bilateral PPIs have been most widely used in industries where high flow measurement accuracy is required. The main advantage of bilateral PPI compared to unidirectional PPI is that in the bilateral design of PPI, the volume of the measuring section is taken as the passage of the piston in both directions, thus compensating for the error of detectors, thereby increasing measurement reliability and improving repetition.

The experimental installation under consideration it is a two-sided stationary pipe-piston test installation with a capacity of 550 m3 / h.

Operating conditions have a fairly wide range, namely: ambient temperature from minus 50 to 65 °C; the average value of humidity is 80% (possibly for a short time up to 100%); the maximum pressure in PPI to 4 MPa.

The main components of the PPI are shown in Figure 1.

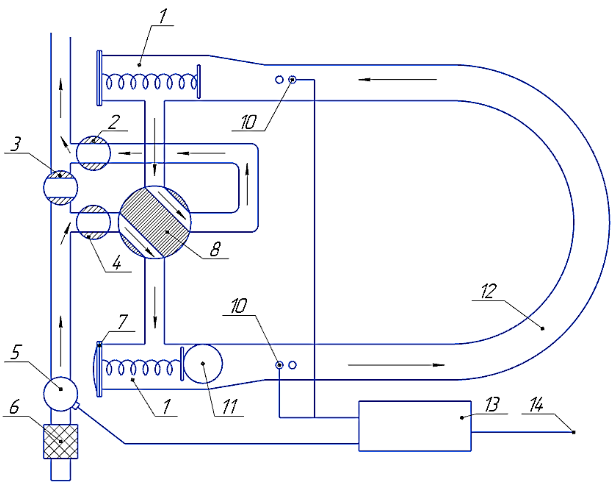

Figure 1 - Scheme of bilateral PPI: 1 – shock absorber; 2, 4 – shut-off valves; 3 – the valve on the main pipeline; 5 – flow meter; 6 – filter; 7 – cover; 8 – four-way valve with a drive that acts as a switch of fluid flow through the loop; 9, 10 – bullet passage detectors; 11 – polyurethane ball; 12 – loop made of steel pipe coated in the middle with epoxy resin to obtain the high-quality, smooth and constant diameter of the pipeline; 13 – pulse counter; 14 – power

The general view of the experimental setup is shown in Figure 2.

PPI is a two-way installation with flow control by a four-way valve, a ball polyurethane piston, and a calibrated area with an internal polymer coating. The calibrated area is made of pipes and taps calibrated for inner diameter. The calibrated area is limited by detectors that detect the passage of the ball piston.

The inner surface of the installation is thoroughly cleaned and covered with a thin layer of special synthetic resin to protect against corrosion and reduce friction when moving the ball.

During the flow transducer test, the ball piston inside the starting chamber starts moving toward the opposite starting chamber. Once in the acceleration section of the PPI, the ball piston completely covers the inner section of the PPI and moves with the fluid at a constant speed.

Figure 2 – General view of the calibrated area between detectors: Experimental setup

Continuous calibration of the flowmeter is carried out by draining the liquid to the auxiliary loop of the pipeline of a certain length, in which a polyurethane ball is installed, and the flow of liquid passes past four sensors of the ball. With the help of bullet passage sensors, switches are triggered, which start and stop the meter connected to the test flow meter. The volume of the calibrated part of the pipe between the sensors of the ball passage is accurate. By comparing it with the value on the flowmeter, it is possible to determine the calibration factor under normal operating conditions. Next, the piston enters the opposite chamber of the PPI and remains there until the position of the four-way valve changes, which causes a change in the direction of fluid flow inside the PPI to the opposite. The flow captures the ball piston, and the measurement process is repeated.

Therefore, PPI has a complexity of design and operation. The reliability of the system of accounting and control of the use of natural resources depends on its metrological characteristics, so the urgent task is to increase the reliability and repeatability of measurements based on the study and improvement of the regulatory framework.

The study of the requirements of international regulations on the application or confirmation of metrological characteristics of PPI did not reveal such.

The technical regulation [7] of measuring instruments, developed based on Directive 2014/32 / EC of the European Parliament and of the Council of 26.02.2014, entered into force on 24.02.2016. The effect of this Technical Regulation of measuring instruments extends to the following categories of measuring equipment (hereinafter – ME), which relate only to: water meters; gas meters and volume conversion devices; active electricity meters; heat meters; measuring systems for continuous and dynamic measurement of liquids other than water; automatic weighing devices; taximeters; material measures; size measuring instruments; exhaust gas analyzers.

