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EROSION AND PROTECTION OF METALS (BOOK)

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FORWARD

A brief examination of this Soviet book indicated material in the portion which we have translated closely related to our cavitation research in this laboratory and in fact referencing it heavily. We hence thought it worthwhile to translate this particular portion of the overall book. The present is this translation.

LIST OF FIGURES

Part I

Theory of Cavitation Erosion.

During the past several years, many papers have been published in the U.S.S.R. and abroad, dealing with the study of cavitation phenomenon. At the same time, other investigations have also been conducted dealing with the accompanying phenomenon of cavitation erosion of materials.

For example, studies have been done by L. A. Glickman, I. N. Bogachev, R. I. Mintz, V. V. Gavrenko, K. I. Shalnev, M. G. Timerbulatov and others.

Although much work has been done, some problems involved in this field have not yet been completely solved. In other cases, working hypotheses have been formulated which have not been completely confirmed by experiment.

The general point of agreement among the many researchers is that cavitation erosion is mainly a consequence of the action on materials of hydraulic flow. Professor I. A. Oding thought that the forces in cavitation erosion are actually similar to those producing destruction on the surfaces of steam turbines blades. This is a result of the purely mechanical action of steam which contains water droplets and solid particles.

At the present, it is agreed that cavitation damage to metals is classified according to the location. In general it depends on localized destruction (instantaneous removal of the metal) which is caused by a local pressure drop in the flow, especially around curvilinear obstructions. There are two different types of cavitation, boundary and turbulent. The first type is generated on the surface of steep obstructions by the stream boundary layer, while the second type is generated in the region of turbulent flow produced by a severely curved section. Local cavitation induces erosion by tearing off the surface of the metal by the fluid in the vicinity of the obstruction.[1]

Generally, erosion appears to be caused by the collapse of vaporous cavities induced by a pressure drop. For example, it occurs in the process of cavitation from ultrasonic waves in the presence of fluid flow with minute particles. Present experience shows that the rate of material erosion can be a hundred times more during cavitation with an abrasive present, even when the cavitation is due to ultrasonic waves.

The reason for this increased damage is not quite clear; a sequence of hypotheses needs to be introduced for the explanation of this phenomena. It is possible to divide these hypotheses into three groups in accordance with the information obtained during experiments on the effect of abrasive particles on metals[2]. The effects may have been caused by:

1) The ponderamotive force of audible level as in hydrodynamic flow (sound of wind).

2) A shock wave as a result of the collapse of a cavitation bubble (a scraping, detonating and fluctuating mechanism).

3) Purely mechanical pulses from an oscillating machine during which it is possible to distinguish the small fine particles coming out of a smoothly coated surface as a result of the shocks impinging upon the surface, or the particles may be found suspended in the medium (as a suspension). The analysis conducted by L. D. Rosenberg and V. F. Kazantsev[2] showed that a coating may act as an indicator of damage. However, spontaneous erosion and damage of some materials (e. g. glass) were examined by using a direct acting oscillating machine and with the help of high-speed

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movies; it showed the coating was being torn away from the surface of the samples.

At the same time, it is possible to account for a completely realistic picture of this form of collapse with the present experiments. It is still more difficult to answer the question, "What is the cause of the generation of cavitation damage erosion in the presence of a turbulent stream (without ultrasonic action) at room temperature?"

The investigations of M. M. Orakhelachvil[3] and S. P. Kozirev, which are applicable to hydroturbine rotors, show that a flowing fluid with abrasive particles creates developed cavitation, and consequently, the erosion damage increases.

It is a fact that water possesses definite composite mechanisms that cause its affinity in quantity and quality to the property of durability, as characterized by its ability to resist rupture. It is known that its strength depends on its degree of purity; the purer the water, the greater is this durability, and consequently the water is more difficult to rupture and induce cavities.

According to the theory of "weak spots," fluids must contain solid particles especially of very small dimensions. It is possible to initiate the formation of bubbles from one side of such particles and additional cavitation nuclei from the other side.

Investigations show that these particles intensify erosion wear which occurs at places of bubble collapse. The effect of the abrasive particles is great when they acquire substantial velocities as calculated from the shock wave generated by the collapsing bubbles or cavity, or generated by the loss of stability.

Particularly, it was emphasized that abrasive cavitation occurance can be aggravated by flow in hot metal pipes, as in the case of hot channels, giving a weak laminated surface that has a reduced resistance for erosion.

