

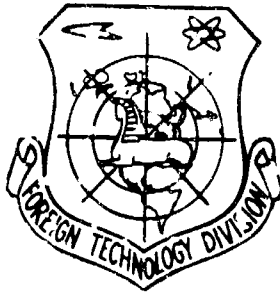
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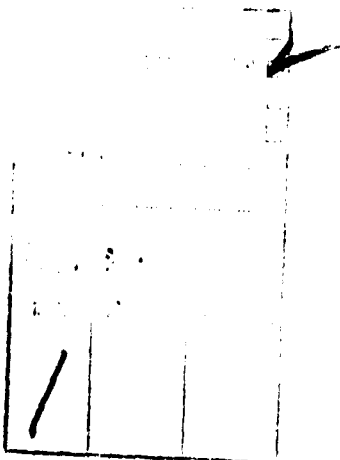
CAVITATION AND HYDROABRASIVE RESISTANCE OF METALS IN HYDRAULIC TURBINES

(Selected Articles)



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CAVITATION AND HYDROABRASIVE RESIS-
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(Selected Articles)

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TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-afb, OHIO.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere.
 When written as ѣ in Russian, transliterate as yĕ or ĕ.
 The use of diacritical marks is preferred, but such marks
 may be omitted when expediency dictates.

THE MECHANISM OF CAVITATIONAL DESTRUCTION AND CHANGES
IN THE SURFACE LAYER OF METALS¹

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This article contains certain opinions regarding the mechanism of cavitation destruction and changes in the surface layer of metals as a result of cavitation effects.

As materials for investigation use was made of steel 1Kh13, 1Kh18N9T, commercial iron, single crystals of aluminum, steel U7, and aluminum bronzes with varying aluminum content.

Tests of the alloys were conducted on a magnetostrictive vibrator in tap water at a temperature of 18°C, with a frequency of oscillations of 7.5 kHz and double amplitude of 60 μ. The degree of destruction of alloys was determined according to loss of weight before and after the test.

In order to study the changes in relief of the micro- and substructure cavitized surface of the alloys methods of roentgenographic, microscopic, and electron-microfractographic analyses, and also a method for measurement of microhardness were used.

¹In view of the insufficiency of experimental data, the article is printed in order of discussion.

Under conditions of cavitation the alloy undergoes from the side of the cavitation bubble periodic time pressure which increases to 550 kgf/mm^2 on an area 10^{-5} mm^2 at a rate of $8 \cdot 10^4 \text{ kgf/mm}^2 \cdot \text{s}$.

Microvolumes of the alloy $\sim 10^{-6} \text{ mm}^3$ which are contiguous with the cavitation bubble are heated to temperatures of $300\text{-}400^\circ\text{C}$. The periodicity of thermal effect and the high speed of change in temperature mean that the microvolumes of the alloy being destroyed by cavitation are subject to thermal shock and thermal fatigue due to compression of the microvolumes during heating and tension during cooling. Compressive stress, by rough estimate, attains 90 kgf/mm^2 .

Deformation of the surface layer during compression should appear in unique buckling of microvolumes of the alloy, and during tension - in the appearance of shear and microscopic cracks. Microfractographic investigation of the cavitized surface of steel 1Kh13 confirms the latter.

The developed relief of surface layer appearing during cavitation destruction increases its stress condition.

Apparently, the effect of all the factors mentioned is sufficient for plastic forming of the surface layer and for brittle breakaway of a microvolume of the alloy.

The incubation period of cavitation is characterized by local mechanical and thermal effects on the comparatively flat surface of the alloy (duration of the conditional incubation period was determined by a test ensuring a weight loss of 1 mg).

During the incubation period, microvolumes of the alloy with dimensions of 10^{-3} mm experienced plastic deformation, which leads to the development of surface relief which is accompanied by distortion of the crystal lattice of a second kind, splitting of blocks of the mosaic, and general disorientation of fragments (Fig. 1), the appearance of slip lines and microvoids, and growth in values of microhardness.

