Modification Hydrodynamic Properties of Narrowing Down Devices of Flow Sensors from Action of an Abrasive Wear

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Abstract. In operation the outcomes of study influencing an abrasive wear of working surfaces of a cylindrical nozzle on operation of a flow sensor of variable pressure differential are introduced. The outcomes are obtained by a numerical modelling of current of fluid through a nozzle. For a nozzle the internal cylindrical surface is resized up to a taper and circularization on radius a crimp on an input. Simulation executed by a finite element method with usage of the program Ansys 5.5ED. Budgeting of numerical experiment and treating of outcomes have fulfilled with applying of the program Statistica 6.1. The quantitative estimation of influencing an abrasive wear on variation coefficient of the outflow of flow sensors is obtained.

1. Introduction
The haul of the liquid and gaseous environments on mains or their waste-handling in conditions of production guesses measuring expenditure is continuum in a stream. For this purpose the flow sensors of different constructions are used. The sensors of pressure differential are most abundant. The pressure differential in the pipeline is constructed by implementation in a stream of complementary resistance. Magnitude of expenditure value on variation of stress on a lease of this resistance. There are two types of such sensors: sensors of constant and variable pressure differential. The sensors of constant pressure differential apply to measuring expenditure of the liquid environments. Flash float on a construction they are very responsive to variations of properties of the environment and presence in it of actuations. It confines area of their applying. Sensors of variable pressure differential favorably differ by the greater stability in operation. Their operation grounded on waist of a stream with usage of diaphragms or nozzles.

2. Actuality
Main defect of flow sensors of variable pressure differential is the variation of their sizes and forms under affecting of a stream of the gaseous or liquid environments. It negatively has an effect for fidelity of measuring. On variation of hydrodynamic properties a diaphragm of flow sensors render influencing and circularization of a crimp of an inlet orifice, residual deformations and hard depositions in front of the constricted device [1]. The quantitative estimation of influencing of the indicated harmful factors on operation a diaphragm of sensors is obtained in operation [2]. The most essential factor is the variation of geometry a diaphragm owing to an abrasive wear. The cylindrical nozzles also are subject to an abrasive wear from affecting on their surface of hard fragments, contained in a fluid flow or gas. The learning of influencing of wear on variation of hydrodynamic
properties of flow sensors with cylindrical nozzles is represented actual enough. In the given operation the outcomes of such study are introduced.

3. Formulation of the task

Simplicity of a construction and no-failure operation in exploitation of flow sensors of variable pressure differential have received wide applying in mains. Constricted a member as a cylindrical nozzle is applied to haul of the gaseous and liquid environments with the rather large contents of abrasive fragments. Because of abrasive fragments there is an intensive wear of working surfaces of nozzles. To the greatest wear are subject his crimp on an input and internal cylindrical surface. The circularization of a crimp and magnification of a diameter on an input with formation of coning (figure 1) is rendered by influencing on outcomes measuring of expenditure.

![Figure 1. Cylindrical nozzle of a flowmeter.](image)

For the pipe line with an inside diameter $D$, equal $200 \cdot 10^{-3}$ m, according to the requirements GOST 8.586.3 – 2005 «Measuring of expenditure both amount of fluids and gases with the help of constricted devices. A part 3. Nozzles and nozzles Venturi. The technical requirements» [3] the magnitude of an inside diameter $d$ of a nozzle was accepted equal $120 \cdot 10^{-3}$ m, length $l$ of a working surface of a nozzle – $75 \cdot 10^{-3}$ m and width $E$ of a flange – $20 \cdot 10^{-3}$ m. At posing numerical experiment the assumption started that owing to an abrasive wear on an input there was a circularization on radius $r$ of a crimp and magnification of an inside diameter of a nozzle $d$ up to a value $d_{in}$. On an output the magnitude of an inside diameter $d_{out}$ remained invariable and equal to a diameter $d$. Length $L$ of a gaging lease of the pipe line accepted equal $400 \cdot 10^{-3}$ m.