As far as these hypotheses are true, it is permissible to explain these phenomena with a lesser degree of complication, but the phenomena of erosion will be explained completely here with little elaboration.

However, some investigators make the assumption by contrasing cavitation erosion damage observed in water pumps to that with liquids (e. g. liquid metals) at high temperatures, that viscosity and surface tension play a serious role. The experiments conducted confirm that the intensity of damage experienced by samples of different metals tested in mercury is twice as great as the intensity experienced in water.

To correlate the experimental results of the various samples and the working fluid, Hammitt [4] introduced a hypothesis which reports that erosion has a definite relation to the energy of the cavitation bubble.

A hypothetical spectrum of a cavitation energy distribution by Hammitt is shown in fig. (1). On the curve, the vertical axis represents the number of bubbles n(E), which transmit through their surface at collapse, an energy E. For each cavitation condition (sonic initiation, visible initiation, cavitation to the first or second mark on the venturi, cavitation to the front or tail of a specimen), it has its own spectral distribution. These hypothetical curves show an energy distribution such that there is a larger number of bubbles with small energy and a smaller number of bubbles with a higher energy. The general form deriving from an established rule, is confirmed by the experimental results (though for each liquid and flow geometry there exists a unique family of curves) in a number of tests at different temperatures.

Thiruvengadam's observations [5] suggest a general theory for cavitation damage which suggests a definite relation between the various metals under cavitation erosion and their deformation (or failure) energy. By deformation energy, the investigator means the area under the curve of the strain-deformation obtained experimentally for various metals under compression (for plastics materials under tension). It was found that the unmeasured quantity called "cavitation damage number" C_D is represented by the ratio between the energy absorbed by the material under deformation and the total energy provided by the collapsing bubbles. This quantity is given by:

$$C_D = \frac{Se\,\Sigma i}{N_{po}\,Ro},$$ where;

Σi = the summation of mean depth of erosion pits;

Se = deformation energy;

N = number of cavities (formed in accordance with the Strouhal number);

Po = pressure in the liquid surrounding the bubble;

Ro = maximum radius of the bubble.

Experimental data for several plastic materials fairly well conforms with this theory (Hammitt, Chatten, Thiruvengadam, Cochran, et. al.).

The theory of Thiruvengadam, in spite of its positive aspects, received critical reports. In particular, it was noted that the theory does not account for the influence of the successive bubbles on the metal and for the time between each stroke. Also, the deformation energy as the criterion discounts the effect of the rate of the deformation upon mechanical properties of the metal, and experimental data for the erosion of elastic materials (such as plastics) will not correlate in such a manner.

Such views on the general theory of cavitation erosion damage still require elaboration and further confirmation by experimental investigations, especially for the cases with the additional influence of abrasive particles.

Part II

Instruments and equipment for the study of cavitation erosion.

For the study of cavitation erosion at scientific laboratories, instruments and equipment are generally used in which specimens of the tested material are exposed to the effect of the working fluid (most of the time, water).

As a rule, the equipment is arranged such that it is possible to regulate the velocity of the water flow or the velocity of the specimen relative to the water stream.

The construction of the specimens (size, shape and supporting method) is done in various ways. In the Parsons, Cook, and Schroter investigations[6] on the stability of metals under cavitation erosion, a hinged specimen was placed at the center of the water stream at the outlet of a nozzle. In the Schroter and Mouson investigations with the distinctive nozzle configuration of fig. (2), the effect of a water jet over the surface of metals was studied under the process of a change in velocity magnitude and direction. The authors obtained interesting results showing that at a water velocity of 60 m/sec., already noticable cavitation erosion took place, damaging the steel specimens. Increasing the velocity up to 90 m/sec. over the specimen, more damage occurred for hard steel specimens in a time between 4 to 16 hours.

In research laboratories, special machines and equipment are used for the study of the resistance of materials which will be used for manufacturing steam turbine blades, as well as for obtaining comparative data about erosion stability. Basically, the principle of operation of such machines is as follows: a wheel, on which different kinds of specimens are mounted, is rotated at different tagential velocities. Specimens are usually manufactured in the form of blades. During the wheel rotation, the specimens will intercept special arrangements of continuous or dispersed water jets, or both, which can be controlled either at the nozzle or the mouthpiece. As a result of the water impacts, and cavitation bubble activity thereby induced, the specimens will become damaged and eventually decrease in weight, which is a measure of its erosion stability.