The legislation does not provide for the verification of standards. The law [4] does not include such an important but specific category of ME as gages in the sphere of legislative regulation. Gages of any accuracy must be calibrated. The essence of calibration is to determine the characteristics, for this purpose, a comparison with the relevant gauge, and not to determine the suitability for using ME. This is reflected in the normative legal act "Procedure for verification of legally regulated measuring instruments in operation and registration of its results", approved by order of the Ministry of Economic Development and Trade of Ukraine No. 193 of 08.02.2016 [5]: "For the gages used during the calibration, the measurement uncertainty limits that these gages must provide must be specified. The ratio between the measurement uncertainty that provides the gages and the maximum permissible error of the ME to be verified is not less than one to three".

According to the Procedure for calibration of secondary and working gages, item 4, II "Calibration of working gages is carried out according to calibration methods contained in national standards or developed by contractors considering national standards harmonized with relevant international and European standards and documents adopted by international and regional organizations in metrology".

Thus, there is currently a scientific and practical problem to ensure reliable control over the measurement of volume outside the legal field, the solution of which will control the measurement of volume by measuring equipment and protect the rights of consumers.

3 Research Methodology

At the beginning of the development of the PPI calibration methodology, it is advisable to investigate its verification procedure according to the requirements of P81 / 24.99-1999 "Recommendation. Metrology. Pipe-piston installations. A typical method of verification by installations based on ОГВ scales or gauges".

Depending on the capacity determination method used, different sets of verification tools are used when performing the PPI calibration. The method of determining the capacity of the PPI is based on the fact that the water displaced from the PPI when moving the piston calibrated area from one detector to another, sent to a special storage tank, and measured its volume. The volume of water is measured by draining it from the storage tank, indirectly (using scales and hydrometers) or directly (meter).

The following methods and means of PPI verification have been established, such as a calibration unit based on ОГВ scales with storage capacity and flow switch;

calibration unit based on meters with storage capacity and flow switch; calibration unit based on ОГВ scales or meters with storage capacity with piston stop; calibration unit based on meters with piston stop (without storage tank); calibration unit based on meters without stopping the piston and without storage capacity; (compact prover) test unit based on meters without piston stop and a storage tank.

The manufacturer foresaw the need for such calibration units, which were built on site of PPI operation (Figure 3). It includes:

− meter type M1R - 1000, capacity 1000 l, scale from 984 l to 1009 l, division price 0.2 l; extended uncertainty of 0.2 l; 1st category (Figure 3, a);

− D400 type scales range from 100 kg to 1500 kg; extended uncertainty of 0.05 kg (Figure 4 b, c).

Figure 3 – Test installation (general view)

a b

Figure 4 – Reference meter (a) and weighing device (b)

Considering the PPI's available equipment and the provision of reference equipment, a method with a calibration installation based on meters with a piston stop (with storage capacity) was chosen.

Before verification, the following preparatory work must be carried out: checking the availability of certificates of verification or prints of calibration marks on them; checking the value of the diameter and condition of the surface (degree of wear) of the ball pistons PPI, which is verified, according to the operating documentation; checking the correctness of installation and connections of PPI, means of verification and auxiliary equipment according to the operating documentation on PPI and means of verification; checking the tightness of PPI, connecting pipes and valves. The test is performed by external inspection at the selected value of the test flow and pressure at the outlet of the PPI not less than 0.1 MPa.

Tests during a trial by testing installations based on meters with a piston stop are carried out as follows. Water is fed into the meter from below. The storage tank’s capacity exceeds not less than (1.2–1.5) times the maximum capacity of the PPI to be verified.

Check the KE valve manually from the control unit by closing and opening it several times. The test is considered to have passed if the valve has to close again when the piston approaches the second detector. Since our installation is two-way, the above operations are performed while moving the piston in the opposite direction.

Determining the capacity of PPI, reduced to normal conditions (temperature 20 °C, absolute pressure 101.3 kPa). For two-way PPI, the capacity is determined separately for each direction of movement of the piston.

For an experimental PPI with two pairs of detectors, the capacity is determined by each pair of detectors.

The temperature (pressure) at the inlet and outlet is equal to the average value of the two measurements - after opening the valve and closing it. The difference between the readings of the thermometers at the inlet and outlet of the PPI should not exceed 0.2 °C. Using thermometers and manometers with visual reading allows it to record the temperature and pressure once during the piston’s passage.