To state of delivery of a nozzle in exploitation there correspond zero values of radius $r$ a circularization of a crimp and coning $k$ of an internal cylindrical surface of a nozzle. These values instituted the calculated schema 1.

By rules of measuring of expenditure of gases and fluids by standard constricted devices RD 50-213-80 [4] the variation of a profile part of an opening of a nozzle is regulated depending on argument

$$m = \frac{d}{D}$$

For $m > 0.25$ the indicated variation should not exceed 3%. In conditions of the given numerical experiment at $m = 0.6$ the max coning $k$ of an internal cylindrical surface accepted equal 0.048. It corresponds to the greatest value $d_{in}$ equal $123.6 \cdot 10^{-3}$ m. By rules the circularization of a crimp quantitative is not regulated, and is characterized only qualitatively as absence of a brightness of a crimp from a dipping ray of a light. Diffusing limitation on a circularization of a crimp on an input, the max value of radius $r$ of a circularization of a crimp was accepted equal by $3.6 \cdot 10^{-3}$ m. The max values $k$ and $r$ instituted the calculated schema 2.
4. The theory a part
Simulation carried out on conditions of full scale hydraulic experiment of operation [5]. Stress of water \( p \) on an input accepted equal \( 2 \cdot 10^6 \)Pa. Gravity \( \rho \) and coefficient \( \mu \) of viscosity of water at temperature accepted accordingly equal 1003.8kg/m\(^3\) и 134\(-\)10\(^{-6}\)Pa\(\cdot\)s. Real mass flow \( q_m \) accepted equal 73.43 kg/s. The boundary conditions reshaped as limitation on speed on internal surfaces, cleaned-up stream of water. The speed of water on an input was accepted equal \( v = 2.4m/s \), that corresponded to the indicated expenditure.

The simulations of current carried out by facilities of the application FLOTRAN CFD of the programmatic complex ANSYS on a finite element method. All area of solution broke down into members FLUID 141 of the library of the program ANSYS. Result of account under each schema was the definition of pressure differential \( \Delta p \) on the constricted device. The values of fluid pressure before and after a nozzle found on lines of pressure distribution (figure 2). The confrontation of lines of pressure distribution on the calculated schemas has allowed drawing a conclusion about their qualitative homogeneity. The essential difference in pressure differential on the constricted device is marked.

![Diagram](image)

**Figure 2.** Lines of pressure distribution, Pa:
\ a – current under the schema 1; b – current under the schema 2.

Still large identity was marked in a velocity distribution of a stream (figure 3). The significant exceeding of rate of flow in its mean stratum under the schema 1 above too speed under the schema 2 can render of significant influencing on results of measuring of expenditure.
Is marked, that the extent of deterioration does not influence pressure distribution in the pipe line up to a nozzle (figure 4), but promotes decrease of pressure differential on it. So the pressure differential $\Delta p_1$ under the schema 1 has compounded $20 \cdot 10^4$Pa against $\Delta p_2$ under the schema 2 – $14 \cdot 10^4$Pa. It testifies to essential variation of hydro dynamical properties of a nozzle at variation of a profile its opening owing to an abrasive wear. The max circularization crimp at the greatest valid coning results in decrease rate of flow on an input and practically of outlet velocity equal on magnitude from a nozzle.

**Figure 4.** On a gagging lease of the pipe line under the schemas 1 and 2

- solid line — fluid pressure;
- dashed line — speed on the average stratum of a fluid flow.
For obtaining a quantitative rating of influencing of a circularization of a crimp and coning on variation of hydrodynamical properties of the constricted device the numerical experiment including nine expertises of the central composite schedule was planned [6]. The schedule have supplemented by two expertises applicable to the schemas of current 1 and 2 (table 1). 

The center of the schedule corresponded to a circularization of a crimp \( r_0 \) equal \( 1.604 \times 10^{-3} \) m and coning \( k \) equal 0.024. On is a curve of pressure distribution instituted magnitude of pressure \( \Delta p \), differential in each expertise.

