

# Problems of hydraulic machine evaluation according to the tests results

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**Abstract.** Computer simulation of hydroelectric units is impossible without calculating vibrations of their assemblies. The permissible oscillations are determined by the norms. The existing norms do not meet modern requirements. In the article there are presented problems of evaluating test results according to the existing norms. Firstly, the operating frequency band of the sensor on the vibro-displacement parameter does not cover the frequency range 0.1-200 Hz. There is no such vibrating sensor. We cannot get technically a complete picture of the vibration state of the hydraulic unit and according to the norms determine its evaluation. Therefore, the frequency band 0.1-2 Hz is proposed to be monitored separately by pressure pulsation sensors. The norms of permissible pulsations are required for this procedure. Secondly, the sensor resonance is in the frequency band of the structure. Thirdly, the frequency band to be monitored is not specified in the norms. Possible errors in estimating oscillations are revealed in the article.

## 1. Introduction

In Russia in the 60-s of the last century, the vibration evaluation norms were created basing on the results of static analyzing the vibration state of hydraulic units. The analysis materials were the results of vibration measurements and they were received by means of primitive measuring instruments and even more primitive methods of results processing. The norms were created for hydroelectric units produced in the 60-s. There were no high-head dams and powerful hydraulic units, and the metal consumption per kW of power was different. Modern power engineering increases single-unit power of hydroelectric units, while quantity of metal is reducing, the growth of specific mechanical loads is increasing; the safe load factor of separate units is reducing. Therefore, high level vibrations appearance leads to decreasing reliability and durability of hydraulic units and can cause accidents.

In different years, the standards were presented in the "Testing methods for determining a vibration state of hydroelectric units" [1-5].

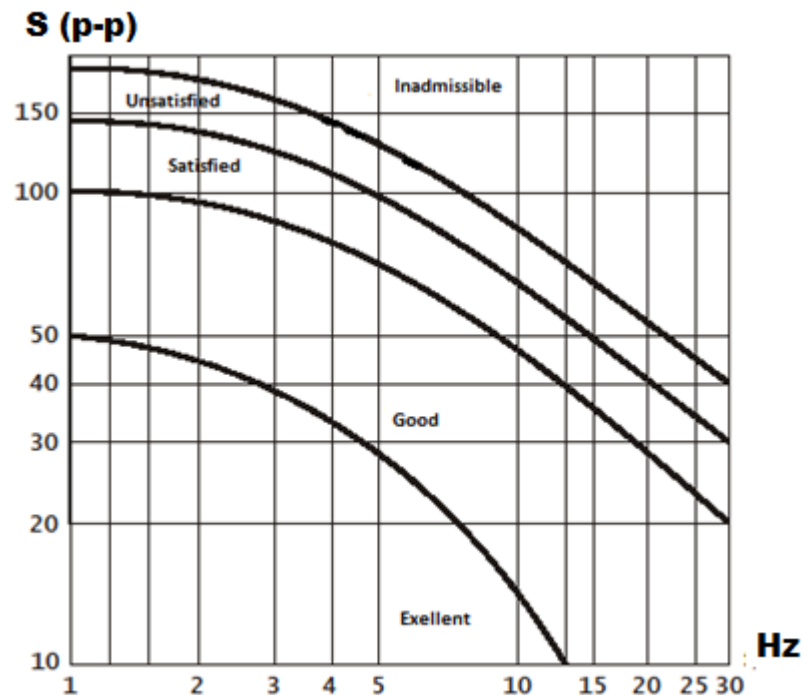
The standards do not meet modern requirements. The criteria created in the last century were copied 10 years later and were remained unchanged nowadays.

As a result, the requirements for monitoring a vibration state of hydraulic units do not take into account the main design features of hydraulic units, namely:

1. Impeller type;
2. Diameter;
3. Pressure;
4. Operating mode;
5. Range of constructive parameters and energy cavitation parameters.



Methodical instructions on the operational control of a vibration state determine the dependence of the vibration amplitude (vibration displacement) produced by the controlled unit on the vibration frequency (Figure 1). The range of vibro-displacement is divided into zones referring to the grades from "excellent" to "unacceptable".



**Figure 1.** Evaluation of vibrating the structures supporting the hydraulic unit.

Evaluation criteria:

- If vibrations are periodic they will occur within the range of vibro-displacement of its every harmonic component and within the total range of vibro-displacement using the dependencies shown in the figure. Thus estimating the total range of vibro-displacement is carried out according to the norms for the lowest of the frequency components. The worst evaluation is accepted among all others.
- If vibrations are non-periodic, the evaluation will be made:
  1. According to the average double amplitude;
  2. According to the average frequency.