In the experiments performed by Gardener, the rotating velocity for the specimens was more than 300 m/sec. The author established that specimens of steel, which include a great portion of chrome as well as tungsten steel, have better resistance for cavitation erosion.

As a whole the research in both cavitation damage for metals and reporduction of metal wear by cavitation and abrasive erosion make use of the so-called jet impact equipment described above. On the basis of the proposed idea of shocks, various sizes of water slugs (water suspension with abrasive particles) are directed toward the surface of the specimens of the material under test.

On the basis of such a working set-up, like the machine under consideration, the idea of transverse jets was tested. The scheme for such a machine is given in fig. (3)[6]. In designing the nozzle, the mouthpiece is interchangeable so that it is possible to investigate the dependence of erosion on the diameter and shape of the jet. The present design has four cylindrical mouthpieces with internal diameters of 6, 8, 10, and 12 mm.

Immediately at the end of the mouthpiece, the jet of the hydro-abrasive is impacted by the specimen which is mounted on a special holder head. The number of simultaneous tests can be varied between two and four (keeping the specimen in its standard conditions).

The linear velocity of the specimen can be changed by chainging the diameter of the rotating wheel as well as the r. p. m. of the driving shaft through changing the gear ratio. In general the size of the testing apparatus is 1200 mm high, 1400 mm long, and 12 mm wide with a weight of 200 kg. Specimens of the material under test are discs of diameters 20 to 30 mm and 6 mm thickness.

The apparent characteristic of the erosion wear which occurred was a decrease in weight for all speciments that varies with the time of test and the setting of the jet impact characteristics. The experiment also showed that when using water with abrasive particles at a ratio of 5 to 10%, the scattering of the results did not exceed ± 4%.

The apparatus used in the Leningrad Metallurgy Factory consists of a drum driven by an electric motor. On the drum, there are mounted 2 specimens of the material to be tested. The size and shape fo the specimen is given in fig. (4). Inside the cavity of the housing, the drum ends with the specimens at about 5 mm away from 2 nozzles connected to a water supply of 0.4 kg/cm^2 pressure (5.88 psig). The specimens rotate at 3000 r.p.m., intercepting the water jets impacting on them from the nozzles, straight and at right angles, and are separated by 0.5 meters from each other. In a one hour test, each specimen will receive 360,000 impacts from the water jets.

I. N. Bogachev and R. I. Mintz[7] investigated the role of cavitation erosion damage on steel, performing the test on an impact erosion facility generally similar to that described. The velocity of the specimens was 80 m/sec., the water pressure 0.28 kg/cm^2 (4.1 psig), and the specimens were mounted at a distance of 1.4 mm from nozzles of diameter of 0.8 mm.

An interesting rotating apparatus for metal testing by water-abrasive erosion was described by M. G. Timerbulatov[8]. In this set-up, fig. (5), water intercepts specimens attached to the blades of a pump rotor where water is also dispersed by several tubes. The effect of the centrifugal force during the rotor rotation is to impart a great velocity to the Slurry flow, necessary for its intensive effect on the test specimens which are plates of size 60 x 30 x 6 mm. It is possible to test 32 specimens of different metals at one time on such a set-up (about 3 pieces of each kind, for that number and size, e.g. for steel; 25).

The coefficient of wear stability is manifested as the ratio between the losses of all standard specimens with that of the specimens under test. The results of the tests showed that the intensity of erosion wear is proportional to the velocity of the flow to the 2.5 to 3 power, while the rate of loss is practically proportional to the concentration of the abrasive in the flow. The corrosion wear for 18-8 stainless steel (type X18H9T) and other types had been established under severe test conditions (abrasive concentration 50 gm/l and flow velocity of 25.6 m/sec.) which contributes much to the abrasive erosion losses.

Besides the impact jet apparatus discussed above and shock erosion stands for the study of the cavitation abrasive erosion phenomena, widely used are hydrodynamic channels and vibrating magneto-striction facilities. In hydrodynamic channels, it is possible to induce cavitation on a streamlined body by the similar conditions occurring in actual hydrodynamic machines.

