Analysis of the wastewater treatment device for the damper tank of sewage pumping stations

D V Skibo¹, A G Kunitsyn² and V R Chupin³

¹Vodokanal Irkutsk Municipal Unitary Enterprise, 2, Stanislavsky st., Irkutsk 664081 Russia

²Irkutsk National Research Technical University, 83, Lermontov st., Irkutsk 664074 Russia

³Irkutsk National Research Technical University, 83, Lermontov st., Irkutsk 664074 Russia

E-mail: d.skibo2013@yandex.ru

Abstract. The article presents a model range of an automated wastewater strainer developed on the basis of utility model “Device to perform primary wastewater treatment of suspended solids at sewage pumping stations”. The device is aimed at efficient mechanical treatment of domestic, storm and industrial effluents at sewage pumping stations and other objects of the water disposal system. The operating parameters of the device are designed based on the gradation of daily flow rates, volumetric solids content and operating conditions. The verification calculation of structural elements for strength and stiffness was carried out taking into account dynamic loads. The parameters of the actuators were determined the selection of gear motors was made.

1. Introduction
The reliability of the water disposal system (WDO) is determined mainly by the operation of pumping stations and pressure pipelines. A significant number of accidents at sewage pumping stations (SPS) and pressure pipelines are caused by impact of the aggressive wastewater environment. Domestic and storm wastewater contain a large number of mechanical inclusions that destabilize the operation of the equipment and reduce its operational resource. There are two ways to solve the problem: filtering wastewater through grids along with separate waste disposal or grinding mechanical impurities by passing wastewater through special grinders. It has been noted that the grinding process is quite technological: the grinded waste is not utilized, but is dumped back into the pumped medium, however, this method requires significant material expenditures associated with the duplication of grinder units and the rapid wear of mechanical units (cutters, support units). At the same time, grinding does not satisfy all needs, in particular relating to stormwater drainage systems ones. The presence of solid inclusions in storm water (fragments of road surface elements: stones, concrete fragments, metal particles) makes the difference between storm and domestic wastewater significant, and therefore implementation of grinders is not acceptable. Therefore, filtering is a necessary measure to provide the trouble-free operation of a sewage pumping station as a part of either the domestic
water disposal system or in the storm one, moreover, emergency control and damper tanks that serve as a storage device require a special approach from this point of view.

2. Materials and experimental techniques

The peculiarities of the operation of the internal sewerage system cause sudden equipment failures at a sewage pumping station, while the existing filtering and grinding plants often do not always cope with the incoming volume of garbage. Material costs of the elimination of communal accidents and the elimination of their consequences are often significant, determining the need for new approaches to organize the operation mode of the water disposal systems.

Based on the results of the study of the water disposal system, the team of authors has developed a utility model "Device to perform primary wastewater treatment of suspended solids at sewage pumping stations" Figure 1, aimed at increasing the reliability of a pumping station, pressure and emergency control pipelines and damper tanks [1]. This research paper, aimed at implementation of an industrial design, is based on an empirical research method and mathematical modeling.

In previous papers, the authors developed the conditions for filtering wastewater and performed static calculation of the main working units and assessed the structural diagram of the device [2].

The process of the implementation of an innovative project includes the analysis of the calculated indicators of typical sewage pumping stations and tanks, as well as the development of a model range of the device. The presented earlier [2] static calculation data confirmed the operability of the main structural units. However, for the further design of the device, it is necessary to study definite structural units on the dynamic impact of the falling wastewater flow, as well as the development and selection of actuators.

3. Model range

Development of parameters for the model range of the automated wastewater strainer AWWS based on the utility model "Device to perform primary wastewater treatment of suspended solids at sewage pumping stations" Table 1 is based on the study of a modular sewage pumping station of domestic and foreign production, as well as emergency control and damper tanks using obtained experimentally data [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17].

The developed parameters of the automated wastewater strainer AWWS Table 1 make it possible to select the operating characteristics of the filtering device both for a newly designed object and for an existing one.
The dimension of the bar spaces of 16 - 30 mm solves problems both in the domestic wastewater disposal system and in the storm drain system. The overall dimensions of the filtration container FC in accordance with the loading are designed for transportation to the place of disposal or processing by low-tonnage special transport at the condition of single unit operation of the device during 24 - 48 hours.