Non-periodic character of vibration is typical of a turbine bearing, a turbine cover. This problem concerns measuring the absolute vibration of units supporting the turbine under conditions of fluctuating loads. Evaluation of turbine condition cannot be performed without its solution.

In MEK [8, p. 89] publication, it is noted on the matter: "The experience of measuring vibrations and pulsations in hydraulic machines shows that the implied oscillating signal should be considered as the sum of oscillations two types:

- periodic oscillations (relating for example to the reverse, blade, harness and other frequencies),
- random oscillations.

For stationary modes of operation, this sum of oscillations can be considered as a stationary random process."

Evaluation of the vibration state according to the document dated 2006 [5, p. 208].

- Average range is defined as the ratio of the peak vibration sum values at the selected time interval to the half of peak number. The time interval must be selected so that it has at least 10 periods of the reverse frequency.
- Average frequency is defined as the ratio of the peak half number during the selected time interval to this interval.

Methodical instructions require carrying out measurements and obtaining an oscillogram of the vibration signal containing at least ten revolutions of the rotor. Using a ruler and working to scale, it is necessary to measure the peak amplitudes. Next step is to determine the average value of the sum of positive and negative peaks. Then the peaks are counted (that is not always possible) and the average frequency of the vibration signal is determined by the formula. The evaluation of the hydraulic unit state is performed, taking into consideration the average range and the average frequency and using Figure 1. This is called an evaluation according to the general level.

It should be noted that now it is the XXI century and the Fourier analysis program installed on the computer is better than a ruler and handmade assessment. Moreover, it is possible to obtain an amplitude-frequency characteristic not only for a periodic signal but also for a non-periodic one.

The analysis of the amplitude-frequency spectrum shows that it is not correct to estimate the vibration level by means of the average value. There are modes of hydraulic units operation (usually at high pressure), where the frequency band-I of the hydraulic unit frequency characteristic (Fig.2) is filled with interference.

It means that in full-scale tests of units' especially high pressure ones there are measuring vibration problems of support units.

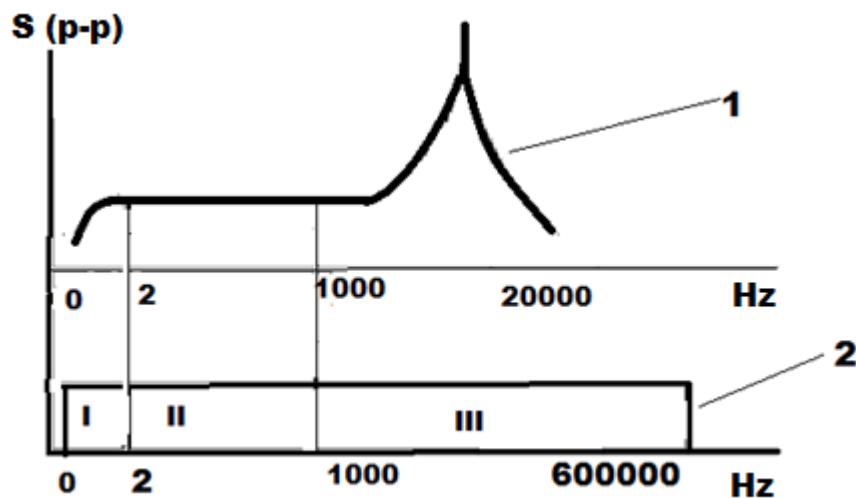
## 2. Problem 1

A parameter measuring vibration is a displacement in Russian hydropower engineering. As sensors for absolute measuring support units of the hydroelectric unit are applied accelerometers (vibro-acceleration) and velocimeters (vibro-velocity). These sensors have a lower limit of measurement of operating frequency range of 0.2 Hz and 0.5 Hz, respectively. In order to transfer to vibro-displacement, two-time integration of the vibro-acceleration parameter and one-time vibro-velocity parameter is required. The integration can be done in analog or digital form. But after the integration the lower limit of the operating frequency ranges of the sensors in the process of vibro-displacement measuring is 2 Hz.

The research of the firm ORGRES conducted on the theme "Use of modern vibration equipment to control the vibration state of hydraulic units" states "the equipment should not be distorted in the presence of shock and high-frequency (over 200 Hz) effects of the object, whose vibration is measured (for example, the turbine cover).

However, in practice most sensors proved to be not suitable for measuring vibration in hydroelectric units installed at hydropower plants. This property of measuring channels is caused by using piezo-accelerometers as sensors that perceive vibro- acceleration. At low frequencies of 0.2-2 Hz the signal is so weak that it "sinks" in noise and interference that are always present in the process of vibration measuring in the hydraulic turbine. If the entire normalizing vibration in hydraulic units is carried out in vibro-displacements, the double integration will be necessary; it is a source of additional errors. All this is a source of errors in the process of measuring at frequencies close to the rotational frequencies of hydraulic units and leads to unsatisfied results in the measurements.