S. P. Kozirev[9], after several trials, developed an experimental installation of a small hydro-dynamic channel to be used in the Mechanical Institute (Academy of Science) U. S. S. R. (6). For the study of cavitation and cavitation abrasive erosion phenomena in this unit, a high speed movie camera (Model SSKS-1) that can produce 200,000 frames per second has been used. Several experiments have been performed with this installation and some of the conclusions have been mentioned before.

Many investigations on cavitation erosion have been done by K. K. Shal'nev[10] using round profile models across hydrodynamic channels. In these channels, water is circulated with different velocities and at different pressures. His test chamber is a straight tube with a rectilinear cross-section. The specimens, which are rolled lead plates with thicknesses of 3 to 8 mm, are exposed for short-duration tests during which heavy erosion occurs. They are mounted at one side of the test section in a special groove. Round profile models are mounted across the channel between the opposite walls. Part of the specimen, which is flush with the wall, is under the model in order to limit the cavitation field to the specimen, fig. (7). The testing chambers are of different dimensions, (7x20 mm, 10x50 mm, 70x200 mm, and 60x640 mm, etc.). The profile models have diameters of 5, 6, 12, 50 and 200 mm. The water velocity varies from 4 to 25 m/sec. The characteristic erosion intensity is the amount of erosion determined by the ratio of the weight loss during the test time in hours to the specific weight of lead (i. e. the volume loss) and the rate of erosion (i. e. the ratio of the volume eroded to the area of the specimen). In addition, the erosion intensity quality is characterized by the localized eroded areas, their forms, sizes, and depths, as well as the acoustic index for the sound effect accompanying the erosion.

K. K. Shal'nev reported the interesting and unexpected conclusion, that primary erosion craters, as well as the region of deepest erosion correspond to a location of cavity regions in the flow filled with bubbles. It was also shown that the form of erosion craters reflects the vitality of the life cycle of the individual flow cavities of the damaging cavitation, during which the largest erosion effect occurred in the initial stage of cavitation. An essential influence on the erosion intensity is due to the Reynolds number.

It was established that erosion pits on the surface occur not as a result of a destructive cavitation bubble, but as a result of the recurrance of torn-off cavitation cavities (frothy regions) on the specimen, and as a result of the recurrent expansion-contraction of such regions.

In recent years, when industrial installations began to use the method of ultrasonic treatment, particularly for delicate metals, the spreading research efforts on hydro-abrasive and cavitation erosion considered the use of magneto-striction vibrators. In this way, Senitmachi [11] was able to build a facility for studying cavitation at frequencies up to 8300 c/sec. and amplitude of 0.075 to 0.1 mm, fig. (8). The unit consists of a test stand inserted into a bed-plate with traveling carriage and magneto-striction vibrator. During operation the vibrator must be cooled by circulating water through the nickel tube. The tube is of 310 mm length, O. D. 18 mm and I. D. 16 mm. Vibrating with a frequency of 8300 c/sec., the nickel core causes the specimen, attached to its end and immersed in the fluid, to induce cavitation erosion and consequently cavitation damage. The erosion which occurred resulted in the formation of cracks, the tearing off of parts of the surface, and the damaging of the crystaline structure of the metal. According to Senitmachi, from the tests done on some groups of steels, the optimum resistance to damage occurred for steel with 10% chrome.

L. A. Glickman and V. Z. Zobachev ran some cavitation tests on stabilized metals in a magneto-striction vibrator, built in the laboratory of M. M. Pisarevsko [12]. According to the authors, the specimens tested are round discs threaded for mounting on the vibrator, fig. (9). The working surfaces of the specimens were carefully ground, washed and degreased by benzine and alcohol, then treated with citric acid and boiled in water for 1/2 hour. Afterwards, the specimens were mounted on the vibrator and immersed in synthetic sea-water of 4 mm depth. The peak-to-peak amplitude of oscillation was 0.07 mm. This criteria evaluates the resistance of metals to cavitation erosion damage by measuring the weight loss of the specimens for the three hour test. Investigations were made to study the effect of the amplitude, frequency, composition, mean temperature, immersion depth and surface conditions, on cavitation erosion damage.

Several set-ups were constructed utilizing the magneto-striction effect for the study of cavitation erosion in the All-Union NII for Hydromachines Construction[13]. Research on different types of steel and iron had been done on such set-ups especially for the study of the effect of heat treatment on the surface and around the specimens to strengthen the metal against cavitation wear. It was established that the best resistance against cavitation erosion resulted from thin plating of the steel by chrome. However very thin coatings do not ensure the necessary protection. Better resistance against cavitation is ensured by seam welding stellite onto the base metals.

