Instrumental inspection of pressure pipelines of the Amuzang-2 pumping station

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Abstract. This article discusses the main results of the field studies conducted to assess the technical condition of the pressure pipelines of the Amuzang-2 pumping station. The research aims to check the stress-strain state of the pipeline material, which occurs during long-term operation under conditions of corrosive and abrasive wear of the shell. The research objectives were as follows: measuring the thickness of the shell of pressure pipelines of the pumping station; verification calculation of the strength of pumping station pipelines. During the research, the method of carrying out full-scale measurements using an ultrasonic device to determine the thickness of the pipeline shell and the method of calculating the stress-strain state of the pipeline material that occurs during long-term operation under conditions of corrosive and abrasive wear of the shell were used. The verification calculation was carried out for the strength of the shell material and the stability of the shape of its section: from the action of external pressure (vacuum in the pipeline), buckling, like a rod, under the action of internal pressure. According to the studies carried out, the pipelines can withstand the maximum vacuum, and the static buckling strength of the pipelines is ensured.

1 Introduction

As is known, in the Republic of Uzbekistan, there is a very developed, powerful system of machine water lifting, which is involved in the general irrigation system of the state. Some of the available pumping stations operating in this system operate in very difficult conditions (high content of abrasive particles in the transported water).

One such pumped irrigation system operating in very difficult conditions is the Amuzang system. A characteristic feature of this system is that the water source is the Amudarya River, and this system includes 3 pumping stations located in a cascade and provides irrigation water to the vast irrigated areas of the Surkhandarya region of the republic.

The Amuzang-2 pumping station (the second stage of the Amuzang cascade) was chosen as the research object.

Significant abrasive wear of pressure pipelines and equipment and insufficient technical equipment of pressure pipelines of pumping stations lead to increased accident rates and

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significant repair costs. Under these conditions, more and more attention is paid to finding ways and taking measures to improve the safety of pressure pipelines of pumping stations. For normal operation of pressure pipeline systems of pumping stations (design pressure), the strength indicators of the pressure pipeline system are determined[1, 2, 2–6] [7–14].

Such indicators are calculated on the maximum working pressure, taking into account its values during transient, abnormal (emergency) modes of operation of the pressure pipeline system, when the magnitude of sharp pressure fluctuations (hydraulic shocks) can significantly exceed the maximum pressure fluctuations in normal operation [15–18].

Summing up, it can be noted that at present, the most acute issue has become the study and verification of the stress-strain state of the material of the pressure pipelines of the Amuzang-2 pumping station, which occurs during long-term operation in conditions of corrosive and abrasive wear of the shell[19, 20].

2 Materials and methods

In the absence of official supervised parameters subject to mandatory control when assessing the technical condition and safety of pipelines, their instrumental examination included the following diagnostic studies:
- measurement of the shell thickness;
- vibration tests;
-checking the straightness of the longitudinal axis of pipelines.

In this article, only the results of measuring the shell's thickness and calculating the pipeline's strength are considered, considering the degree of corrosive and abrasive wear.

2.1 Control measurements of the thickness of the shell of pressure pipelines

Systematic supervision of the wear of the pipeline shell is necessary to obtain data that provides:
- checking the static strength of pipelines as a beam structure;
- checking the stability of pipelines, which determines the ability of the shell to withstand the external (vacuum) and internal pressure of the pumped water;
-analysis of the dynamics of wear of the shell material in time, along the cross-section and along the pipeline route to localize work to protect the inner surface of the shell from corrosion and abrasive wear.

Measurements are made in characteristic (beginning, middle, and end of each pipeline section between adjacent anchor supports or terminations) and fixed pipeline alignments. The layout of the control points was agreed upon with the department of pumping stations of the "Uzdavsuvloyikha" Institute, and Fig. 1 and 2 are diagrams of the distribution of measurement points along the perimeter of the shell.