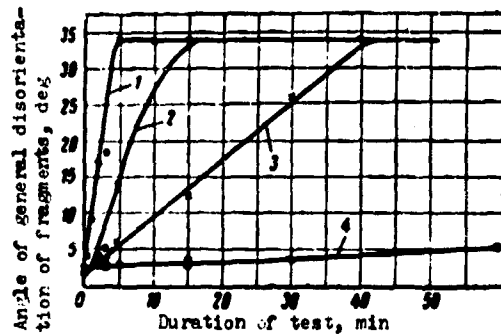


Fig. 1. Angle of general disorientation of fragments of α -phase of bronze Br A⁴ (1), Br A⁸ (2), Br A¹² (3) α - and β - phases of bronze Br A¹² (4) depending upon the duration of the cavitational test.

Along with these changes of the surface layer characteristic for all the investigated materials, in certain groups of alloys special phenomena are observed. Thus, in fine-grained materials (dimension of grain less than 3-5 μ) there is revealed a selective destruction of crystallites unfavorably oriented with respect to operational loads. In unbalanced alloys (hardened perlite steels and unstable austenitic steels) the mechanical and thermal effect of the cavitational zone causes phase transitions - tempering, transition of γ -phase to α -phase (Fig. 2).

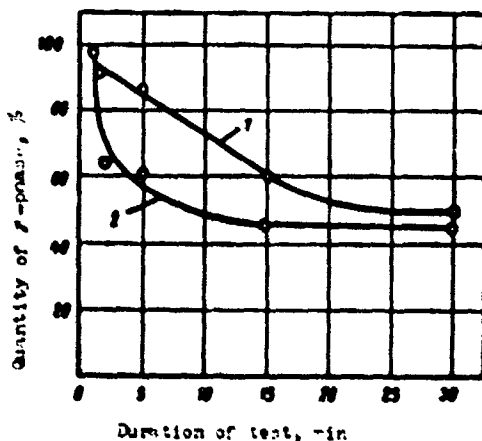


Fig. 2. Quantity of γ -phase in a cavitated layer of annealed (1) and hardened (2) steel 1Kh18N9T depending upon the duration of cavitation testing.

The period of uniform cavitation of alloys, in contrast to the incubation period, pertains to the developed relief of the surface layer determining the constancy of rate of cavitation and brittle character of the destruction of crystallites. The latter was established by roentgenographic investigation revealing in the relief of the surface of the cavitized materials of planes of chipping (breakaway) characteristic for brittle rupture.

On the basis of what has been expounded, cavitation-resistant alloys are characterized by the following features: dispersed micro- and substructure, a considerable submicrohomogeneity of structure, high disorientation resistance of fragments, and a high limit of elastic deformation of microvolumes of crystals, and homogeneity of microstructure.

Among those investigated were two groups of alloys which, after specified heat treatment, manifested high resistance to cavitation where their micro- and substructure in this respect is characteristic. These were hardened aluminum bronzes. As an example, it is possible to cite steel 30Kh10G10 produced in the Ural Polytechnical Institute [1]. This unstable-austenitic steel resulting from the transformation of γ to α , occurring under cavitation influence, obtains a micro- and substructure which meets the requirements of dispersiveness, high limit of elastic deformation of crystals, and manifests high resistance to cavitation.

Macromechanical properties of alloys characterize their resistance to plastic deformation if the dimensions of maximum stress zones exceed the dimensions of regions of structural heterogeneity (grains) by no less than 10 times. Since during cavitation destruction the dimensions of maximum stress zones equal 1-10 μ , then the resistance to cavitation of alloys only with a dimension of grain of less than 0.1-1 μ can be estimated according to their mechanical properties (plasticity and resistance to brittle breakaway).

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CAVITATIONAL DESTRUCTION IN HYDROTURBINES OF THE
KAMSK HYDROELECTRIC POWER PLANT

Engineer L. N. Mineyev

Kamsk Hydroelectric Power Plant

At the Kamsk Hydroelectric Power Plant there are 23 vertical hydrounits with type PL-510-VB-500 turbines and one experimental horizontal semidirect hydrounit with a type PL-548-G-450 turbine (Table 1).