4. Calculation of internal friction between layers of a moving fluid forces
Based on the actual operating conditions, the rotational speed of the rotary mechanism in Figure 2 should be taken equal to 1 revolutions / minute, while its operating cycle is not associated with the mode of filling / emptying the receiving tank of a sewage pumping station. In this regard, we consider some additional efforts expended by the actuator to overcome the forces of internal friction between the layers of the moving fluid, Figure 1.

| h, spaces x 10⁻³ m | Model range (number of inhabitants - thousand people / flow rate - m³ / day) | Daily value of waste removed out of wastewater |
|---------------------|-------------------------------------------------|-----------------------------------------------|
|                     | 1/250               | 2/500              | 3/750               | 4/1 000                     | 5/1 250                      |
| m³                  | t                   | m³                 | t                   | m³                          | t                           |
| 16                   | 0.059               | 0.044              | 0.118               | 0.088                       | 0.177                       | 0.132                       | 0.236                       | 0.176                       | 0.295                       | 0.22                        |
| 20                   | 0.056               | 0.042              | 0.112               | 0.084                       | 0.168                       | 0.126                       | 0.224                       | 0.168                       | 0.28                        | 0.21                        |
| 30                   | 0.047               | 0.035              | 0.094               | 0.07                        | 0.141                       | 0.105                       | 0.188                       | 0.14                        | 0.235                       | 0.175                       |

Table 1. Automated Wastewater Strainer AWWS Parameters.

| h, spaces x 10⁻³ m | Model range (number of inhabitants - thousand people / flow rate - m³ / day) | Daily value of waste removed out of wastewater |
|---------------------|-------------------------------------------------|-----------------------------------------------|
|                     | 6/1 500                      | 7/1 750                      | 8/2 000                      | 9/2 250                      | 10/2 500                      |
| m³                  | t                   | m³                 | t                   | m³                          | t                           |
| 16                   | 0.354               | 0.264              | 0.413               | 0.308                       | 0.472                       | 0.352                       | 0.531                       | 0.396                       | 0.59                        | 0.44                        |
| 20                   | 0.336               | 0.252              | 0.392               | 0.294                       | 0.448                       | 0.336                       | 0.504                       | 0.378                       | 0.56                        | 0.42                        |
| 30                   | 0.282               | 0.21               | 0.329               | 0.245                       | 0.376                       | 0.28                        | 0.423                       | 0.315                       | 0.47                        | 0.35                        |

Filter container diameter, m

Filter container height, m

Filter container weight, t

Estimated single unit operation of the device (filling 2 FC), h

| h, spaces x 10⁻³ m | Model range (number of inhabitants - thousand people / flow rate - m³ / day) | Daily value of waste removed out of wastewater |
|---------------------|-------------------------------------------------|-----------------------------------------------|
|                     | 16     | 20                            | 30                            | 28                           | 35                           | 24                           |
| m³                  | t                   | m³                 | t                   | m³                          | t                           |
| 16                   | 1.296               | 1.470              | 1.627               | 1.800                       | 2.005                       |
| 20                   | 1.207               | 1.369              | 1.518               | 1.680                       | 1.865                       |
| 30                   | 1.023               | 1.159              | 1.287               | 1.422                       | 1.571                       |

Filter container weight, t

Estimated single unit operation of the device (filling 2 FC), h

24
In this case, with a relatively slow motion of the body in liquid medium with an uneven distribution of velocities in the cross section of the flow, the tangential force arising in the liquid can be correctly determined by the formula [18]:

\[ F = \mu \frac{d\mu}{dn} = 0.00134 \cdot 2.64 \cdot \frac{3.64 - 0.63}{0.48} = 0.022 \, H, \]  

where: \( F \) is tangential force, \( H \), arising between two adjacent layers within the area \( S \); 
\( \mu \) is dynamic viscosity of water at temperature \( 10^5 \, ^\circ C \) according to [18] equal \( 0.00131 \, H \cdot s/m^2 \); 
\( S \) is FC area \( (\pi dh) = 2.64 \, m^2 \); 
\( \frac{d\mu}{dn} \) is velocity gradient, expressed as a change in layer velocity.

Thus, the loads acting during the rotation of the FC in liquid medium turned out to be insignificant, what is explained by the low speed of rotation of the mechanism. As a result, the cross-section of the fastening (section with \( b \)) of the FC is taken constructively (arbitrarily).

5. Calculation of dynamic loads
The design of the device during operation perceive the impact of kinetic energy, this process is caused by the force of pressure from the side of a fast-flowing liquid on the blank bottom of the FC, in addition, one cannot neglect random influences caused by impacts of solid inclusions, the definition of which is based on Newton's second law [19].

