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Analysis of the effect of mechanical impurities in water on the hydroabrasive wear of the turbines of the Bozsu hydroelectric power plant

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Abstract. The peculiarity of the operation of hydropower facilities (pumping stations and hydroelectric power plants) in the Republic of Uzbekistan is that the equipment works with liquids containing a large amount of mechanical impurities. The purpose of the research is to assess the effect of the content of mechanical impurities in water on waterjet wear. The object of research is the Bozsu HPP (Uzbekistan). To assess the hydroabrasive properties of a liquid with impurities, an analysis of the granulometric and mineralogical composition of sediments and especially those fractions of impurities that pose a danger was carried out. For water passing through the turbins of the Bozsu HPP, these are fractions of feldspar and quartz. Most of the composition of mechanical impurities are feldspar minerals (58.46% with an average diameter of 0.093 mm). The total content of hazardous fractions (feldspar and quartz) is 77.07% or 0.3-0.4 kg/m^3, which exceeds the maximum permissible norm (0.2 kg/m^3). But at the same time, no dangerous fractions in diameter (more than 0.25 mm) were detected. A full-scale inspection of the turbine parts showed that waterjet wear is present. The type of waterjet wear is fine-scaled wear with rare, separately located, shallow scales and deep (deep) type of wear with long grooves. The degree of waterjet wear quantitatively and qualitatively, this can be attributed to the wear of low and medium activity.

Keywords: sediments, hydroabrasive wear, hydro turbine, hydroelectric power plant, granulometric composition

1 Introduction

The problem of increasing efficiency is one of the most demanded and urgent in the field of hydropower [1,2,3]. This problem is complex and should be considered at all stages of the life process of a hydropower object [4,5], both at the design stage [6,7,8] and during

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operation [9,10]. This problem can be solved both by increasing the efficiency of operation of hydraulic structures of a hydropower object [11,12,13,14] and by increasing the efficiency of equipment operation [15,16,17]. The efficiency of the equipment of hydropower facilities is influenced by a large number of various factors [1,2,4], one of the main of which is the presence of a large amount of mechanical impurities in the pumped water [3,18,19]. Many hydropower plants in the Republic of Uzbekistan are located on mountain rivers transporting a large amount of suspended and bottom sediments [2,3,17]. Sediments accumulating on water supply tracts and regulating tanks significantly complicate and worsen the operation of hydroelectric power plants [2,11,13]. Turbines of such hydroelectric power plants suffer to one degree or another from the abrasion effects of sediment, require significant expenditures to combat the negative effects of sediment and to maintain the turbines in working condition [1,2,14]. According to research by A. Abgottspon et al. [20] the efficiency of Pelton turbines in seasons with a large amount of sediment decreased by 0.4-1.0%.

When designing turbines for hydroelectric power plants located on mountain rivers, it is necessary to assess the abrasive ability of sediments suspended in river water that will pass through hydroelectric power plants, and predict the degree of danger of these sediments for hydro turbines. With a sufficiently significant effect of these sediments, the technical condition of the turbines deteriorates rapidly, their efficiency (efficiency) decreases and power losses increase at hydroelectric power plants and, accordingly, electricity generation. Many prominent scientists were engaged in the theory of waterjet wear of hydraulic machines: V.B.Dulnev [21,22], V.Ya.Karelin [21,23], G.I.Krivchenko [21], M.Mamazhanov [19], W.A. Stauffer [21], G.F.Wislicenus [21,24] and many others. V.B.Dulnev and V.Ya.Karelin made a particularly significant contribution to the study of phenomena and the development of the theory of waterjet wear of hydraulic turbines and pumps for the conditions of Central Asia [22,23].

The purpose of this work is to study the composition of mechanical impurities and assess their impact on the waterjet wear of the Bozsu hydroelectric power plant (Uzbekistan) and assess its impact on operational reliability. The scientific novelty of the research lies in the fact that for the first time an assessment of the technical condition of the equipment was made taking into account the influence of waterjet particles on the details of the Bozsu hydro plant's turbines.