Variation of properties of a nozzle valued on main hydrodynamic to argument of constricted devices – coefficient of the expiration \( C_i \) [7]:

\[
C_i = \frac{q_m(1-m^4)^{0.5}}{\left(\pi/4\right)d_{in}^{0.5}(2\rho\Delta p)^{0.5}}.
\]  

(1)

For exception of influencing of absolute values on outcomes of experiment for varied arguments accepted the ratio \( r_i/r_0 \) and \( k_i \). Response function also was the self relative magnitude \( C_i/C_0 \), where \( C_0 = 0.302 \) – coefficient of the expiration for expertise with conditions on the schema 1.

The square-law equation of regressions obtained by results of data processing of numerical experiment by facilities of the program Statistica 6.1, looks like:

\[
C_i/C_0 = 1.01 - 0.08\frac{r_i}{r_0} + 1.41k_i + 0.07\left(\frac{r_i}{r_0}\right)^2 - 1.53\frac{r_i}{r_0} \cdot k_i - 23.52k_i^2.
\]  

(2)

The opposite signs at square-law member of equations correspond by a surface of a response function as a hyperbolic paraboloid (figure 5).

**Table 1.** The central composite schedule of numerical experiment.

| Number of expertise | Circularization on radius \( r_i \) \((10^{-3}m)\) | \( r_i/r_0 \) | Diameter Input \( d_{in} \) \((10^{-3}m)\) | Coning \( k_i \) | Pressure differential \( \Delta p_i \) \((10^5 Pa)\) | Coefficient of the expiration \( C_i \) | \( C_i/C_0 \) |
|---------------------|---------------------------------|-------------|---------------------------------|-------------|---------------------------------|-----------------|-----------------|
| 1                   | 0.472                           | 0.294       | 120.5                           | 0.007       | 18                              | 0.315           | 1.043           |
| 2                   | 0.472                           | 0.294       | 123.1                           | 0.041       | 18                              | 0.301           | 0.994           |
| 3                   | 2.732                           | 1.703       | 120.5                           | 0.007       | 12                              | 0.386           | 1.278           |
| 4                   | 2.732                           | 1.703       | 123.1                           | 0.041       | 19                              | 0.299           | 0.991           |
| 5                   | 0                               | 0           | 121.8                           | 0.024       | 17                              | 0.316           | 1.048           |
| 6                   | 3.2                             | 1.995       | 121.8                           | 0.024       | 22                              | 0.302           | 0.921           |
| 7                   | 1.604                           | 1           | 120                             | 0           | 26                              | 0.265           | 0.877           |
| 8                   | 1.604                           | 1           | 123.6                           | 0.048       | 24                              | 0.257           | 0.852           |
| 9                   | 1.604                           | 1           | 121.8                           | 0.024       | 17                              | 0.316           | 1.048           |
| 10                  | 0                               | 0           | 120                             | 0           | 20                              | 0.302           | 1               |
| 11                  | 3.2                             | 1.995       | 123.6                           | 0.048       | 14                              | 0.337           | 1.116           |
5. **Practical significance**

The analysis of absolute values of coefficients of the equation (2) has allowed to draw a conclusion about more essential influencing on variation of coefficient of the outflow of coning of an internal surface of a nozzle, than circularization of a crimp. It is necessary to recognize share manifestation of considered variations of a profile of his opening significant.

The coordinates of a dot A of a surface of a response function on a map of level lines (figure 6) correspond to values of the factors $k$ and $r_i/r_0$, equal 0.005 and 0.65 accordingly.

![Figure 5. Surface of a response function.](image1)

![Figure 6. Map of level lines a surface of a response function.](image2)

6. **The concluding**

The results of expertise fulfilled during numerical experiment, have allowed making the following deductions.

The method of application of an estimation of influencing circularization a crimp of a cylindrical nozzle on an input and coning of a profile of its internal surface on variation of hydrodynamic properties of the constricted device is designed.

Is installed, that more essential influencing on variation of coefficient of the outflow renders coning of an internal surface of a nozzle.
The extremes of radius of a circularization of a crimp and coning of an opening of a nozzle are determined, before reaching it is necessary to consider which one hydrodynamic properties of the constricted device stable.

7. References
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