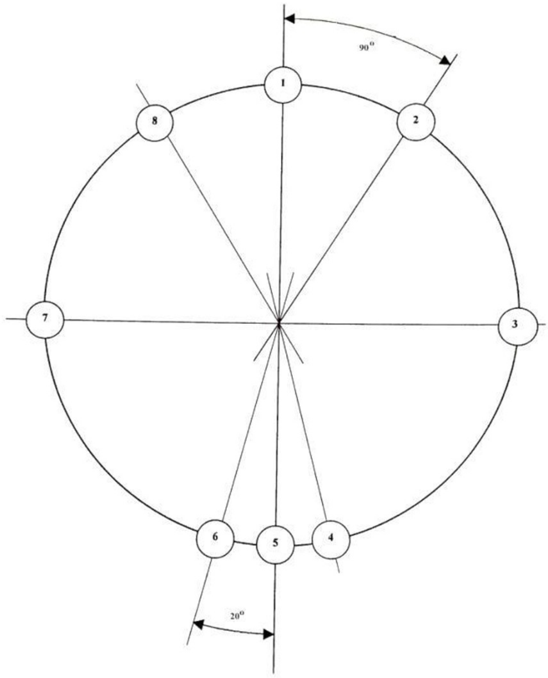

Fig. 1. Scheme of section for measuring thickness of shell at initial section of pipelines of Amuzang-2 pumping station (Ø 2440 mm)

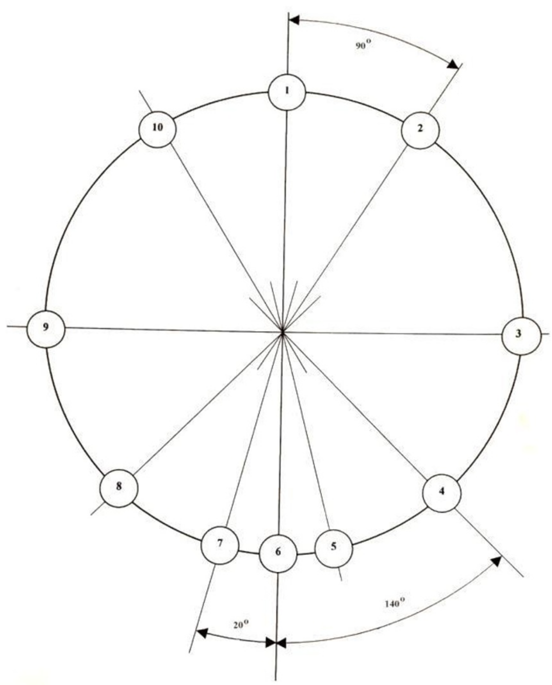

Fig. 2. Scheme of section for measuring thickness of shell at main section of pipelines of Amuzang-2 pumping station (Ø 3240 mm)

For individual pipelines Ø 2440 mm, control points are 8, and for combined conduits Ø 3240 mm - 10.

The measurements were carried out according to the standard method using an ultrasonic thickness gauge UT-93P with the following main characteristics:
- measurement range - 0.6 ... 300 mm;
- discreteness of the digital reading device - 0.1 mm;
- limit of the permissible value of the main error
in the working range - 0.1 mm.

The measurement data show that at the points of transition to a smaller thickness, fragments of conduits (indicated by the symbol "a") have retained the thickness of the underlying section. For this reason, the average thickness in individual sections exceeds the design one.

The wear is unevenly distributed over the cross-section and along the length of the pipelines. Tees at the confluence of flows into combined conduits, two turns, and significant alternating distortions of the longitudinal axis introduce additional perturbations in the flow of pumped water, preventing the sedimentation of abrasive suspension, which, due to the lack of a head sump, is contained in an increased amount.

Between the pipelines, there is no absolute geometric similarity. Therefore there is no symmetry in the wear of the points of the same name of the same sections of different pipelines. In addition, there is a smoothing of local irregularities in the shape of pipelines that arbitrarily fall into the measuring sections.

According to the average wear, the conduits were distributed as follows:

Conduit # 1	Conduit # 2	Conduit # 3	Conduit # 4
1.8 mm	2.3 mm	1.6 mm	1.9 mm

Among conduits, conduit #2 (2.3 mm) has the greatest wear; among individual pipelines is conduit # 1 (1.9 mm); among measuring sections is # 8 of conduit # 2 (2.9 mm); among points is point # 8 of section # 13 (3.4 mm) and point # 4 of section # 8 (3.4 mm) of conduit # 2.

As the measurement results show, due to the increased initial thickness in sections # 1, 3, 7, 9, 10, the residual thickness is close to or exceeds the design value.

Increased wear in sections # 1, 2, 3 is associated with lower flow velocities in individual pipelines and the maximum wear in section # 11 (the middle of the section between AO3 and AO4) is located in the zone of deflections of the longitudinal axis and coincides with the areas of resonant vibration activity of water conduits.

For sections, the average wear of water conduits is:

primary site	between AO1 & AO2	between AO2 & AO3	between AO3 & AO4	from AO4 to outlet
1.5 mm	2.0 mm	1.9 mm	1.9 mm	2.0 mm

Generally, for all PS pipelines, the wear amounted to 1.86 mm, corresponding to an average wear rate of 0.11...0.12 mm/year.