From the moment of starting to 31 December 1961, the units of the hydroelectric power plant have generated 11,376,956,000 kWh.

In the period of overhauls it was revealed that a region in the chambers of the rotor wheels 700-950 mm in height from the axis of rotation of the blades and the lower part of the copper blades are subjected to cavitation destruction which requires their repair.

Repair of Rotor Wheel Chambers

The rotor wheel chambers are made out of L30 steel castings with the exception of hydrounits No. 17, 18, and 24, whose chambers are of stampwelded steel St. 3. After 10,000-15,000 hours of operation of the hydrounits, the chambers of the rotor wheels have insignificant cavitation destruction, but after 30,000 hours cavitation destruction of the chambers attains a depth of 8-10 mm with a height of the region of 850-750 mm.

Table 1. Specifications of turbine and hydraulic generator equipment.

Indices	Unit		Indices	Unit	
	Horizontal	Vertical		Horizontal	Vertical
Type of turbine	PL-548-B-450	PL-510-VB-500	Maximum permissible height h_g (in m) of suction under pressure H (in M) and power of 21,000 kW	$H = 15$; $h_g = -0.3$	$H = 15$; $h_g = -0.3$
Diameter of rotor wheel in mm	4500	5000	Type of regulator	RK-100	RK-150
Maximum pressure in m	21	21	Type of forced oil system (MNU)	MNU-20 on three units	MNU-20 on three units
Pressure in m: calculated	16	16	Total weight of turbine with regulator and MNU in tons	2-3.27	325.84
minimum:	11	11	Type of generator	$S_g = \frac{620}{145} - 48$	$\frac{700}{100} - 48$
Power of turbine in kW: at rated pressure	21,800	21,800	Plant-producer	"Electrosila"	"Elektroapparat"
maximum	26,500	26,500	Power factor	0.8	0.8
Number of revolution per minute: minimum	125	125	Voltage ratio in V	10,500	10,500
rated acceleration	280	280	Rated power in kW	25,300	25,300
Consumption at rated pressure in m ³ /s	167	167	Runaway speed (permissible) in 3 h in r/min	220	-
Direction of rotation (according to flow)	Right	Right	Runaway speed in r/min	330 (in 20 s)	280 (in 2 min)
Weight of rotation parts in tons	~300	375	Flywheel moment of generator in tm ²	~2800	3000
Maximum longitudinal force on step tearing from turbine according to technical specifications, in tons	With flow 290 and reverse 100	With flow 500	Total weight of generator in tons.	~330	261
			Number of hydrounits	1	23
			Total weight of hydrounits in tons	593.27	586.84

Beginning in 1959, at the Kamsk Hydroelectric Power Plant the chambers of the rotor wheels of the hydrounits during overhauls are faced with noncorroding strips according to a technology developed by the [Central Scientific Research Institute of Machinery-Manufacturing Technology] TsNIITMASH.

The essence of this technology consists of the following. The sections of the chamber and blades which are subject to cavitation are faced with bands of stainless steel 1Kh18N9T 3-4 mm thick and 100 mm wide with longitudinal cuts in the middle of a strip 80 mm in length, 10 mm wide and with 20 mm crosspieces. The bands are welded to the prepared (purified of cavitational destruction) surface of the chamber by corrosion-resistant electrodes 3-4 mm in diameter made of grades ENTU-3, TsL-9, and TsL-24-59. Then the electricwelded seams are trimmed with grinding wheels.

The facing of the rotor wheel chamber includes the following operations: preparation of the surface for welding and ensuring normal clearance between chamber and blades; installation and electric arc welding of the corrosion-resistant strips; stripping the electric welding seams.

Preparation of surface for welding and ensuring the normal clearance between the rotor wheel chamber and the blades are the most labor-consuming operations.

On hydrounits No. 1, 2, and 5, the chambers of which were first covered in 1959, the preparation of surface of the chambers for welding was conducted by stripping the cavitation spots with emery wheels, and ensuring the clearance between chamber and blades was achieved by cutting off the edges of the blade by electric welding.