5.1. Interaction of water with an obstacle
Within each second, the bottom is touched by all water particles that are at a distance from the bottom no more than \( v_{v.f} \cdot 1s \) Figure 3.

It can be concluded that a mass of water equal to its volume is in contact with the bottom, [19]:

\[ m = \rho S_f v_{v.f}, \]  

where: \( \rho \) is density of water; 
\( S_f \) is useful flow area, \( m^2 \) in the horizontal section of the pipeline prior to the device according to [16] 
\( v_{v.f} \) is the vertical fluid flow rate determined by the assumption [19]:
where: $v_0$ is initial gravity flow rate in a horizontal pipeline prior to the device, m/s; 
$h_{f\text{r}},f_{al}$ is the maximum path traversed by the body in free fall Table 2, determined by the assumption:

\[ h_{f\text{r}},f_{al} = \sum h_{bac\text{lev}}, h_{was}, h_{f\text{it}},b_{ac}, h_{ben} \tag{4} \]

where: $h_{bac\text{lev}}$ is hydraulic backwater level in the working range of the control sensor equal to 0.18 m [20]; 
$h_{was}$ is height of the waste level in the FC at maximum load determined by the assumption:

\[ h_{was} = \frac{W_{was}}{\pi D_e^2} \tag{5} \]

where: $W_{was}$ is calculated volume of waste substances in gratings by one FC [20]; 
$D_e$ is FC diameter. 
$h_{f\text{it}},b_{ac}$ is height of the water layer in the filtering element of the FC, determined by the assumption:

\[ h_{f\text{it}},b_{ac} = \frac{Q_{spac}}{b_{spac}} + h_{gr} \tag{6} \]

where: $Q_{spac}$ is water flow through one space of the FC, m$^3$/s, determined as:

\[ Q_{spac} = \frac{Q_{\text{max}}}{N_{spac}} \tag{7} \]

where: $Q_{\text{max}}$ is maximum flow Table 1, 3; 
$N_{spac}$ is number of spaces in the FC; 
$v_{spac}$ is flow velocity in the grids, according to [18, 20] equal to 0.8 m/s; 
$b_{spac}$ is the size of the spaces between the bars in the FC; 
$h_{gr}$ is pressure losses in the grids determined by the formula (Weisbach) [18]:

\[ h_{gr} = \frac{\xi_{gr} v_0^2}{2g} \tag{8} \]

where: $\xi_{gr}$ is the coefficient of local resistance of the grid in a direct arrangement with respect to the incident flow, calculated by the Kirshmer formula:

\[ \xi_{gr} = \beta \frac{S_{bar}}{b_{spac}}^{4/3} \sin \alpha \tag{9} \]

where: $S_{bar}$ is the bar thickness equal to 0.01 m; 
$b_{spac}$ is value of the gap between bars, 0.016 m; 
$\beta$ is the coefficient, for the round shape of the cross-section of the bar, according to [18] equal to 1.79; 
$\alpha$ is the angle of inclination of the grid to the horizon, 90°. 
$h_{ben}$ is the amount that determines the bend radius of the branch 90° according to [21] 
g is 9.8 m/s acceleration of gravity. 

Thus, according to formula (4), the velocity of the vertical flow at the moment of contact with the bottom of the FC is equal to $v_{ver,fl} = 6.4$ m/s.

Further determination of the quantity of motion $- mv$, arriving to the bottom of the FC, is multiplying mass by speed [19]:

\[ mv = \rho S_{f}\nu_{ver,fl} \quad v_{ver,fl} = \rho S_{f}\nu_{ver,fl}^2 \tag{10} \]

At the moment of contact with the bottom of the FC, the water spreads evenly, while the quantity of motion of the entire mass is equal to the sum of the quantities of motion of water particles emanating in different directions to the perimeter of the grid [19, 21].

If the particle $A$ motion at a predetermined speed is deflected to the left, then in the condition of equable spreading similar particle $B$ at the same speed modulo will go to the right.
The quantity of motion of these particles is equal in number, but the direction is reverse, while, the total quantity of motion for a pair of these particles is equal to zero. Consequently, the total quantity of motion of the fluid is equal to zero after hitting the obstacle. Thus, the quantity of motion of the wastewater before contact with the FC bottom and after it is known. Based on this change in the motion, the calculation of the impulse received by water from the bottom of the FC in one second has the following form [21]:

\[
F \Delta t = m v_2 - m v_1.
\]  
(11)

Substituting the values \(\Delta t = 1 \text{s}, m v_1 = \rho S_f y_0^2, m v_2 = \rho S_f v_{srf,l}^2\), we deduce

\[
F \cdot 1 \text{s} = \rho S_f (v_{srf,l}^2 - y_0^2).
\]  
(12)

The impulse received by the bottom of the FC in the same second.