The firm ORGRES produced testing devices for various firms at many HPP, the result of the test devices proved often to be unsatisfied. So when vibrating (vibro-displacement) at the rotational frequency of the hydraulic unit is at the rate of 100 microns, the tested devices showed 300-500 microns, it is an unacceptable state. At the same time, the readings of such devices were unstable.



**Figure 2.** Combined amplitude-frequency characteristic of the piezoaccelerometer sensor (acceleration) (1) and frequency characteristic of the hydraulic unit (2). I is “interference band”, II is operating band of sensor, III is frequency band containing cavitation disturbing forces.

### 3. Problem 2

Penetration of errors caused by the accelerometer resonance into the low-frequency area ("interference area" in Figure 2) can be considered as one of the problems.

Due to sensitivity of the accelerometer increasing in the resonance area, the electric signal will not be exactly proportional to the acceleration of mechanical vibrations. This is true in the area covering the frequency of its own resonance ("area III" Figure 2). If there are certain pressures at the hydraulic unit, the measuring process is influenced by distortions caused by the coincidence of the resonance frequency of the sensor and the cavitations processes frequencies.

Recommendations of the firm Bruel and Kjaer [2]. In the process of the low-frequency area working, the unwanted effect of high-frequency oscillations of the accelerometer resonance can be eliminated by mechanical filters. Such filters do not solve the problem.

Vibration measurements of hydraulic units are usually carried out in the band 1-200 Hz. Analyzing the amplitude-frequency spectrum of the vibration signal (vibro- displacement) with the frequency band of measurement from 1 to 200 Hz, we cover information frequencies:

1. Rotational and double rotational frequencies.
2. Frequency of the stator columns.
3. Frequency of rectifying vanes.
4. Pole frequency.

The experience of measurements show an attempt of reducing the lower limit of measuring low frequency (even to  $f = 0.6$  Hz) and metering oscillations of the "harness" leads to the vibrations range that may not be in the turbine (piezo accelerometers, velocimeters were used). Accordingly, the analysis of the 0.2 - 2 Hz band is usually ignored in the reports.

In this "interference band" we are interested in the contribution to vibrating the unit that is made by pressure pulsations with the frequency of the harness, flow pulsations, unsteadiness in the flow part of the turbine, natural frequencies of the flow part, high-frequency pulsations. Such instrumental control would be a good way to find weak points of the unit. We consider the use of pressure pulsation sensors to be a solution of operational controlling problem the "interference band".

The magnitude of interference depends on the pressure, load mode, cavitations properties of the hydraulic unit.

#### 4. Problem 3

The data taken off incorrectly in the "interference area" distort the general signal, and estimating the state according to the general level leads to gross errors. Let us consider the matter on examples. In the process of the state of the unit on the general level evaluating, the average value of the vibration signal is required. The existing standards do not indicate the frequency band of the vibration signal to control the state of the unit. This is very important!

We measure the average value of the same vibration signal in different frequency ranges.

*Example 1.* In Figure 3, the vibration signal in the frequency range of 0.2-200 Hz is presented. The measuring channel uses a piezo accelerometer as a sensor, senses vibro-acceleration. The double integration of the analog signal is provided to obtain a vibro-displacement in the channel. The vibration signal is unstable. The average value of the oscillation range is 70 microns.

