Device to perform primary damper tank wastewater treatment at sewage pumping stations. Static calculation

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Abstract. The design of “Device to perform primary wastewater treatment of suspended solids at sewage pumping stations” utility model is considered to be implemented in existing and newly designed sewage pumping stations, as well as in automated damper tanks. Exemplified by real conditions, static loads on the main structural elements are modeled. The construction arrangement is evaluated in the terms of possibility to be used as a base for the development of the model range. The possibility of developing an industrial design is determined based on the results of analysis of the strength of the units.

1. Introduction

Primary treatment of entering the sewage pumping station wastewater is a preparatory stage of further transportation of the water in pressure mode. The content of wastewater mechanical impurities varies greatly in composition and quantity that complicates the operation of pumps and pressure pipelines. An effective wastewater treatment process is of special importance at the stage of passing through a damper tank of a sewage pumping station [1] during the adjustment or accident period. To perform such tasks, the following technical devices are known: all kinds of gratings, screens and strainers, however, the low level of automation, absence or insufficient level of hardware control were noted during the analysis process , what is more, the operation involves significant labor costs of the personnel [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23].

2. Materials and experimental techniques

To improve the efficiency of the mechanical wastewater treatment, the team of authors proposed an utility model, "Device to perform primary wastewater treatment of suspended solids at sewage pumping stations", figure 1 [2]. The initial stage of research, focused on the wastewater treatment issues, determined the practical feasibility of performing this operation using the device as a part of a sewage pumping station and a damper tank of a sewage pumping station [3].

The design of the prototype requires the calculation of support frames cross-sections, slewing rings, drive rods, rotary platforms, as well as modeling sliding bearings and the selection of actuators. The design technique will optimize the operating parameters to determine the model range of industrial products.
Figure 1. Device to perform primary wastewater treatment of suspended solids at sewage pumping stations [2]: 1 is a foundation slap; 2 is a lower support frame; 3 is a lower rotary platform; 4 is a slewing unit; 5 is intermediate slides; 6 is an upper rotary platform; 7 is an upper support frame; 8 is multifunctional operating module; 9 is actuating rod; 10 is a support; 11 is a filtration container; 12 is a monitor sensor; 13 is a communication cable; 14 is a load sling; 15 is a metal bracket; 16 is a running limiter [2]

In the design of the utility model, the basic elements to receive static load are slewing units, including the upper and the lower support frames, actuating rods, rotary platforms, slider bearing and supports.

Design solutions in development of a pre-production model should be based on the engineering analysis.

The model of a typical sewage pumping station of modular type with 2.2 m diameter of the receiving tank and 8.5 m height; the inlet gravity pipe diameter is 0.3 m; the daily wastewater flow rate is 1250 m³/ day per a residential settlement with an estimated population of 5 000 thousand people [3] is the basis to choose the dimensions of the swivel block for a pre-production model, figure 2.

3. Rotary platforms design model
We consider rotary platforms as a structural element that perceives the concentrated load of the weight of the filter container and its contents, figure 2 [2], where $G$ is the total weight of the filtration container (if lattice gap width is 16 mm, in condition of garbage loading equal to 50% of the daily value $= 10 + 57$ kg $\approx 1670 H$.
Figure 2. Design model of a swivel block

Section D – A of a rotary platform, figure 3, is presented in the form of a design diagram, and N epure: axial forces, M: bending moments, and Q: cross-axis forces [24].

Figure 3. Epures of internal power factors

Longitudinal section is presented as N epure:

\[ N_{AB} = G = 1670 \, H \, . \]

Load action line G is at the distance:

\[ e = \frac{\varnothing}{2} + 0.10 \, m = \frac{0.48}{2} + 0.1 = 0.34 \, m . \]