Considering that the impulse of the force is numerically equal to the force per unit time, the quotation for its modulus will look like [19]:

\[
F_{fl} = \rho S_f (v_{srf,l}^2 - y_0^2).
\]  
(13)

The flow force is calculated for each model range and is shown in Table 3

5.2. Interaction of a rigid body with an obstacle

While the device is in operation, an accidental fall of foreign objects on the bottom of the FC is possible, the contact with the obstacle time is less than a second and the impact force significantly exceeds the weight of these objects. As an example, let us imagine the fall of a cast-iron ball with a diameter of 0.1 m and a mass of 4.08 kg onto a blank bottom of a FC.

When an object falls from a height \(h_{fr, fal}\), according to Newton's third law, at a speed equal to the speed of the transported medium, the bottom of the FC will receive a full impulse from the ball [19]:

\[
F \Delta t = 2m v_{srf,l}.
\]  
(14)

When \(\Delta t = 1\text{s}\) average force is:

\[
F_{sp} = 2m v_{srf,l}.
\]  
(15)

Thus, the impact on the FC \(- F_{max}\) is expressed as \(\sum F_{fl} + F_{sp}\).

| Model range | AWWS 1/2 3/4 5/6 7/8 9/10 | dm³/s 5.21 10.42 15.63 20.83 26.04 31.25 36.46 41.67 46.88 52.08 |
|-------------|-----------------------------|---------------------------------|
| m           | 0.216 0.216 0.216 0.216 0.216 0.216 0.271 0.271 0.271 | Nominal diameters of supply automatic flow tanks d [26] |
| m           | 0.007 0.007 0.007 0.007 0.007 0.007 0.005 0.005 0.005 | Hydraulic slope of the automatic flow tanks prior to SPS [26] |
| h/d         | 0.21 0.3 0.38 0.45 0.52 0.59 0.66 0.54 0.58 0.63 | Estimated filling of the automatic flow tank prior to SPS |
| m²          | 0.006 0.009 0.013 0.016 0.019 0.022 0.026 0.031 0.035 0.038 | Flow velocity in the automatic flow tank prior to SPS, \(v_0\) |
| m/s         | 0.912 1.102 1.211 1.291 1.353 1.395 1.422 1.323 1.35 1.588 | Vertical fluid flow velocity at free falling, \(v_{srf,l}\) |
| m/s         | 4.576 5.765 5.497 6.094 5.293 5.620 5.922 6.241 6.513 6.865 | Maximum path covered by the object in free falling, \(h_{fr, fal}\) |
| m           | 1.026 1.634 1.467 1.810 1.336 1.512 1.686 1.898 2.071 2.276 | Maximum flow force affecting the FC: \(F_{max}\) |
| H           | 486.63 749.19 813.20 1054.61 920.47 1100.9 1332.07 1651.36 1940.29 2242.69 | Downstream diameter |

Table 2. Flow Parameters for an Automated Wastewater Strainer.
The maximum load will be in the event if it is applied compactly, i.e., in the form of a jet with a diameter \( d_f \). Table 2, determined by the formula:

\[
d_f = \sqrt{\frac{4E_f}{\pi}}.
\] (16)

5.3. Interaction of water flow with an obstacle

The water flow falling to the bottom of the FC can be represented as a linear load \( q \), applied to the strengthening rib of the FC.

Considering the load \( F \) according to the length of the downstream \( d_f \):

\[
F_{fl} = q \cdot d_f,
\] (17)

where:

\[
q = \frac{F_{fl}}{d_f}.
\] (18)

The strengthening rib is presented in the form of a beam, at the edges hinged to the walls of the FC (design scheme) Figure 4.