To assess the resource of pipelines, it is also required to perform a verification calculation of the stress-strain state of their shell.

2.2 Verification calculation of pipeline strength

The purpose of the calculations is to predict the stress-strain state of the pipeline material that occurs during long-term operation under conditions of corrosive and abrasive wear of the shell.

According to generally accepted methods, the verification calculation of the pipeline is carried out for shape stability:

A) buckling, like a rod, under the action of internal pressure.

B) from the influence of external pressure.

Initial data.

The piping scheme and dimensions are taken following drawing 759 GM-14 SB of the working draft of the National Assembly, developed by the Uzgiprovodkhoz Institute.

Considering the actual distribution of internal pressure and the location of the catastrophic discharge to divert leaks in the event of an emergency rupture of pipelines, two sections were selected for testing, located on both sides of the AOI. ("left" - underlying between NS and AOI; "right" - overlying between AOI and AO2. The main prerequisites and simplifications are chosen from the condition of not underestimating the stress value. The static design scheme is a multi-span continuous beam, rigidly clamped at one end (Fig. 3).

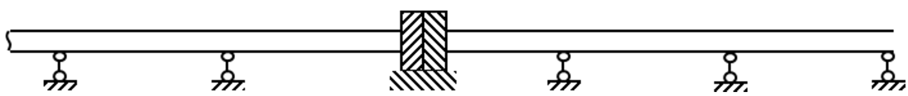

Fig. 3. Diagram of pipeline

Main dimensions:

External diameter of the pipeline: D_l= 2.44 m; D_r = 3.24 m

Initial wall thickness: $S_l = S_r$= 1.6 cm

The angle of inclination of the axis of the pipeline to the horizon: φ_l =11° ; φ_r =9°.

For simplicity, the design head is taken according to the manometric head of the left section without considering the difference in elevations of the calculated sections of pipelines and neglecting the difference in elevations at the upper and lower points of the section. This makes it possible to determine the stresses according to the Laplace momentless theory, then $P_l=P_r$=4.2kg/cm^2.

Distance between supports (starting from A01):

$(L_l)_{1=}$16m; $(L_l)_{2=}$16m; $(L_r)_1$=19 m; $(L_l)_2$ =18 m; $(L_l)_3$ = 11m.

Distributed load:

$$q = \pi D(\frac{D}{4}\gamma_b n_4 + \delta\gamma_{ct} n_3)\cos\varphi$$

where γ_b and γ_{ct} is specific gravity of water (1 t/m^3) and steel (7.8 t/m^3);

n_3 and n_4 are overload factors n_3 =1.1, n_4=1.0.

$$q_l = 3.14 * 3.24(\frac{2.44}{4} * 1.0 * 1.0 + 0.016 * 7.8 * 1.1)\cos 11° = 5.8 \text{ t/m}$$

$$q_l = 3.14 * 3.24(\frac{3.24}{4} * 1.0 * 1.0 + 0.016 * 7.8 * 1.1)\cos 9° = 9.5 \text{ t/m}$$

Normal bending stresses from the action of a distributed load (weight of water and shell):

$$\sigma_0^{\max} = \frac{M}{W} \quad (1)$$

where M is the maximum bending moment, t/m;
W is the moment of resistance of the ring, cm^3.
The compressive and tensile stresses at the upper and lower points of the pipeline are equal in absolute value.
Radial stresses from internal pressure:

$$\sigma_r = \frac{PD}{2\delta} \tag{2}$$

Under the action of stresses σ_0 and σ_r , the material is in a plane stress state.
The strength condition has the form:

$$\sigma_{eq} \leq [\sigma]$$

where [σ] =1600 kg/cm^2 is allowable stress for steel.

$$[\sigma] = \frac{\sigma_T c(M_1 M_2 M_3)}{K \times K_n}$$

where σ_T is yield strength, kg/cm^2. For low-alloy steel 09G2S according to GOST 19282-73 with a thickness of 11-20 mm σ_T = 3300 kg/cm^2.

C=1.0 is coefficient of transition to derivative resistances.

M_1=0.95 is coefficient of operating conditions of pipeline elements.

M_2=0.75 is coefficient of pipeline operating conditions.

M_3=1.0.

K=1.18 is material safety factor.

K_n=1.2 is coefficient of reliability of the structure.