This method of stripping the surface and cutting of the blade has the following deficiencies.

1. It is impossible to qualitatively prepare the surface with a grinding wheel since cavitational cavities, as a rule, have a depth

of 3-5 mm. Because of this, welding of plates to the surface thus prepared is unreliable, which can lead to breaking off of the plates.

2. Trimming or cutting by electric welding makes it difficult to obtain an even edge of the blade. Furthermore, under conditions of an assembled turbine, trimming the blades is a rather labor-consuming operation.

At the Kamsk Hydroelectric Power Plant there has been developed and introduced a method of oxyacetylene treatment of the cavitized surface with subsequent stripping by abrasive discs. The essence of this method consists of the following.

At first the cutter with an oxyacetylene cutter melts out horizontal grooves of required depth (5-7 mm) at a distance of 200-300 mm vertically from each other. Then the metal between the grooves is melted down from above (vertically) to a depth equal to the depth of the groove.

Finally, the fused surface is cleaned with a grinding wheel. For this, a machine of the ShR-2 type and grinding wheels (granularity 24-32, diameter 120-150 mm) are used.

One gas cutter fuses 0.5 m^2 of surface per shift; three metal workers using two ShR-2 machines per shift can clean 1 m^2 of fused surface.

To melt 1 m^2 of surface requires 30-40 kg of carbide and four-five bottles of oxygen.

It is necessary to pay special attention to the quality of fitting the plate to the chamber. The better the plate is pressed, the more reliable and higher quality is the welding. Clamping of plates can be expediently performed with electrodes with diameter of 3 mm, welding - by electrodes 4 mm in diameter. Before welding, the plate is pressed to the surface of chamber by hammer blows. A welder can weld 8-10, and three metal workers with two machines can clean 16-20 running meters of seam per shift.

In view of the limited period of repair of a unit at the Kamsk Hydroelectric Power Plant according to TsNIITMASH recommendation there has been developed a constant-flow method of production of work, including the fact that the chamber of turbines with a four-blade rotor wheel is divided into four equal sections where simultaneously different operations are performed: fusion of the surface, stripping it, installation, clamping and welding of the strips and, finally, final trimming of the seams. With such an organization of labor the facing of a cavitized belt with an area of 12-14 m² is performed in 6-7 working days by two electric welders or gas cutters and three metal workers. A team of four metal workers installs a scaffold in one shift (7 h).

On 1 January 1962 at the Kamsk Hydroelectric Power Plant 20 rotor wheel chambers with a total area of 311.4 m² were faced. The chambers of units No. 16 and 24 were not faced, and the chambers of units No. 17 and 18 with an area 15.8 m² were faced under plant conditions.

The described method of facing the chambers of hydroturbines according to the TsNIITMASH method introduced into the hydrounits of the Kamsk Hydroelectric Power Plants.

Repair of Rotor Wheel Blades

On the hydroturbines of the Kamsk Hydroelectric Power Plant there are installed 35 blades made of stainless steel 25Kh14NL, 30 blades of copper steel 18DGSL, and 31 faced blades of steel 20GSL.

On hydroturbines No. 1-6, 19, and 21 there are installed blades of stainless steel, on hydroturbines No. 11, 13, 14, 16, 17, and 24 - blades made of copper steel, on hydroturbines No. 7, 10, 20, 22, and 23 - faced blades. On each of hydroturbines No. 12, 15, and 18 there are installed blades made of different materials, namely: on hydro-turbine No. 12 - two blades of stainless steel and two faced blades; on hydro-turbine No. 15 - three blades of copper steel and one of stainless; on hydro-turbine No. 18 - three blades of copper steel and one faced.

The result of use of blades made of stainless steel turned out to be sufficiently satisfactory: after 27,000-30,000 hours of operation of the turbines only on certain blades from below did there turn out to be very slight traces of cavitation.

It was noted that in the case of loss of assembly plugs there appears deep cavitation destruction from beneath the blade behind the hole in the direction of the trailing edge.