Define support reactions:

\[
V_A = V_B = \frac{q \cdot d_f}{2} \text{ kN}.
\] (19)

Design the epures of bending moments due to water pressure (Ep. M):

\[
M_{t.e} = V_A \cdot \frac{D_e - d_f}{2};
\] (20)

\[
M_{max} = M_{t.e} = V_A \cdot \frac{D_e}{2} - q \left( \frac{d_f}{2} \right)^2.
\] (21)

Figure 4. Design scheme of the FC base
(upper: Filtration Container bottom; right: strengthening grid; design scheme)
Let's accept a strengthening grid of 2 I-beams with parallel flange faces Figure 5 [22]: Enter the necessary geometric characteristics taken in the assortment:

**Figure 5.** Design scheme of the strengthening grid of the base (unit A).

In this case the geometric characteristics for 2 I-beams:

- Moment of inertia: \( J_x = 2J_x = 2 \cdot 198 = 396 \text{ sm}^4 \);
- Moment of resistance: \( W_x = 2W_x = 79.4 \text{ sm}^2 \).

Static stress in the strengthening grid:

\[
\sigma_{st} = \frac{M_{max}}{W_x} \text{ MPa.} \tag{22}
\]

Static stress \(\sigma_{st}\) is significantly less than the permissible stress for structural steel st. 3 \([\sigma] = 160 \text{ MPa.}\)

Since the water falls from a height, the bottom experiences dynamic stresses, which are calculated by the formula:

\[
\sigma_{dyn} = k_d \cdot \sigma_{st}, \tag{23}
\]

where: \(k_d\) the dynamic bending coefficient is as follows:

\[
k_d = 1 + \sqrt{1 + \frac{2f_{st}}{f_{st}}}; \tag{24}
\]

\(f_{st}\) is static deflection, which is determined by Vereshchagin method. With this aim, it is necessary to design the epure of bending moments based on unit force \(\vec{F} = 1 \text{ (ep. M)}\):

Support reactions:

\[
V_x = V_y = \frac{F}{2} = 0.5; \quad M_{tr.c} = V_x \cdot \alpha \text{; where: } \alpha = \frac{V_x - \overline{f}_{x}}{2}; \quad M_{tr.c} = V_y \cdot \overline{f}_{y}; \quad f_{st} = \sum \frac{\alpha_1 \overline{V}_x}{E_{tr.c}}.
\]

where: \(\alpha_1\) is area of the figure at the epure (ep. M).

\[
y_1 = \frac{1}{2} \cdot M_{tr.c}; \quad \omega_2 = \frac{\overline{f}_{x}}{2} \cdot M_{tr.c}; \quad \omega_3 = \frac{1}{2} \cdot \overline{f}_{y} \cdot (M_{max} - M_{tr.c}); \quad \omega_4 = \frac{q \overline{V}_x^3}{M_{tr.c}^3}.
\]

\[
y_1 = \frac{1}{2} M_{tr.c}; \quad y_2 = \frac{2}{3} (M_{tr.c} - M_{tr.c}); \quad y_2 = m_2.
\]

\[
f_{st} = \frac{2}{E_{tr.c}} \left(\omega_1 \cdot y_1 + \omega_2 \cdot y_2 + \omega_3 \cdot y_3 + \omega_4 \cdot y_4\right) m.
\]

\[
\sigma_{dyn} = k_d \cdot \sigma_{st} \text{ MPa.}
\]

\(\sigma_{dyn}\) is significantly more than permissible stress \([\sigma] = 160 \text{ MPa.}\) (st. 3)

In the presence of a spring with a deformation coefficient \(\alpha_d = 30 \cdot 10^{-6}\);

Complete deformation: \(\Delta_{st} = f_{st} + f_{dam}\);

where: \(f_{dam} = \alpha_d V_A = 30 \cdot 10^{-3}\).

\[
k_d' = 1 + \sqrt{1 + \frac{2f_{st}f_{dam}}{\Delta_{st}}}. \tag{25}
\]
Table 3 Values of the design parameters of the automated wastewater strainer