Many investigations using the vibratory method to study cavitation erosion damage were made by M. S. Plesset, whereas F. G. Hammitt has studied scale and thermodynamic effects on cavitation erosion on stationary and rotating elements of hydrodynamic machines. Details of the data, method and experimental results are obtainable in Russian through the A.S.M.E.[4]. For the study of cavitation processes and hydro-abrasive erosion for both flowing and ultrasonic cases, high speed movies were used at the Acoustic Institute, Academy of Science, U.S.S.R.[14]. The scheme of the set-up used for the study of ultrasonic cavitation on metals is given in fig. (10). A cover glass of thickness 0.1 mm was placed between two thicker glass plates so that they formed a reservoir, the walls of which are the heavy-walled glass, and are sealed by cement. From the top of the reservoir, the working instrument is introduced. It is similar to a piece of safety razor blade of thickness 0.1 mm and 14x14 mm cross-section. This blade shape is mounted at the end of a magneto-striction pivot. Abrasive suspension is introduced into the reservoir, the grains of which are arranged in a row to allow the visualization of the damaging process of the material (the edge of the cover glass) at a direction perpendicular to the plane of the instrument. The objective lens of the camera is placed on one side, and on the other side a light source, a reflector and a condenser. The filming is made with a high speed 8 mm movie camera FP-22. The photography is done in the direction of the light at speeds of 20,000 and 50,000 frames/sec.

During shooting, it is necessary that the specimen be adjusted to fill the full width of the field which is equal to 3 mm. When the magneto-striction vibrator was used, the resonant frequency was 6.8 kc/sec. The average size of the abrasive particles used was about 0.22 micron. The results obtained from the film, after development and data reduction, confirmed that there was less volume loss with the tested material in the direct impact apparatus, than with the abrasive particles lying on the surface of the machined material (cover glass). In similar results the direct impact on the surface of the material generated micro-cracks into which micro-bubbles are induced. These bubbles initiate the knocking out of massive pieces.

V. V. Gaveranka [15] tells of various methods of metal testing in cavitation erosion and describes special cameras and diffusers as well as different schemes of magneto-striction vibrators. Useful information on the study of this aspect of erosion is available in the book of A. D. Pernika [16]. It should be noted that the problem of cavitation erosion damage of metals was investigated not only on such devices and in scientific laboratories, but also with models of actual units, as well as on special stands.

For example, the testing stand on which it is possible to test pump models operating with liquid metals and molten salts at temperatures up to 760°C[17], should be mentioned. The scheme of such stand is given in fig. (11). The tested pump is mounted inside a vessel with a short closed stream. The main resistance to the flowing working fluid are 2 diaphrams (aperatures). The stand has all the necessary instruments for control and measurement, allowing for adjustment of the pressure of the pump, its output, its power, the speed of rotation, and the temperature of the working fluid. The criteria for the estimation of the possibility of cavitation erosion of the working rotor is the drop in the characteristic of the rotor (power and pressure) for a finite working time.

After the test cycle, the damage area will undergo metallographic analysis. The cavitation damage of metals in abrasive media with ultra-high frequency was investigated on a stand for ultra-sonic treatment. Detailed data concerning the present set-ups for ultra-sonic erosion treatment of delicate metals are presented in the work of L. I. Popilov[18].

In conclusion, it is desirable to mention, that instruments with cavitation erosion damage components applied to hydromachines did not settle finally the question concerning the construction and choice according to erosion wear of metals and their protection. However, the research on the phenomena of wear and protection of components can be enhanced by the study of the characteristics of the working flow, its liquid and particles, and also the use of special additive materials, lowering the mechanical stress factor of the influence of the fluid on the metals. These questions have been discussed in special literature, and especially in the work of I. N. Bogachev and R. I. Mintz.[7]

1) Cavitation to the first mark
2) Standard cavitation
3) Cavitation to the backing edge
4) visille cavitation
5) noise cavitation
6) limiting energy for metal specimens

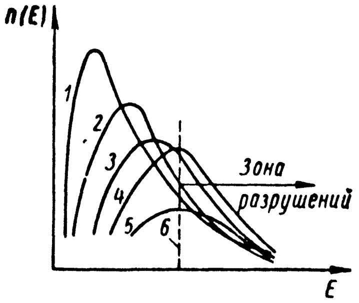

Рис. 13. Гипотетический спектр распределения энергии пузырьков:

1 — кавитация до первой условной отметки; 2—нормальная кавитация; 3—кавитация до передней кромки; 4 — появление видимой кавитации; 5 — возникновение шума; 6 — граничная энергия для материала образца

fig. 1. Hypothetical spectrum of bubble energy distilation.