3.1 Rated force determination

The horizontal components of the upper \( F_C \) and lower \( F_B \) are equal: \( F_C = F_B \). It is proved by the equations of the sum of the projections of all forces on the horizontal axis \( X \), figure 4.
The sum of the moments relative to the point \( B \), figure 4, to determine forces \( F_C \) and \( F_B \) is presented as follows [24]:

\[
\sum M_B = 0; \\
G \cdot e - F_C \cdot 0.6 = 0, \Rightarrow F_C = \frac{G \cdot e}{0.6} = \frac{1670 \cdot 0.34}{0.6} = 946.3 \text{ H}; \quad F_C = F_B = 946.3 \text{ H}.
\]

Determination of the support reactions [24], figure 3:

a) \( \sum M_A = 0; \quad -H_D \cdot 1.5 + F_C \cdot 0.9 - F_B \cdot 0.3 = 0; \Rightarrow H_D = 378.5 \text{ H}; \)

b) \( \sum M_B = 0; \quad -F_C \cdot 0.6 + F_B \cdot 1.2 - H_A \cdot 1.5 = 0; \Rightarrow H_A = 378.5 \text{ H}; \)

v) Check: \( \sum x = 0; \quad -H_D + F_C - F_B + H_A = 0; \quad -378.5 + 946.3 - 946.3 + 378.5 = 0. \)

Design the epures of bending moments \((M \text{ epure})\) and cross-axis forces \((Q \text{ epure})\) [24].

\[ M_{T,A} = 0; \quad M_{T,C} = H_D \cdot 0.6 = 227.1 \text{ H} \cdot \text{m}; \quad M_{T,B} = -H_A \cdot 0.3 = -113.6 \text{ H} \cdot \text{m}; \quad M_{T,A} = 0. \]

\[ Q_{A,B} = -H_A = -378.5 \text{ H}; \quad Q_{B,C} = -H_A + F_B = +567.8 \text{ H}; \quad Q_{D,C} = -H_D = -378.5 \text{ H}. \]

3.2 Static calculation of the \( H \)-shaped part of the frame

Unfavorable position in slewing units is formed by 90° rotation of rotary platforms with filtration containers placed on them, figure 5, where the reaction is transmitted at \( D \) point \( \perp \) plane of the frame.
Figure 6. Epures of internal power factors

\[ M_{\text{epure}}: M_{T,D} = 0; M_{T,\ell} = H_D \cdot e_{DE} = 378.5 \cdot 2 = 757 \text{ } H \cdot \text{m}. \]

\[ Q_{\text{epure}}: Q_{D,\ell} = -H_D = -378.5 \text{ } H \cdot \text{m}. \]

3.3 Design calculation

The design calculation is performed to determine the safe cross-sectional dimensions of the support-guide frame.

Due to the condition of bending strength [24]:

\[ \sigma_{\text{max}} = \frac{M_{\text{max}}}{W_x} \leq [\sigma], \]

where: \( \sigma_{\text{max}} \) is maximum bending stress \((H \cdot \text{m} = \text{Pa})\); \([\sigma]\) is allowable stress for the material. For steel grades Сt3 \([\sigma] = 160 \text{ MPa}\);

\( M_{\text{max}} \) is maximum moment in the section area

\( M_{\text{max}} = 757 \text{ } H \cdot \text{m} \cdot \text{m} \cdot \text{m} \cdot \text{m} \);

\( W_x \) is section modulus.

\[ W_x \geq \frac{M_{\text{max}}}{[G]} = \frac{757 \text{ } H \cdot \text{m}}{160 \cdot 10^6 \text{ Pa}} = 4.73 \cdot 10^{-6} \text{m}^3 = 4.73 \text{sm}^3. \]

Accepted by assortment [26] \( W_x^\text{ta} = 4.81 \text{sm}^3 \cdot A = 40 \text{ mm} \cdot S = 3 \text{ mm} \)

40 \times 40 \times 3 \times 1250 \text{ kр ГОСТ 8639 – 82.}

В 10 ГОСТ 13663 – 86 » [25] figure 7.

Figure 7. Cross-section

According to the design reasons \( A = 100 \text{ mm} \cdot S = 5 \text{ mm} \). Figure 7 (100 \times 100 \times 5 \times 1 250).

The calculation of stiffness is made in order to limit elastic displacements [24].