Choose the capacity of the meter based on the capacity of the PPI, which is verified, so that when measuring the volume of water, get the smallest integer number of fillings of the meter. It is allowed to use meters of different capacities. If the meter has a scale on the neck, pre-determine the amount of water to be poured so that the water level was within the scale in all measurements. Pour a certain amount of water into the meter from the storage tank. If the meter does not have a scale, it is filled to the mark of nominal capacity.

When verifying the bilateral PPI, the above operations are performed in the direction of piston’s movement.

After passing the piston of the calibrated area in one direction and taking measurements, open the valves and move the piston further to the receiving chamber, then change the direction of movement.

Determine the capacity of the PPI under test conditions using a meter according to formula:

$$V = K_T \times \sum_{j=1}^{r} V_{ij};\ j = 1...r \tag{1}$$

For bilateral PPI:

$$V_i = V_{i_{(1-2)}} + V_{i_{(2-1)}} \text{ and } V_i = V_{i_{(1-3)}} + V_{i_{(3-1)}} \tag{2}$$

$$\bar{V} = \frac{\sum_{i=1}^{n} V_i}{n} \tag{3}$$

The value of PPI capacity under standard conditions:

$$V_o = \bar{V} \cdot K_{tрм} \tag{4}$$

where K_{tpm} – the value of the coefficient taking into account the temperature and water pressure on the PPI tank and the volume of water in the PPI:

$$K_{tрм} = 1 + \beta(t_у - t_{ом}) - 3\alpha_T(t_у - 20) + 3\alpha_м(t_{ом} - 20) - FP_у - \frac{0{,}95}{E} \cdot \frac{D}{S} \cdot P_у \tag{5}$$

where β – the coefficient of volumetric expansion of the fluid; a_T – coefficient of linear expansion of PPI wall material; a_M – the coefficient of linear expansion of the material of the meter; F – the coefficient of compressibility of the liquid, 1/MPa; P_y – average pressure in PPI for one measurement, MPa; D – inner diameter of the calibrated section of PPI, mm; E – modulus of elasticity of PPI wall material, MPa; S – PPI wall thickness, mm.

The standard deviation of the random component of the error is determined by the formula:

$$S_o(\overset{o}{\Delta}) = \sqrt{\frac{\sum_{i=1}^{n}(V_{oi} - V_o)^2}{n-1}} \cdot \frac{100}{V_o}, \tag{7}$$

where $V_o = \frac{\sum_{i=1}^{n} V_{oi}}{n}$.

Must comply with the condition: $S_0 \le 0.015\%$ – for PPI of the 1st category; $S_0 \le 0.030\%$ – for PPI of the 2nd category.

4 Results

As a result of research, the method of calibration of MK.RU.XX.0XX: 2021 “Metrology. Gage pipe-piston installations. Calibration Method”, which applies to PPI type 550-64-40, which corresponds to the operating documentation on them and establishes the content and procedure for their calibration. If this technique is used to calibrate other installations according to the customer's special requirements (at certain points in the range, in special operating conditions), it is necessary to assess its suitability.

As the State Enterprise implemented the proposed methodology “Sumy Regional Scientific and Production Center for Standardization, Metrology and Certification”, this section provides the content of the methodology and the main scientific results.

When using the proposed method, there is a requirement to use the following documents: instructions for operation of the installation to be calibrated; guidelines for the operation of gages and ancillary equipment used in the calibration of the installation; standards of calibration of standards, and instructions on labor protection.

The following operations must be done during calibration: (1) external review, (2) functional check, (3) definition of metrological characteristics, (4) estimation of measurement uncertainties, (5) establish traceability of measurements, (6) registration of calibration results.

Estimating measurement uncertainties during installation calibration is carried out according to the requirements of EA 4/02.

To build a model equation, it is necessary to identify the primary sources of uncertainty in measuring the volume of liquid by installations *Vi*. After considering these sources, the model equation will take the form:

$$V_i = V_o + \Delta_e + \Delta_d + \Delta_o + \Delta_s + \Delta_v, \quad (8)$$

where V_o – data from the gauge; Δ_e – component due to the expanded uncertainty of the standard; Δ_d – component due to the drift of metrological characteristics of the standard; Δ_o – components due to the error of reading the readings of the installation and the standard operator; Δ_s – component due to the influence of random factors; Δ_v – component due to fluid flowing through the seal of the sphere.