1) nozzle
2) tested specimen

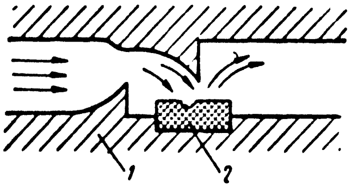

Рис. 36. Схема испытания образцов на кавитационную эрозию:

1 — сопло; 2—испытуемый образец

fig. 2. Scheme for testing specimens under cavitation erosion.

1) pump
2) water feed to gland
3) electric motor
4) driving pulley
5) driving V-belt
6) driving pulley
7) bearings
8) jet distilations
9) mouth piece
10) specimens
11) overflow tube
12) specimen holder
13) by pass-water pipe
14) pump
15) reservoir
16) shaft
21, 17) three way valve
18) by pass line
19) drainage tube
20) suction line
22) casing reservoir

fig. 3. Scheme for jet impact testing machine.

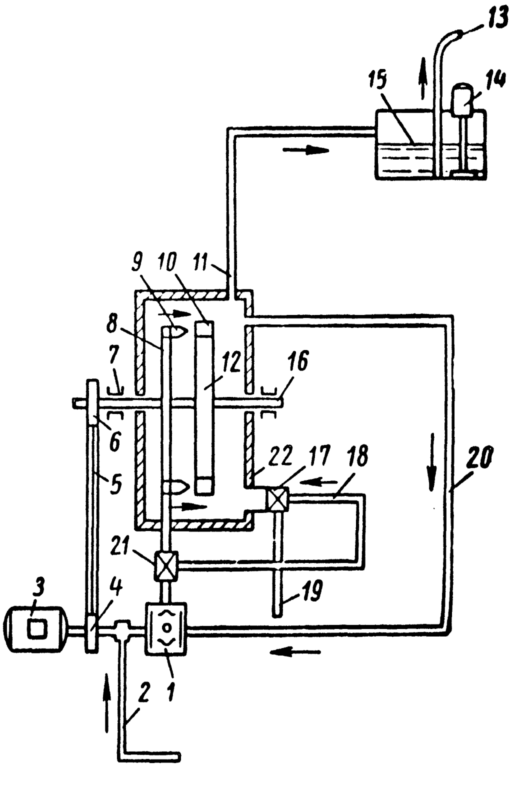

Рис. 37. Схема струеударной установки:

1 — насос; *2* — подача воды в сальник; *3* — электродвигатель; *4*—ведущий шкив; *5*—клиновые ремни; *6*—ведомый шкив; *7* — подшипник; *8* — струераспределитель; *9* — насадки; *10* — образцы; *11* — сливной трубопровод; *12* — держатель образцов; *13*—трубка отвода воды; *14* — насос; *15* — бак; *16* — вал; *17* и *21* — трехходовые краны; *18* — перепускной трубопровод; *19* — трубопровод отвода смеси; *20* — всасывающий трубопровод; *22* — кожух бака

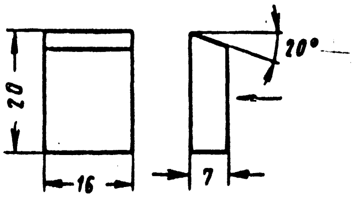

Рис. 38. Образец для испытания в ударно-эрозионной установке

fig. 4. Specimens for jet erosion machine test.