\( A = 100 \text{ mm} \cdot S = 5 \text{ mm} \cdot F = 18.57 \text{sm}^2 \cdot J_x = f_x = 276.3 \text{sm}^4 \)
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\[ f = \frac{H_D \cdot e^3}{3E J_X} = \frac{378.5 \cdot 2^3}{3 \cdot 2 \cdot 10^5 \cdot 276.3 \cdot 10^{-8}} = 1.826 \cdot 10^{-3} \text{m} = 1.826 \text{ mm}. \]

Analyzing stiffness:

\[ f = \frac{1.826}{2 \cdot 10^3} \approx 0.001. \]

We conclude that the stiffness is sufficiently high, where: \( E \) – Young's modulus [26] (steel grades Cr3 \( E = 2 \cdot 10^5 \text{ MPa} \)).

4. Actuating mechanism drive design model

The shaft with length \( L \), figure 8, is an actuating mechanism drive.

Shafts are calculated simultaneously for strength and stiffness.

![Figure 8. "Swivel" shaft L = 15 m. Design diagram](image)

Due to the insignificant resistance created by the frictional forces in the bearing of a slewing unit of the lower support frame and the lower rotary platform, as well as by the forces of internal friction between the moving fluid layers when the filter container is rotated in an aqueous medium, the torque \( M_{kp} \), is taken with a margin of 20 \( N \cdot \text{m} \).

4.1 Selection of section due to strength

Torsional strength condition [24]: \( \tau_{max} = \frac{M_{kp}}{W_{\rho}} \leq [\tau] \),

where: \([\tau] = 90 \text{ MPa} \) is torsional strength limit (MPa);
\( W_{\rho} \) is polar resistance limit (m³).

\[ W_{\rho} = \frac{M_{kp}}{[\tau]} = \frac{20 \cdot H \cdot M}{90 \cdot 10^6} = 2.222 \cdot 10^{-7} \text{sm}^3. \]

a) for round section (solid):

\[ W_{\rho} = \frac{\pi d^3}{16} \Rightarrow d = \sqrt[3]{\frac{16 \cdot W_{\rho}}{\pi}} = \sqrt[3]{\frac{16 \cdot 2.222 \cdot 10^{-7}}{3.14}} = 1.04 \text{ sm rounded to 1.2 sm} = 12 \text{ mm}. \]

b) for tubular section:

\[ W_{\rho} = \frac{\pi d^3}{16} (1 - \alpha^4), \]

where: \( \alpha = 0.8 \) is ratio of inner to outer diameter \( \frac{d_0}{d} \).

\[ D = \sqrt[3]{\frac{16 \cdot W_{\rho}}{\pi (1 - \alpha^4)}} = 1.11 \text{ sm} = 12 \text{mm} \Ø. \]

To check the stiffness, we take structurally the shaft diameter equal to 28 mm.

4.2 Strain determination
Shaft twist angle [24]:

$$\varphi = \frac{M_{kr} \cdot L}{G \cdot J_\rho},$$

where: $G$ is shear modulus;
$G = 0.8 \cdot 10^5$ MPa (Cr3);
$J_\rho$ is polar moment of inertia.

a) for round cross-section:

$$J_\rho = \frac{\pi d^4}{32} = \frac{3.14(2.8 \cdot 10^{-2})^4}{32} = 6.03 \cdot 10^{-8} \text{ m}^4;$$

$$\varphi = \frac{20 \cdot 15}{0.8 \cdot 10^5 \cdot 10^6 \cdot 6.03 \cdot 10^{-8}} = 62.2 \cdot 10^{-3} \text{ rad.}$$

In degrees:

$$\varphi' = \frac{\varphi \cdot 180}{\pi} = 3.56^\circ.$$

b) for ring cross-section:

$$J_\rho = \frac{\pi d^4}{32} (1 - \alpha^4) = \frac{3.14(2.8 \cdot 10^{-2})^4}{32} (1 - 0.8^4) = 3.561 \cdot 10^{-8} \text{ m}^4;$$

$$\varphi = \frac{20 \cdot 15}{0.8 \cdot 10^5 \cdot 10^6 \cdot 3.561 \cdot 10^{-8}} = 105 \cdot 10^{-3} \text{ рад.}$$