After substitution, we have:

$$[\sigma] = \frac{3300*1.0*(0.95*0.75*1.0)}{1.18\times1.2} = 1660, \text{ kg/cm}^2$$

According to the energy theory of strength:

$$\sigma_{eq} = \sqrt{(\sigma_0^2) - (\sigma_0 \sigma_r) + (\sigma_r)^2} \tag{3}$$

The dangerous point of the pipeline section will be the one where the signs σ_r and σ_o are opposite. At the same time, σ_r always has a "+" sign, and σ_o, depending on the specific diagram of moments, has a "+" sign at the top points of one section and a "-" sign at the bottom, or vice versa.
Since, in our case, Mmax occurs on the support, the dangerous point will be the lower point of the section, in which σ_o is negative.
The condition of local stability from the action of external pressure:

$$\sigma_k' \leq \gamma_c \sigma_{cr} \qquad (4)$$

where σ_k' is ring voltage from the action of external pressure when vacuum is reached;

γ_c= 1.0 is coefficient of working conditions.

Critical voltage:

$$\sigma_{cr} = 0.55E\frac{R}{S}(\frac{\delta}{R})^{\frac{3}{2}}$$

where: E is modulus of elasticity of steel, E=2*10^6 kg/cm^2;

R is pipeline radius; S is the distance between the annular stiffeners, S = 300 cm.

The design load under the action of external pressure on the pipeline in the event of emergency emptying should be taken equal to 1 kg/cm^2.

When a vacuum occurs:

$$\sigma_\kappa' = n_6 \frac{P * R}{\delta} \qquad (5)$$

where: R is pipeline radius, cm; n_6=1.2 is overload factor.

3 Results and Discussion

Longitudinal stresses from loads q are found according to the modified three-moment equation. From the moment diagram (not shown), we get:

for the left section: Mmax=160 tm - on the intermediate support

for the right section: Mmax=300 tm - at the anchor support.

Further calculations are made for several values of the shell thickness:

δ=1.6; 1.0; 0.5 cm.

Geometric characteristics of the cross-section of the pipeline:

Ring moment of inertia: $I_x=0.05[D^4_{ex} - (D_{ex} - 2\delta)^4]$, cm^4;

Момент сопротивления: $W= 2 I_x / D_{ex}$, cm^3.

Moment calculations I_x and W depending on the thickness of the shell, are summarized in Table 1. The longitudinal stresses are also presented there δ_0^{max} according to (1).

Table 1.

δ,	Left section			Right section		
cm	I_x, cm^4	W cm^3	δ_0^{max}, kg/cm^2	I_x, cm^4	W cm^3	$\delta_{0,}^{max}$ kg/cm^2
1.6	9.1x10^6	74600	214	20x10^6	123000	170
1.0	5.7x10^6	46700	343	13.5x10^6	83000	360
0.5	3x10^6	23800	670	5x10^6	31000	970

Radial stresses according to formula 2 and equivalent ones according to formula 3 are summarized in Table 2.

Table 2.

δ,	Left section		Right section	
cm	δ_r, kg/ cm ^{2}	kg	δ_r, kg/ cm ^{2}	δ_{eq}, kg/ cm ^{2}
1.6	320	466	455	550
1.0	512	745	680	915
0.5	1050	1480	1450	2080

As the results of the studies showed, the wear of the shells is permissible:

for the left section is up to 0.45cm.

for the right section is up to 0.55cm.

when analyzing the state of pipelines, the larger of the found values of the allowable thickness is considered.

Calculation of stability according to condition (4) using expression (5) is presented in Table 3.

Table 3.

δ	Left section		Right section	
cm	σ_{cr}, kg/cm ^{2}	σ'_{κ} kg/cm ^{2}	σ_{cr}, kg/cm ^{2}	σ'_{κ}, kg/cm ^{2}
1.6	705	91	580	390
1.0	350	146	288	194
0.5	123	292	102	214

As the results of the studies showed, the wear of the shell is permissible:

for the left section is up to 0.65 cm.

for the right section is up to 0.85 cm.

According to the accepted method of calculation for the design of steel pipelines, a verification calculation is made for the strength of the shell material and the stability of the shape of its section:

- from the action of external pressure (vacuum in the pipeline);
- for longitudinal bending, like a rod, under the action of internal pressure.

As the measurement results showed, for the initial section of the pipelines, without compromising the strength of the sheath material, wear of at least 4.5 mm is acceptable (the actual residual thickness of the sheath in the measuring section closest to the dangerous measuring section (No. 2, pipeline 1) is 13.8 mm).

Thus, the static buckling strength of pipelines is ensured.

The calculation of stability in the event of a vacuum in the pipeline according to condition (4) using expression (5) is presented in Table 3.

From the condition of the integrity of the pipelines when a vacuum occurs in them, the minimum thickness allowed for the same section is 6.5 mm.