To achieve this goal, the following research objectives are set:

- To collect, process and analyze data from the HPP operation service.
- To evaluate the hydroabrasive properties of the water source and the water passing through the flow part of the hydro turbine.
- To determine the type and nature of waterjet wear of hydraulic turbine parts.

2 Methods

The methodological foundations of the conducted research are based on a systematic approach, since the research topic is a complex physical phenomenon that occurs under conditions of a complex of factors during the hydroabrasive wear of the turbine. Research methods include: collection, processing and analysis of data from the HPP operation service, field survey of the object, generalization and scientific analysis of available stock and published materials.

The Bozsu HPP is part of the cascade of Tashkent HPPs located on the Chirchik – Bozsu waterway. The HPP is located on the Boz-Su canal and is the first stage of the Tashkent HPP cascade. Bozsu HPP is located in Tashkent and is the first-born in the hydropower industry of the Republic of Uzbekistan. The first unit of the station was put into operation in 1926, the entire station was put into operation in 1937 [25].

In the HPP building there are 4 Francis turbines, double, boiler-shaped, horizontal, with two suction pipes, with a nominal capacity of 1.1 MW each, with a design head of H = 13.5 m and a flow rate of 12 m^3/s. Two turbines of units No. 1 and No. 2 of the company Fr. Neumayer (Munich) was established in 1926. Turbines of units No. 3 and No. 4 of the Leningrad Metal Plant were installed in 1929 and 1936.

Twin units are currently practically not used. This is an old design, it began to be used at the beginning of the last century, when there were no slow-speed units. On such types of units, due to the installation of two impellers on one shaft, the turbine power was increased without increasing the diameter of the impeller.

Waterjet wear is usually understood as the destruction of parts of the flow part of hydraulic machines as a result of the mechanical action of solid particles in water or other working fluid [22, 23]. Destruction occurs due to continuous collisions transported by a stream of solid particles with the surface of the part. At the moment of impact, the kinetic energy of the moving particle is transformed into the work of deformation of the material of the part being streamlined by the flow. that the abrasive wear of a stationary part, streamlined by a hydraulic mixture, is directly proportional to the concentration of sediments in the flow, the time of the impact of the hydraulic mixture on the part and the mass of one grain of sand.

The presence of suspended sediments in the water causes abrasive destruction of its working organs. The degree of waterjet destruction of the material depends on [23,26,27]:

• turbidity or concentration of waterjet impurities;
• granulometric and mineralogical composition;
• forms of sediment particles;
• the time of the impact of the flow with waterjet particles on the details of the hydraulic turbine;
• the material from which turbine parts subject to waterjet are made.

Not all sediments suspended in river water, but only those particles whose hardness exceeds the hardness of the materials used to manufacture the parts of the flow part of the turbines, pose a real danger to hydraulic turbines. Turbine parts are usually made of carbon steel, the hardness of which (according to the Mohs scale) is 5-5.5. Less hard minerals have significantly less abrasive ability and it can, without much error, be neglected. Consequently, with the current state of knowledge of the issue under consideration, the assessment of the abrasive ability of suspended river sediments can practically be organized by taking into account only those minerals in the composition of these sediments, the hardness of which is equal to 5 and higher.

3 Results and discussions

The granulometric composition of the sediments of the Bozsu channel was analyzed according to the analysis of single samples of channel sediments taken by JSC "Gidroproekt" in the upstream of the hydroelectric power station (before the pressure basin) on August 27, 2015 and in the downstream on September 2, 2015 [25] and is presented in Table 1.

The average diameter is defined as the weighted average according to the following formula:

$$d_{aver} = \frac{\sum P_i * d_i}{P} \tag{1}$$

Where di is the diameter of the fraction particles, mm;

P is the percentage of the fraction.

The results of determining the average diameter of mechanical impurities in water are presented in Table 1.