In degrees:

$$\varphi' = \frac{\varphi \cdot 180}{\pi} = 6.04^\circ.$$

5. Calculation of a swivel block for a cut

Determination of cut-off area [24], figure 9:

$$F_{cp} = F_{прм} - F_{кр} = \frac{a^2}{4} - \frac{\pi d^2}{4} = 9^2 - \frac{3.14 \cdot 3^2}{4} = 73.935 \text{ sm}^2.$$

Figure 9. Swivel mechanism of support unit design model

Design power $P = H_D = 378.5 \text{ H.}$

Shearing test:

$$\tau_{max} = \frac{P}{F_{cp}} \leq [\tau],$$

where: $[\tau]$ is allowable shear stress for bronze: $[\tau] = 60 \text{ MPa}$ [24],

$$\tau_{max} = \frac{378.5}{73.935 \cdot 10^{-4}} = 5.14 \cdot 10^{-4} = 5.14 \cdot 10^{-4} \text{ MPa.}$$

Strength conditions are observed.

6. Calculation of the suspension support (verification of strength and stiffness)

The support, shown in figure 10 “a”, is presented in the form of a design diagram. The support top view, figure 10 “b”, is presented in cases of adverse application of load.
Figure 10. Support design model

It follows from the equitation of projection of forces on the X axis [24]:
\[ \sum X = 0; \Rightarrow R_1 = F_C = 946.3 \, H. \]

We design the bending moment epure by points, figure 10.

Figure 11. Epure of support bending moments

\[ M_{epure} = M_{T,2} = R_1 \cdot 0.115 \, m = 108.82 \, H \cdot m. \]
\[ M_{T,3} = F_C \cdot \frac{0.115}{2} = 54.412 \, H \cdot m. \]

Strength test [27]:
\[ \sigma_{max} = \frac{M_{max}}{W_x} \leq [\sigma], \]
where: \( W_x = \frac{220 \cdot 10^2}{6} = 3667 \, \text{mm}^3 = 3.667 \cdot 10^{-6} \, \text{m}^3 \) – section 2 resistance moment;
\[ M_{max} = M_{T,2} = 108.82 \, H \cdot m \) – maximum bending moment.
\[ \sigma_{max} = \frac{108.82}{3.667 \cdot 10^{-6}} \approx 29.7 \, \text{MPa} < [\sigma] = 160 \, \text{MPa}. \]

Strength conditions are observed.

6.1 Stiffness calculation
Using the same technique as when calculating the frame for stiffness [27], we write the deformation $t_1$:

$$f_1 = \frac{R_{D1} \cdot e_{1-2}}{3EJ_x} = \frac{946.3 \cdot 115}{3 \cdot 2 \cdot 10^5 \cdot 18 \, 333} = 9.89 \times 10^{-6} \text{ mm},$$

where: $e_{1-2} = 115 \text{ mm}$;

$$E = 2 \cdot 10^5 \text{ MPa} = 2 \cdot 10^{11} \text{ Pa} = 2 \cdot 10^5 \text{ H/mm}^2;$$

$$J_x = \frac{220 \cdot 10^3}{12} = 18 \, 333 \text{ mm}^4.$$

The deformation of $t_1$ is negligible, respectively, the support stiffness is provided with a large margin.

7. Conclusion

The results obtained in the process of calculating the units of "Device to perform primary wastewater treatment of suspended solids at sewage pumping stations" prototype give reason to consider the design diagram acceptable to be used in a damper tank of a sewage pumping station, pumping stations, as well as in emergency control tanks. The calculation is a theoretical justification for the further development of the device. Analyzing the obtained data, we can conclude that the design has sufficient margin of safety and can be considered as basic one to develop a model range of industrial products.

This article is one more step in the innovative project implementation. In the next work, the authors will consider the optimization of operating parameters, as well as the selection and adaptation of actuators.

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