Extended uncertainty U_e of the standard is indicated in the certificate (certificate) of calibration of the gauge together with the value of the coverage factor k (k = 2). The uncertainty component of the standard, which is taken into account in the budget of uncertainties ue, is estimated by the formula:

$$u_e = \frac{U_e}{k} \quad (9)$$

Extended uncertainty u_d, due to the drift of metrological characteristics of the gauge, is estimated by the formula (type B, uniform distribution law):

$$u_d = \frac{\Delta V_м \cdot \Delta\tau}{T \cdot \sqrt{3}}, \quad (10)$$

where $\Delta V_м$ – change of metrological characteristic of the gauge (meter) for the previous inter-calibration interval T;

Δτ – the time interval that has elapsed since the last calibration.

The component of uncertainty due to the accuracy of reading impressions u_o is equal to (type B, uniform distribution law):

$$u_o = \frac{d}{m \cdot \sqrt{3}}, \quad (11)$$

where m – the share of the scale division that distinguishes the operator (m = 2 for digital indicators).

To estimate the uncertainty of the measurement due to the contribution of random factors, n repeated measurements of the value must be performed by the same verifier under the same conditions, the results of which we obtain a statistical estimate of the standard deviation:

$$СКВ = u_s = \sqrt{\frac{\sum_{i=1}^{n}\left(V_i - \overline{V}\right)^2}{n \cdot (n-1)}} \quad (12)$$

The number of repeated measurements must be at least three.

To assess the measurement's uncertainty due to fluid flow through the installation's seals, perform the operations described in p. 6.4 Р81 / 24.99 and determine the relative deviation of the capacity of the installation Δ*np*.

Given the normal distribution law, the measurement uncertainty due to fluid flows through the seals of the installation u_v, estimated by the formula:

$$u_v = \frac{\Delta_{np}}{2} \quad (13)$$

The sources of uncertainty are independent of each other, so the values of the correlation coefficients are zero.

The uncertainty budget method requires to be made as shown in Table 1.

Table 1 – Calculation results

Input value	Estimation of input value	Standard uncertainty	Probability distribution	Coef-ficient of influence	Contri-bution to uncertainty
V_o	X,XXX	u_s	Normal	C_s	$C_s \cdot u_s$
Δ_e	0	u_e	Normal	C_e	$C_e \cdot u_e$
Δ_d	0	u_d	Uniform	C_d	$C_d \cdot u_d$
Δ_o	0	u_o	Uniform	C_o	$C_o \cdot u_o$
Δ_υ	0	u_υ	Normal	C_v	$C_v \cdot u_v$
Initial value	Estimation of the initial value	Standard total uncer-tainty	Confi-dential confidence	Cove-rage ratio	Advanced uncertainty
V_i	Y,YYY	***u(V) =***	***p =***	***k =***	***U(V) =***
			Deviation of installation readings		
			ΔV =		

The formula calculates the total standard measurement uncertainty when calibrating the installation:

$$u(V) = \sqrt{(C_e \cdot u_e)^2 + (C_d \cdot u_d)^2 + (C_o \cdot u_o)^2 + (C_s \cdot u_s)^2 + (C_v \cdot u_v)^2} \quad (14)$$

The formula estimates the expanded uncertainty for the confidence interval:

$$U(V) = k \cdot u(V), \quad (15)$$

where k – coverage ratio with p=0,95.

The formula estimates the relative extended uncertainty:

$$U(v) = \frac{U(V)}{V_i} \cdot 100 \quad (16)$$

The deviation of the value of the capacity of the installation from the value obtained during the pre-calibration will be estimated by the formula:

$$\Delta V = V_{np} - V_0 \quad (17)$$

The calibration technique also establishes requirements for the traceability of measurements and registration of their results. The requirements for establishing the recommended inter-calibration interval are also specified.

5 Conclusions

Based on the conducted research for carrying out control of the definition of indicators of expense and metrological characteristics and verification of means of measurements of volume and weight on a place of operation without disturbance of process of the account of a working product that in the majority of measurements.

It is established that there are currently no methodological documents regulating the calibration procedure of these working standards.

The result of the work is the proposed Calibration technique "Metrology. Installations are standard pipe-piston. Calibration technique". Implementing this technique allows you to control the metrological characteristics directly on site without disrupting the accounting process of the working product and increase the efficiency of PPI by increasing the reliability of measurements and ensuring repeatability.