| Model range | AWWS 1/250 | AWWS 2/500 | AWWS 3/750 | AWWS 4/1 000 | AWWS 5/1 250 | AWWS 6/1 500 | AWWS 7/1 750 | AWWS 8/2 000 | AWWS 9/2 250 | AWWS 10/2 500 |
|-------------|------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| V_θ _A_ | 0.24 | 0.37 | 0.41 | 0.53 | 0.46 | 0.55 | 0.67 | 0.83 | 0.97 | 1.12 |
| M_t.c | 0.033 | 0.047 | 0.071 | 0.089 | 0.075 | 0.086 | 0.099 | 0.116 | 0.13 | 0.146 |
| M_max | 0.041 | 0.062 | 0.091 | 0.117 | 0.101 | 0.121 | 0.145 | 0.178 | 0.207 | 0.238 |
| σ_v1 | 0.5 | 0.8 | 1.1 | 1.5 | 1.3 | 1.5 | 1.8 | 2.2 | 2.6 | 3 |
| ω_1 | 2.27·10^{-3} | 3·10^{-3} | 6.26·10^{-3} | 7·99·10^{-3} | 6.04·10^{-3} | 6.74·10^{-3} | 7·39·10^{-3} | 8.15·10^{-3} | 8.78·10^{-3} | 9.48·10^{-3} |
| ω_2 | 1.44·10^{-3} | 2.54·10^{-3} | 4.6·10^{-3} | 6.35·10^{-3} | 5.82·10^{-3} | 7·19·10^{-3} | 9.03·10^{-3} | 9·15·10^{-3} | 9.15·10^{-3} | 9·15·10^{-3} |
| ω_3 | 1.73·10^{-3} | 4.02·10^{-3} | 6.34·10^{-3} | 1.01·10^{-4} | 1.05·10^{-4} | 1.44·10^{-4} | 2.06·10^{-4} | 3.06·10^{-4} | 4.05·10^{-4} | 5·09·10^{-4} |
| ω_4 | 0.00117 | 0.01969 | 0.0355 | 0.03675 | 0.02613 | 0.02632 | 0.02522 | 0.02397 | 0.02331 | 0.02333 |

Summary indicators of dynamic characteristics

- k_d = 556.14, 686.01, 474.41, 506.07, 503.01, 520.59, 541.14, 560.82, 573.35, 579.81
- σ_dyn = 288.2, 539.3, 543.9, 746.5, 642.9, 790.8, 986.2, 1254.6, 1491.3, 1740.1
- f_{dam} = 0.007299, 0.01123, 0.01123, 0.01581, 0.0138, 0.01651, 0.01998, 0.02477, 0.0291, 0.03364
- A_f = 17.79, 18.08, 16.53, 16.15, 14.94, 14.56, 14.03, 13.42, 12.97, 12.67
- σ_d = 9.2, 14.2, 19, 23.8, 19.1, 22.1, 25.6, 30, 33.9, 38

Static deflection, m

- f_{sl} = 6·6·10^{-6}, 9·6·10^{-6}, 1·3·10^{-5}, 1·41·10^{-5}, 1·06·10^{-5}, 1·2·10^{-5}, 1·15·10^{-5}, 1·21·10^{-5}, 1·27·10^{-5}, 1·36·10^{-5}

- σ_d = k_d · σ_{eq} = Pa;
- σ_d ≤ 2.6 < \gamma = 160 MPa.

Static stresses for a FC lying on a rigid foundation do not satisfy the strength conditions, which makes it necessary to reduce the dynamic effects.

To fulfill the strength conditions in the structure, we introduce a damping base device.

6. Actuators

Autonomous replacement of the FC includes the operation of actuators (gear motors) that move the FC in the aquatic environment. The selection of the parameters of the actuators depends on the acting frictional forces in the bearing of the slewing bearing of the lower support frame and the lower slewing platform Figure 6 (Table 4), determined by the formula:

\[ F_{fric} = \mu_{fric} F_{tot}, \]

where \( \mu_{fric} = 0.05 \), coefficient of friction for fluoroplastic [23];

\( F_{tot} \) is the total value of the forces acting on the bearing of the slewing bearing of the lower support frame and the lower slewing platform Figure 6, determined by the formula:

\[ F_{tot} = F_{max} + m_{fc} \gamma, \]

where: \( F_{max} \) is maximum flow rate, \( \gamma \) affecting FC (Table 2);

\( m_{fc} \) is maximum weight of the filled filtration container, kg (Table 1);

In this case, the torque \( M_{tot} \) in the bearing of the slewing bearing of the lower support frame and the lower rotary platform is determined by the formula:

\[ M_{tot} = \frac{F_{fric} \cdot \gamma_{sup}}{2}, \]
where: \( d_{\text{sup}} \) is support node of the swivel mechanism Figure 6

\[ \text{Figure 6. Swivel support assembly [2]} \]

Taking into account the generated torque values \( M_{\text{tor}} \) for the device model range (Table 1), verification calculation is necessary to check the actuator shaft for strength and rigidity for a given section of the supporting unit of the rotary mechanism, Figure 6.