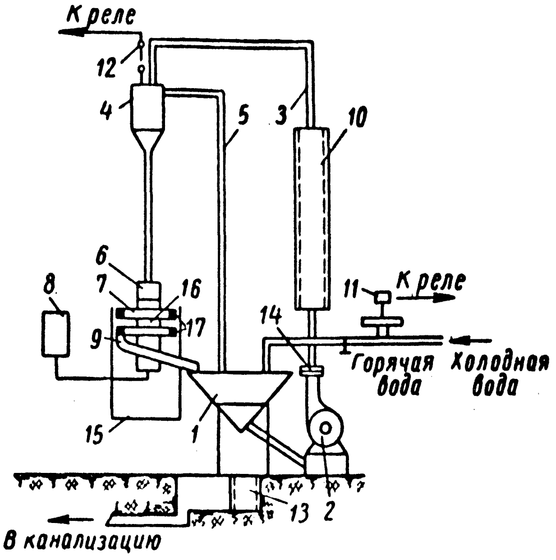

Рис. 39. Схема установки для испытания металлов на гидроабразивную эрозию:

1 — бункер; 2 — насос; 3 — трубопровод; 4 — напорный бачок; 5 — переливная труба; 6 — приемник ротора; 7 — трубки; 8 — электродвигатель; 9 — сливной патрубок; 10 — холодильник; 11 — электромагнитный вентиль; 12 — контактный термометр; 13 — бак; 14 — вентиль; 15 — корпус ротора; 16 — вал ротора; 17 — образцы

fig. 5. Scheme of the machine for hydro-abrasive erosion of metal.

1) hopper
2) pump
3) pipe line
4) pressure tank
5) transfering pipe
6) adapter rotor
7) pipes
8) electric motor
9) filling line
10) cooler
11) electro-magnetic valve
12) contact thermometer
13) reservoir
14)
15) rotor casing
16) rotor shaft
17) specimen

1) pump
2) electric drive
3) gland cooling tube
4) pressurizing tube
5) cooler
6) super charging pipe
7) water inlet tube
8) water outlet tube
9) overflow pipe
10) converging section
11) test section
12) diverging section
13) suction pipe
14) sampling pipe
15) reservoir
16) drawing line
17) air line from compressor
18) equalizing tank

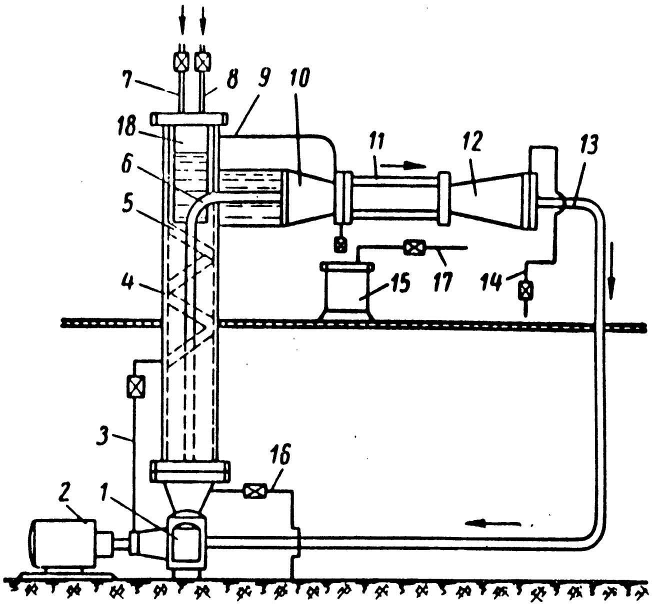

Рис. 40. Схема гидродинамической трубы:

1 — насос; *2* — электродвигатель; *3* — труба промывки сальника; *4* — напорная труба; *5* — холодильник; *6* — нагнетательный трубопровод; *7* — труба подвода воды; *8* — труба отвода воды; *9* — трубопровод сжатого воздуха; *10* — конфузор; *11* — рабочая камера; *12* — диффузор; *13* — всасывающая труба; *14* — труба отбора проб; *15* — ресивер; *16* — труба слива воды; *17* — трубопровод воздуха от компрессора; *18* — уравнительная башня

fig. 6. Scheme for the Hydro-machine tunnel.

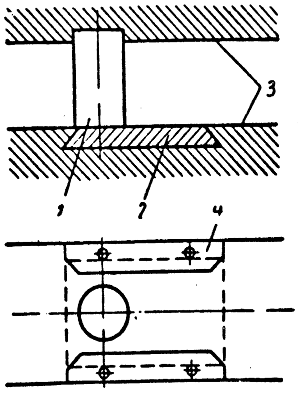

Рис. 41. Схема опытов с эрозией образцов металла:

1 — модель; *2* — образец; *3* — стенки; *4* — крепление образца

fig. 7. Set up for Erosion Test of Metal Specimen.