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References

1. Tai, B., Stephenson, D., Shih, A. (2011). Improvement of surface flatness in face milling based on 3-D holographic laser metrology. *International Journal of Machine Tools & Manufacture*, Vol. 51(6), pp. 483–490. doi: 10.1016/j.ijmachtools.2011.02.006.
2. Wu, W.G, Yu, Q.X., Chang, X., Pang, S.Q. (2004) Design Theory and Experiment of the Step Face Milling Cutter Based on Free Cutting. *Advances in Grinding and Abrasive Processes*, Vol. 259–2, pp. 132–136. doi: 10.4028/www.scientific.net/KEM.259-260.132
3. Ramakrishnan, S., Wysk, R. (2002) Optimization of The Length of Travel in Face Milling Operations for Flat Surfaces. *Transactions of The North American Manufacturing Research Institute of SME*, Vol. XXX, pp. 431–438.
4. Hadad, M., Ramezani, M. (2016) Modeling and analysis of a novel approach in machining and structuring of flat surfaces using face milling process. *International Journal of Machine Tools and Manufacture*, Vol. 05, pp. 32–44. doi: 10.1016/j.ijmachtools.2016.03.005
5. Ivanov, V., Dehtiarov, I., Pavlenko, I., Kosov, M., Hatala, M. (2020) Technological assurance and features of fork-type parts machining. *Advances in Design, Simulation and Manufacturing II. DSMIE 2019. Lecture Notes in Mechanical Engineering*, pp. 114–125. doi: 10.1007/978-3-030-22365-6_12
6. Taurit, G.E. (1981) Machining Large Parts. *Tekhnika*.
7. Kushnirov, P., Zhyhylii, D., Ivchenko, O., Yevtukhov, A., Dynnyk, O. (2020) Investigation of the dynamic state of adjustable milling heads. *Advances in Design, Simulation and Manufacturing II. DSMIE 2019. Lecture Notes in Mechanical Engineering*, Vol. II, pp. 169–179. doi: 10.1007/978-3-030-22365-6_17
8. Ivanov, V., Dehtiarov, I., Pavlenko, I., Kosov, I., Kosov, M. (2019) Technology for complex parts machining in multiproduct manufacturing. *Management and Production Engineering Review*, Vol. 10(2), pp. 25–36. doi: 10.24425/mper.2019.129566
9. Ivanov, V., Dehtiarov, I., Zaloga, V., Kosov, I., Savchuk, V. (2020) Increasing Productivity of Connecting Rods Machining. *In: Ivanov, V., Trojanowska, J., Pavlenko, I., Zajac, J., Peraković, D. (eds) Advances in Design, Simulation and Manufacturing III. DSMIE 2020. Lecture Notes in Mechanical Engineering*, Vol. III, pp. 264–275. doi: 10.1007/978-3-030-50794-7_26
10. Hlembotska, L., Melnychuk, P., Balytska, N., Melnyk, O. (2018) Modelling the loading of the nose-free cutting edges of face mill with a spiral–stepped arrangement of inserts. *Eastern Eur. J. Enterp. Technol*, Vol. 1(91), pp. 46–54.
11. Lishchenko, N. V., Larshin, V. P., Pitel, J. (2020) Vibrational impact on milled surface irregularities. *Journal of Engineering Sciences*, Vol. 7(1), pp. A8–A16. doi: 10.21272/jes.2020.7(1).a2
12. Permyakov, A., Dobrotvorskiy, S., Dobrovolska, L., et al. (2019) Computer modelling application for predicting of the passing of the high-speed milling machining hardened steel. *In: Ivanov, V., et al. (eds.) Advances in Design, Simulation and Manufacturing. DSMIE-2018. Lecture Notes in Mechanical Engineering*, pp. 135–145. doi:10.1007/978-3-319-93587-4_15
13. Klimenko, S. (2017) Improvement of performance of finishing of details with a cutting tool. *J. Zhytomyr State Technol. Univ* Vol. 2(88), pp. 56–66.
14. Ivanov, V., Pavlenko, I. (2017) Comprehensive analysis of the mechanical system system "fixture–workpiece". *Journal of Engineering Science*, Vol. 4(1), pp. A1–A10.
15. Ivanov, V. (2018) Process-Oriented Approach to Fixture Design. *In: Ivanov, V. et al. (eds) Advances in Design, Simulation and Manufacturing. DSMIE 2018. Lecture Notes in Mechanical Engineering*, pp. 42–50. Springer, Cham. doi: 10.1007/978-3-319-93587-4_5.
16. Coromant, S.: Cutter path and chip formation in milling, https://www.sandvik.coromant.com/en-gb/knowledge/milling/pages/cutter-path-and-chip-formation.aspx, last accessed 15/05/2021.