**Table 4 Summary indicators of the automated wastewater strainer**

| AWWS | 1/ | 2/ | 3/ | 4/ | 5/ | 6/ | 7/ | 8/ | 9/ | 10/ |
|------|----|----|----|----|----|----|----|----|----|----|
|      | 250| 500| 750| 1 000| 1 250| 1 500| 1 750| 2 000| 2 250| 2 500|

| Friction magnitude, \( F_{\text{fric}} \) | 0,33 | 0,60 | 0,87 | 1,12 | 0,80 | 0,94 | 1,08 | 1,22 | 1,35 | 1,49 |
|----------------------------------------|------|------|------|------|------|------|------|------|------|------|

| Torque value, \( M_{\text{tor}} \) | 16,6 | 29,8 | 43,5 | 56,2 | 40,1 | 47,1 | 54,0 | 61,0 | 67,7 | 74,7 |
|-------------------------------------|------|------|------|------|------|------|------|------|------|------|

| Polar moment of resistance, \( W_p \) | 1,84·10^{-7} | 3,31·10^{-7} | 4,83·10^{-7} | 6,24·10^{-7} | 4,46·10^{-7} | 5,23·10^{-7} | 6·10^{-7} | 6,78·10^{-7} | 7,52·10^{-7} | 83·10^{-7} |
|--------------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|

Torsional strength condition (Table 4), [2]:

\[ \tau_{\text{max}} = \frac{M_{\text{fric}}}{W_p} \leq \tau, \]  

where: \( \tau = 90 \text{ MPa} \) – torsional strength (MPa);
\( W_p \) is Polar moment of resistance (m³).

\[ W_p = \frac{M_{\text{fric}}}{\tau}; \]  

For round section (solid):

\[ W_p = \frac{\pi d^4}{16}; \Rightarrow d = \sqrt[4]{\frac{16 W_p}{\pi}}. \]

To check the rigidity, we take the structural diameter of the shaft equal to 28 mm.

As the power plant of the actuator, we take a worm two-stage geared reducer of domestic production of the company "Industrial Reducers", which is a general-purpose drive designed to change the torque and speed.

**Table 5 Operating parameters of the actuators of the device wastewater treatment for suspended solids [25]:**

| Reducer Standard Size | Power, kW | Output revolution n = n, rpm | Torque on the output shaft \( T_{\text{nom}} \), \( H \cdot m \) | Gear Ratio, \( U \) | Cantilever Load \( F_{\text{nom}} \), H | Service-factor, \( S_{\text{nom}} \) | Electric engine revolution n = \( n_{\text{ent}} \), rpm |
|-----------------------|-----------|-----------------------------|-------------------------|-----------------|-----------------|-----------------|-----------------|
| DRV 030/040           | 0,06      | 0,91                        | 166                     | 1 500           | 4 840           | 0,7             | 1 400           |
| DRV 030/040           | 0,06      | 1,2                         | 143                     | 1 200           | 4 840           | 0,7             | 1 400           |
This type of geared motors is designed for continuous operation up to 24 hours a day or with periodic breaks, as well as operation in continuous and intermittent modes when the shafts rotate in any direction. Thanks to the improved housing, the unit can be installed in various positions.

7. Conclusion

This paper presents a model range for industrial products of an innovative project “Device to perform primary wastewater treatment of suspended solids at sewage pumping stations”, developed on the basis of optimization of operating parameters and operating features of a sewage pumping station. The operating conditions of the rotary mechanism in the mode of filling / emptying the receiving tank of the SPS are considered. The section "Dynamic loads" contains the definition of forces arising from the interaction of a vertical flow of water with structural elements, as well as the process of accidental contact of the FC with foreign objects, which are the basis for the verification calculation of the structural strength. On the basis of the calculation of the friction forces in the bearing of the slewing bearings, the conditions of the hydraulic processes, the parameters of the actuators were determined and the selection of gear motors was made.

The carried out studies have proved the efficiency of the structure “Device to perform primary wastewater treatment of suspended solids at sewage pumping stations” as well as the possibility of applying it at the facilities of Vodokanal in the Russian Federation.

As part of the implementation of an innovative development, the team of authors will consider the issue of automation and economic efficiency of the device in the next paper.