Table 1. Granulometric composition of sediments in the upstream and downstream of the hydrounit.

d, mm	1.0 - 0.5	0.5 - 0.25	0.25 - 0.1	0.10 - 0.05	0.05 - 0.01	0.01- 0.005	0.005- 0.002	<0.002	D_{aver}, mm
dumping of the Tashkent canal									
P, %	0.9	12.4	12.0	7.1	35.0	12.8	13.4	6.4	0.09
$P*d_i$	0.675	4.588	2.04	0.5325	1.05	0.096	0.0469	0.0064	
Nizhny Bozsu Canal- Nizhne Bozsuyskaya HPP No. 1									
P, %		8	6.9	16.8	47.8	11.5	4.5	4.5	0.069
$P*d_i$		2.96	1.173	1.26	1.434	0.0862	0.0157	0.0045	
The Bozsu Canal-the lower reaches of the Aktepinskaya HPP									
P, %	11.3	52.9	24.0	11.8					0.33
$P*d_i$	8.475	19.573	4.08	0.885					

Figure 1 shows the integral curves of the granulometric composition of sediments in the streams of the Bozsu HPP, constructed according to the available data of fractional composition (Table 1).

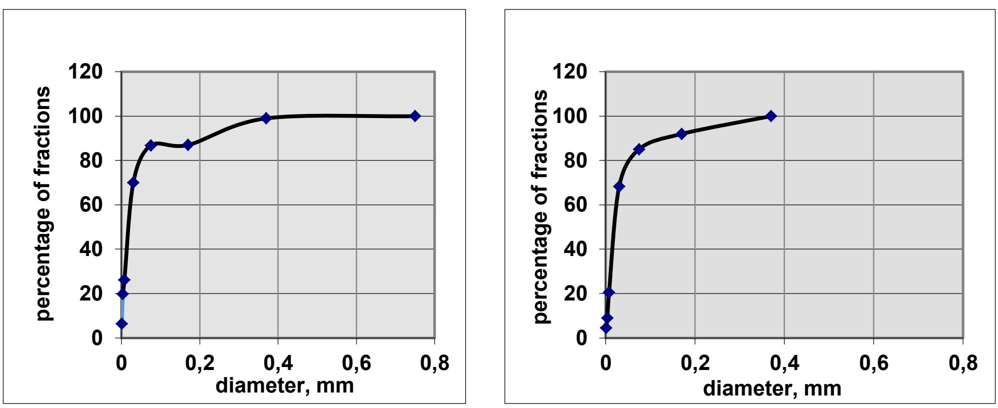

Fig. 1. Integral curves of the granulometric composition of sediments in the streams of the Bozsu HPP.

Table 2 shows the mineralogical and petrographic composition of sediments of the Bozsu channel (downstream). These are the mechanical impurities that pass through the turbines and participate in waterjet wear.

The analysis of the data in Table 2 shows that the channel sediments in the upper reaches of HPP-1 are mainly represented by silty (dusty) particles (fractions d=0.1-0.01 mm), in the lower reaches both sand particles (fractions d=1.0-0.1mm) – 57.3% and silty - 42.7 %.

The mineralogical composition is dominated by mineral fragments – 80.6%, rock fragments make up 9.3%. Of minerals, feldspar predominates – 58.5%. The quartz content in siltstone (0.05-0.1 mm) and sand (0.10-1.0 mm) fractions varies from 12.1 to 6.5% (Table 2). It should be noted that in the selected sample there were a sufficient number of small particles of broken glass, which could affect a greater percentage of quartz particles in the sample.