1) rectifier
2) oscillator
3) nickel tube
4) feed back coil
5) exciting coil
6) bed stead
7) magnetizing coil
8) amplitude indicator coil
9) tested specimen
10) water bath

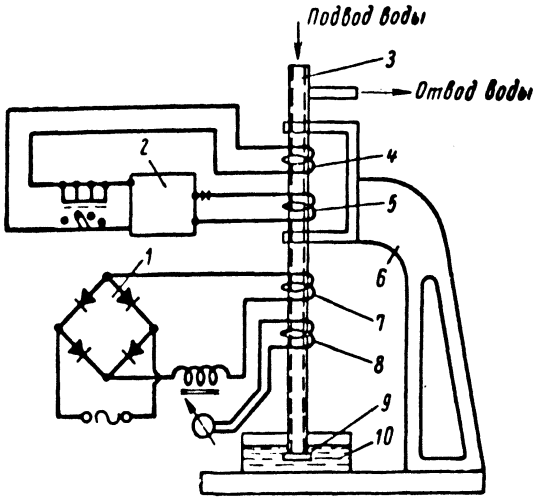

Рис. 42. Схема установки для кавитационных испытаний:

1 — выпрямитель; *2* — усилитель; *3*—никелевая трубка; *4* — катушка обратной связи; *5* — катушка возбудителя; *6* — станина; *7* — катушка подмагничивания; *8* — катушка указателя амплитуды; *9* — испытуемый образец; *10* — ванна с водой

fig. 8. Set up for Cavitation Investigation.

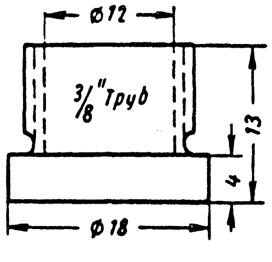

Рис. 43. Образец для кавитационных испытаний

fig. 9. Specimen for Cavitation Investigation.

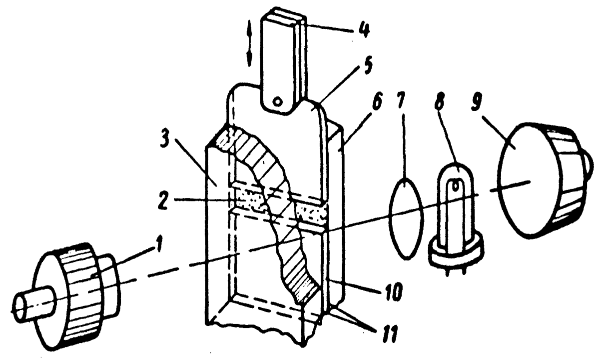

Рис. 44. Схема установки для высокоскоростной киносъемки процесса эрозии, протекающей с ультразвуковой частотой:

1 — кинокамера; *2* — абразивная суспензия; *3* и *6* — стекла; *4* — кассета; *5* — рабочий инструмент; *7*—конденсатор; *8*—источник света; *9*—рефлектор; *10*—покровное стекло; *11* — слой склейки

fig. 10. Scheme of the Equipment for High Speed Movies for Erosion Tests by Ultrasonic Frequencies.

1) movie camera
2) abrasive
3, 6) glass
4) plate holder
5) working section
7) condenser
8) light source
9) reflector
10) protecting glass
11) glued layers

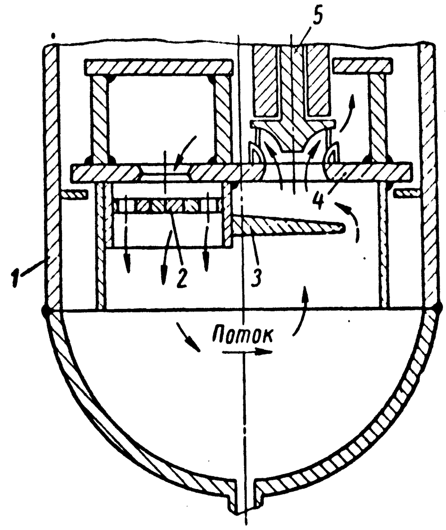

Рис. 45. Схема стенда для испытания насосов, работающих на жидких металлах и расплавах соли:

1 — обечайка; 2 — диафрагмы; 3 — дефлектор; 4 — нижняя плита корпуса; 5 — испытуемый насос

fig. 11. Scheme for the Stand of Testing Pumps working with Liquid Metals and Molten Salts.

1) casing
2) diaphram
3) deflector
4) lower body plate
5) tested pump

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