References

[1] Skibo D V, Sudnikovich V G, Tolstoy M Yu, Kurtin A V 2018 Device to perform primary wastewater treatment of suspended solids at sewage pumping stations Utility Model Patent RU No. 179 790 U1, Published: May 24, 2018 Bull. 15

[2] Skibo D V and Kunitsyn A G 2020 Device to perform primary damper tank wastewater treatment at sewage pumping stations. Static calculation IOP Conf. Ser.: Mater. Sci. Eng. 880 012054

[3] Chupin R V 2015 Optimization of developing drainage systems. Monograph (Irkutsk: Publishing House of ISTU) p 418

[4] Chupin V R, Melekhov E S and Chupin R V 2011 Development of the theory and practice of modeling and optimization of water supply and sanitation systems p 325

[5] Salomeev V P 2009 Reconstruction of engineering systems and water disposal facilities p 192

[6] Alekseev M I, Baranov L A, Ermolin Yu A 2017 Estimation of the life time of water supply facilities under the influence of a periodically changing flow of failures Water supply and sanitary technique 4 pp 50-54

[7] Ignatchik S Yu 2012 Energy conservation and reliability in the reconstruction of sewage pumping stations Water supply and sanitary technique 12 pp 37-43

[8] Skibo D V and Tolstoy M Yu 2018 Study of problems in the operation of the sewage pumping station of the Beryozovsky microdistrict of the city of Irkutsk and methods to solve them. Construction and industrial safety 12 (64) pp 123-132

[9] Karmazinov F V, Melnik E A, Probirsky M D, Pankova G A, Mikhailov D M, Ilyin Yu A, Ignatchik V S and Ignatchik S Yu 2013 Technical inspection of pumping stations of St. Petersburg sewage system Water supply and sanitary technique 1 pp 20–28

[10] Chupin V R, Melekhov E S and Chupin R V 2012 Development of an information system for modeling the modes of movement of wastewater in drainage systems Irkutsk State Technical University Bulletin 12(71) pp 148-155

[11] Chupin R V, Pukemo M M, Melekhov E C and ChupinV R 2019 Improvement of the optimization methodology and development of a proposal for the creation of a unified drainage scheme for the central ecological zone of the Baikal natural territory on the example of the Slyudyansky district of the Irkutsk region Proceedings of universities.
Investments. Building. Estate property 9(28) pp 144-157
[12] Skibo D V and Tolstoy M Yu 2019 Automated damping tank of sewage pumping stations Utility Model Patent RU No. 186682 U1, Published: January 29, 2019 Bull. 4
[13] Skibo D V and Tolstoy M Y 2019 and Chizhik K I Automated damping tank of sewage pumping stations IOP Conf. Ser.: Mater. Sci. Eng. 687 044030114-125
[14] Ignatchik V S, Ignatchik S Yu, Kuznetsova N V, Spivakov M A 2019 Probabilistic-statistical method for assessing the volume of wastewater discharges through storm outlets of general-purpose drainage systems Water and ecology: problems and solutions 1 (77). pp 23-29
[15] Zhitinev A I, Kurganov Yu A, Ignatchik V S, Sarkisov S V and Vinokurov P V 2019 Results of experimental studies of hydraulic shocks occurring during the operation of sewage pumping stations Water supply and sanitary technique 11 pp 55-59
[16] SP32.13330.2018 Sewerage External networks and facilities Updated edition SNiP 2.04.03-85 Available at: http://docs.cntd.ru/document/1200094155
[17] MDK 3-02.2001 Rules for the technical operation of systems and facilities for public water supply and sanitation Available at: http://docs.cntd.ru/document/1200025707
[18] Kiselev P G 2011 Hydraulic calculations handbook p 312
[19] Targ S M 2010 Short course in theoretical mechanics p 416
[20] Skibo D V and Tolstoy M Yu 2018 Mechanical wastewater treatment at sewage pumping stations as a way to reduce anthropogenic environmental impact Construction and industrial safety 10(62) pp 117-125
[21] GOST 17375-2001 Seamless welded pipeline parts made of carbon and low-alloy steel. Elbows, steeply curved type 3D (R~1,5DN) Available at: http://docs.cntd.ru/document/gost-17375-2001
[22] GOST R 57837-2017 Hot-rolled steel I-beams with parallel flange edges Available at: http://docs.cntd.ru/document/1200157342
[23] Anuryev V I 2006 Handbook of a designer - machine builder 2(9) p 928
[24] OOO Industrial Reducers Kremenkul Reducers Factory Available at: https://www.evropivod.ru/catalogue/podbor-motor-reduktora/
[25] Korsis Product catalog Two-layer corrugated pipes for free-flow and storm sewers Available at: http://vostokpipe.ru/storage/editor/to_corsys.pdf