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Table 2. Mineralogical and petrographic composition of sediments of the Bozsu channel (downstream) (from source [25])

fraction size, mm	fraction content, %	carbonate content in % per fraction	quartz	feldspars	mica(glist)		fragments of rocks		
					muscovite, biotite	chlorite	erupted	metamorphic shales	siliceous rock
< 0.002	There is no fraction								
0.005 – 0.002	There is no fraction								
0.01 – 0.005	There is no fraction								
0.05 – 0.01	4.58	26.32	1.17	2.62	0.055	0.018	0.17	0.092	0.096
0.10 – 0.05	38.14	27.19	10.91	20.25	0.53	0.27	2.49	0.53	0.46
0.25 – 0.10	38.52	18.4	4.66	27.39	0.54	0.19	0.77	1.04	1.04
0.5 – 0.25	17.80	26.4	1.85	8.19	0.64	0.18	1.78	0.36	0.43
1.0 – 0.5	0.96	19.4	0.02	0.013	0.15	0.021			0.021
2.0 – 1.0									
5.0 – 2.0									
Content	100	100	18.61	58.463	1.915	0.679	5.21	2.022	2.047

fraction size, mm	fraction content, %	accessories (amphibole, pyroxene)	ore mineral hematite	fragments of var resin	carbonaceous substance	clay material	plant residues
< 0.002		There is no fraction					
0.005 – 0.002		There is no fraction					
0.01 – 0.005		There is no fraction					
0.05 – 0.01	4.58	0.018	0.046		0.04	0.23	0.0188
0.01 – 0.05	38.14	0.15	0.27	0.15	0.34	1.64	0.15
0.25 – 0.10	38.52	0.12	0.19	0.19	0.27	1.73	0.39
0.5 – 0.25	17.80	0.053	0.053	0.034	1.87	1.78	0.58
1.0 – 0.5	0.96			0.051	0.17	0.064	0.45
2.0 – 1.0		There is no fraction					
5.0 – 2.0		There is no fraction					
Content	100	0.341	0.559	0.425	2.69	5.444	1.5888

The results of the analysis of the composition and mineralogical composition of suspended sediments passing through the turbines of the Bozsu HPP (Tables 1-2 and Fig.1) are presented in Table 3. Table 3 presents generalized characteristics of mechanical impurities (suspended) sediments in water passing through the flow part of the turbines of the Bozsu hydroelectric power plant, which can be used in the analysis and prediction of waterjet wear of hydraulic turbine parts.

Table 3. General characteristics of suspended sediments.

Characteristics of suspended sediments	The content of particles with a diameter of 0.1 - 0.05 mm is 30.4%.
Average annual turbidity of water, the highest monthly average, g/m3	Up to 4-5 g/l
Гранулометрический состав наносов	The content of particles with a diameter of 0.05 - 0.01 mm is 61.2%.
Granulometric composition of sediments	The quartz content in particles with a diameter of 0.05-0.01 mm ranges from 12.1 to 6.5%.
Chemical composition of water and its characteristics	By chemical composition, water is of medium mineralization. In terms of hardness - within 1.89 - 2.80 mg-eq/l. According to pH = 7.4 - 7.9

Figure 2 shows the integral curves of the granulometric composition of abrasive sediments (feldspar and quartz) constructed according to the available data of fractional composition.

Table 4. Granulometric composition of hydroabrasive sediments.

d, mm	1.0 - 0.5	0.5 - 0.25	0.25 - 0.1	0.10 - 0.05	0.05 - 0.01	0.01- 0.005	0.005- 0.002	<0.002	D_{aver}, mm
Feldspar									
P, %	0.013	8.19	27.39	20.25	2.62				0.093
$P*d_i$	0.0097	3.0303	4.6563	1.5187	0.0786				
Quartz									
P, %	0.02	1.85	4.66	10.91	1.17				0.023
$P*d_i$	0.015	0.6845	0.7922	0.8182	0.0351				