In March 1958 on one stainless steel blade of hydrounit No. 4 there was revealed on the trailing edge a broken angle with dimensions of 540 × 320 mm, on another blade - a crack with dimensions of 100 × 200 mm. In the broken angle of the blade the same part was welded and the crack on the other was welded with an X-shaped seam.

In November 1959 in the period of overhaul of hydrounit No. 4 it was discovered that on the blade damaged earlier a second time a piece of approximately the same dimensions and of approximately the same section was broken.

In December 1961 hydroturbine No. 15 with one stainless and three copper steel blades was stopped for overhaul after 19,505 hours of operation. The stainless blade was in excellent state, without cavitation destruction. On the blades with facing made from sheets welded by electric rivets there were observed breakdowns in the facing from below, and also bulging of the facing over considerable areas.

In March 1960 hydroturbine No. 22, also with faced blades was stopped for overhaul. On all the blades there was revealed considerable bulging of the facing from below and on two blades on the trailing edge there were broken angles with dimensions of 210 × 160 and 220 × 320 mm.¹

¹Welding of sheets was replaced by welding of strips, just as on the chambers, which brought positive results.

The resistance to cavitation destruction of blades made from copper steel is insufficient. Hydrounits with these blades were introduced into operation in 1956 and worked under load through 31 December 1961 from 14,000 (hydrounits No. 13, 17, 18) to 34,120 hours (unit No. 11).

In the first inspection period of hydroturbines with copper steel blades in three years there was revealed insignificantly deep cavitation destruction of the lower surface of the blades. Special repair was not performed and polishing of the lower surface of the blades was carried out.

In March 1961 hydrounit No. 11 which had operated 28,992 hours up to the beginning of repair was stopped for scheduled overhaul.

Inspection of the underwater part revealed that the lower side of all four copper steel blades had been subjected to cavitation destruction over an area of not less than 80%, where there was also destroyed also the place of transition from blade to flange and the flange itself. Depth of cavitation destruction attained 15 mm in separate places. The same amount of destruction of peripheral edges from the end and from beneath of blades was attained. A convergent angle for all four blades 50 cm^2 in area was missing.

In March 1961 jointly with TsNIITMASH there were determined a method and a technology for repair of copper steel blades of hydroturbines including unit No. 11. This repair consisted of the following. Cavitation destruction was removed by emery wheels. Deep cavities were fused by the method of hand electric arc welding with subsequent stripping. On the whole lower surface of the blade and the cavitized part of the flange there were installed strips of stainless steel 1Kh18N9T 3 mm thick and 100 mm wide with cuts in the middle; the strips were disposed in direction of flow. Welding of the strips was produced by corrosion-resistant electrodes ENTU-3 4 mm in diameter (wire without titanium) due to lack of electrodes TsL-24-59 and TsL-9 recommended by TsNIITMASH.

The peripheral tip edge of the blades destroyed by cavitation was cut by an oxyacetylene cutter to a width of 10 mm and covered with stainless 3 mm sheets with welding along the periphery.

By 1 February 1962 according to the technology mentioned copper steel blades on hydrounits No. 11, 13-15, and 17 (all 19 blades) had been faced. On hydroturbines No. 16-18, and 24 (all 11 blades) the copper steel blades subsequently will also be faced.

DATA HANDLING PAGE

01-ACCESSION NO. 98-DOCUMENT LOC		39-TOPIC TAGS		
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<p>(U) The article reports details of a study made on steels 1Kh13, 1Kh18N9T, commercial iron, single aluminum crystals, steel U7, and various aluminum alloys. Tests were made using a magnetostrictive vibrator in tap water at 18 degrees centigrade with a frequency of oscillations of 7.5 kHz and 60 micron double amplitude. One of the most satisfactory metals tested was steel 30Kh10M10 produced by the Ural Polytechnical Institute.</p>				

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ABSTRACT

(U) This article discusses studies made on turbine wear resulting from cavitational effects. Overhaul and repair procedures included facing the blades with strips of various corrosion resistant materials. The technique is described in detail. Studies were made over a period of time from 1958-1961.