As can be seen from the nomograms, the residual thickness of the pipeline shell, permissible under the conditions of stability from the effects of vacuum, for the same sections is:

For the left section - 7.2mm (actual average thickness over the section at the time of examination - 13.8mm);

For the right section - up to 8.5mm (actual -13.7mm).

Thus, the pipelines can withstand the maximum vacuum.

According to the generally accepted calculation method, the design load in the event of a vacuum should be taken equal to 1.0 kg/cm^2. However, there are no shut-off devices on the pressure pipelines of PS.

From the condition of the continuity of the flow, the vacuum can only be in the outlet siphon and not more than the difference between the marks of the axis of the siphon neck and the minimum water level of the upper pool.

For PS Amu-Zang 2 this is:

$$Pvac = (372.78-367.8)*10 = 0.5 \text{ kg / cm}^2.$$

In reality, the vacuum is less due to the leakage of the SWR.

The condition for maintaining the stability of the shell shape against the action Pvac = 0.5 kg/cm2 for the final section of the conduits located above the minimum level marks in the pressure basin, where the limiting thickness is 6.19 mm. The actual minimum thickness (section # 15, conduit # 2) is currently 7.9 mm.

Thus, the static strength of pipelines is ensured in both cases.

From the nature of the action of forces that cause the stress-strain state and taking into account the relationship of the main design dimensions used in the calculations, it follows that under existing operating conditions, maintaining the strength of pipelines is possible in two ways:

- containment of the wear rate of the inner surface of pipelines with the help of wear-resistant protective coatings, elimination of conditions for biocorrosion;

additional finning of pipeline sections adjacent to the siphon outlet.

Quick-acting gates are not installed on pressure pipelines of the National Assembly; therefore, checking the pipeline for shape stability against hydraulic shock is not provided.

The pressure increase in the Amu-Zang 2 PS pipeline with the gradual closing of the butterfly valve can be estimated using an approximate method.

Initial data:

Pipeline length L = 500 m;

Pipeline diameter at the butterfly valve D = 2.2 m;

The thickness of the shell directly at the shutter, taking into account wear $\delta = 0.016$ m;

Working pressure behind the gate (according to field tests)$P_м = 450$ кPa;

Minimum shutter closing time (according to test data) $t_з = 25$ sec;

Velocity in the pipeline before closing the gate (according to test data) V =3.5 m/s;

Permissible stress of sheath material $[\sigma] = 160*10^3$ кPa;

Bulk modulus of water $K = 21*10^8$ кPa;

Modulus of elasticity of steel $E = 2*10^{11}$ кPa;

Density of water $\rho = 1000$ kg /m^3.

1. The velocity of shock wave propagation, taking into account the elasticity of the pipeline shell:

$$c = \frac{\sqrt{K/\rho}}{\sqrt{1 + \frac{(K*D)}{(E*\delta)}}}$$

for known input data:

$$c = 1450 / 1.58 = 918 \text{ m/s}$$

2. Water hammer phase:

$$T = 2L / c = 2*500/ 918 = 1.1 \text{ s}$$

3. For an incomplete water hammer ($t_3 >> T$), the calculated shock increase in pressure at the beginning of the pipeline

$$\Delta p = c*\rho*V*(T/ t_з) = 918*1000*3.5*(1.1 / 25) = 141.4 \text{ kPa}$$

4. Stability condition

$$\sigma =(P_m+\Delta p)*D/\delta*2 < [\sigma]$$

where σ is the actual stress in the shell material from the joint action of the working Pm and the impact pressure increment Δp.

$$\sigma = (450+141.4)*2.4/2*0.016 = 44355 \text{ кPa} < [\sigma]$$

Thus, the stability of the shape of the pipeline shell against pressure increase when the butterfly valves are closed is ensured.

4 Conclusions

- It has become necessary to study and check the stress-strain state of the material of the pressure pipelines of the Amuzang-2 pumping station, which occurs during long-term operation under conditions of corrosive and abrasive wear of the shell.
- During the research, the method of field measurements using an ultrasonic device to determine the thickness of the pipeline shell and the method of calculating the stress-strain state of the pipeline material that occurs during long-term operation under conditions of corrosive and abrasive wear of the shell were used.
- Verification calculation was carried out for the strength of the shell material and the stability of the shape of its section: from the action of external pressure (vacuum in the pipeline), buckling, like a rod, under the action of internal pressure.
- According to the studies carried out, the pipelines can withstand the maximum vacuum, and the static buckling strength of the pipelines is ensured.

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