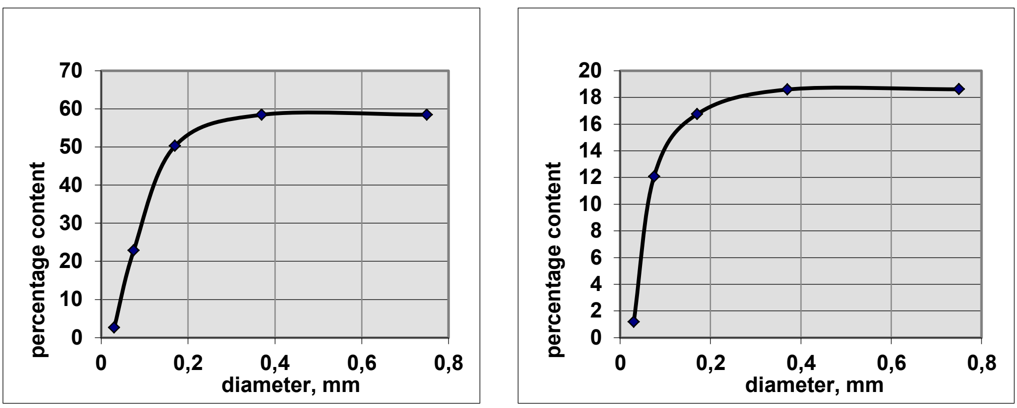

Fig. 2. Integral curves of the granulometric composition of abrasive particles in water (feldspar and quartz)

In accordance with the existing classification [22-23], the turbidity of the Bozsu channel can be attributed to zone III (with high turbidity of river waters (150— 500 g/m^3)). That is, there is a risk of waterjet wear.

We will evaluate the composition of mechanical sediments for water-abrasive properties.

It is believed that there is a risk of abrasive wear under the following conditions [22-23]:

• when the sediment content in the flow exceeds 0.5 kg/m^3;

• when the number of fractions dangerous for turbines is not less than 0.2 kg/m^3.

Fractions with sediment particle diameters of 0.25 mm or more for abrasive particles (quartz) and not less than 0.4 mm for softer particles are considered dangerous.

Analysis of Tables 2-3 shows that there are minerals of various abrasiveness in the composition of the water passing through the turbines. The greatest danger for hydraulic machines is represented by particles whose hardness exceeds the hardness of the materials of the parts (hardness on the Mohs scale 5-5.5). Most of the composition of mechanical impurities, as can be seen from Tables 2-3, are feldspar minerals (58.46% with an average diameter of 0.093 mm). Feldspar has a hardness on the Mohs scale of 5-7, and can be attributed to rocks of medium abrasiveness. Quartz rocks (hardness on the Mohs scale of more than 7) have a medium and high degree of abrasiveness, and make up the second group of minerals in terms of content (18.61% of the total mass of the entire sample with an average diameter of 0.023 mm). Thus, the total content of hazardous fractions (feldspar and quartz) is

77.07% or 0.3-0.4 kg/m^3, which exceeds the maximum permissible content. But at the same time, no dangerous fractions in diameter (more than 0.25 mm) were detected.

As practice shows, when operating hydraulic turbines in conditions of waterjet wear, the front parts of the impeller blades, the outer part of the guide vanes and the inner part of the housing are most intensively affected. A full-scale examination of worn parts of hydraulic turbines (impeller blades, guide vanes) made it possible to classify the type of waterjet wear. The nature of damage to the blades indicates fine-scaled wear with rare, separately located, shallow scales and deep (deep) type of wear with long grooves. Which indicates the presence of hydroabrasive wear of the details of the Bozsu hydroelectric plant's turbines. Quantitatively and qualitatively, this waterjet wear can be attributed to low and medium activity. Despite the presence of the process of hydroabrasive wear, the main reason for the decline in the energy efficiency of the Bozsu HPP units should be considered general physical wear associated with a long period of operation of hydraulic units and their moral wear.

4 Conclusion

The analysis of the above material on the examination of the equipment condition of the Bozsu HPP-1 allows us to draw the following conclusion:

1. Despite the relatively insignificant turbidity of the water passing through the flow part of the turbine, the composition contains minerals with medium and high degrees of abrasiveness (feldspar more than 50.5% and quartz -18.6% of the total amount of solid impurities).

2. Type of waterjet wear is fine-scaled wear with rare, separately located, shallow scales and deep type of wear with long grooves. Quantitatively and qualitatively, hydroabrasive wear of turbines can be attributed to low and medium degree wear.

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