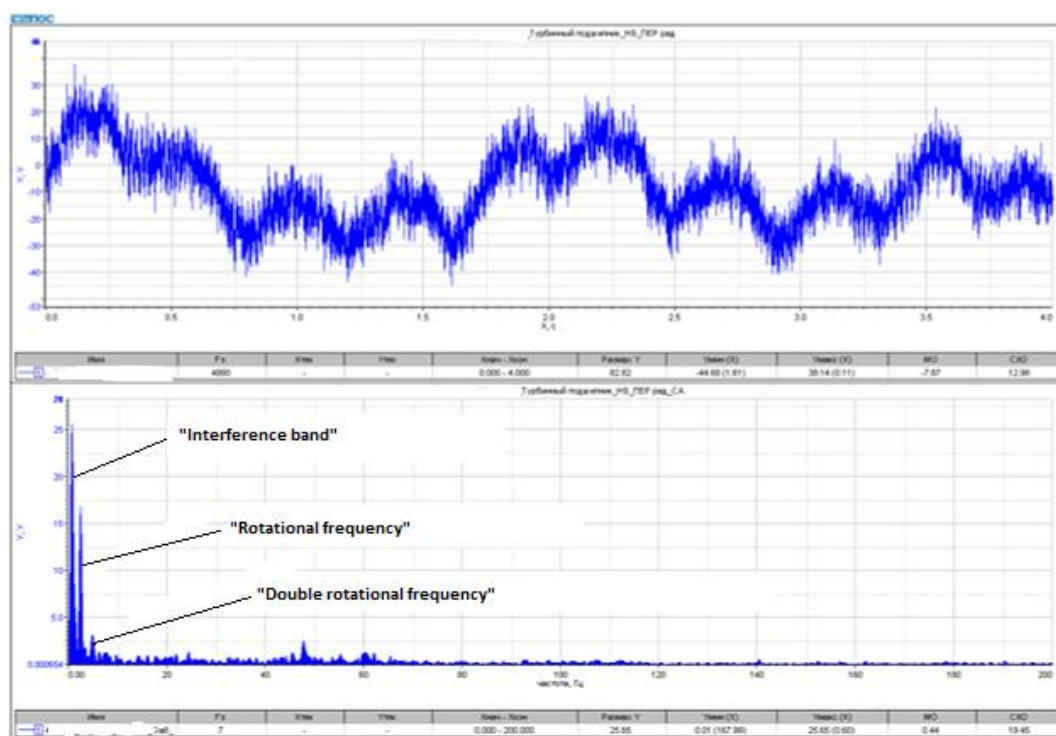


Figure 3. Case 1.

*Example 2.* Let us consider the same vibration signal in the band from 2 to 200 Hz (Figure 4).

The vibration signal is stable. The average value of the oscillation range is 40 microns. "Interference band" is cut out by the filter.

*Example 3.* Let us consider the same vibration signal in the band from 10 to 200 Hz (Figure 5).

The vibration signal is stable. The average value of the oscillation range is 20 microns. The vibration signal is remarkable; unfortunately it controls a few information frequencies.

Three results of processing the same vibration signal are obtained. Result 2 is the most authentic, if we do not take into account the useful frequencies of the "interference band".

The selection of useful components from the recorded signals total amount or the noise maximum suppression and interference in the information signal while maintaining its useful components; it is one of the main tasks of primary signals processing (observation results).

The fact is the vibration state assessment of the equipment (on the general level) according to the indications of sensors with unsatisfied technical characteristics is apparently associated with

development engineers' ignorance and misunderstanding of the hydraulic nature and cavitation loads in hydraulic turbines, depending on the mode of operation of the turbine.

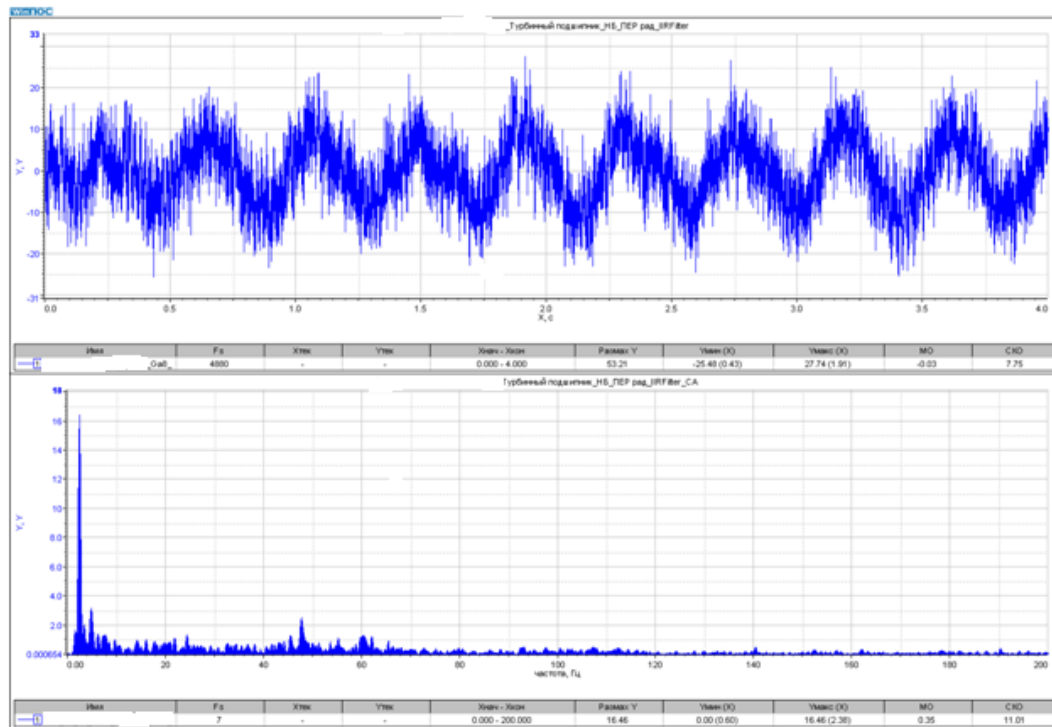


Figure 4. Case2.

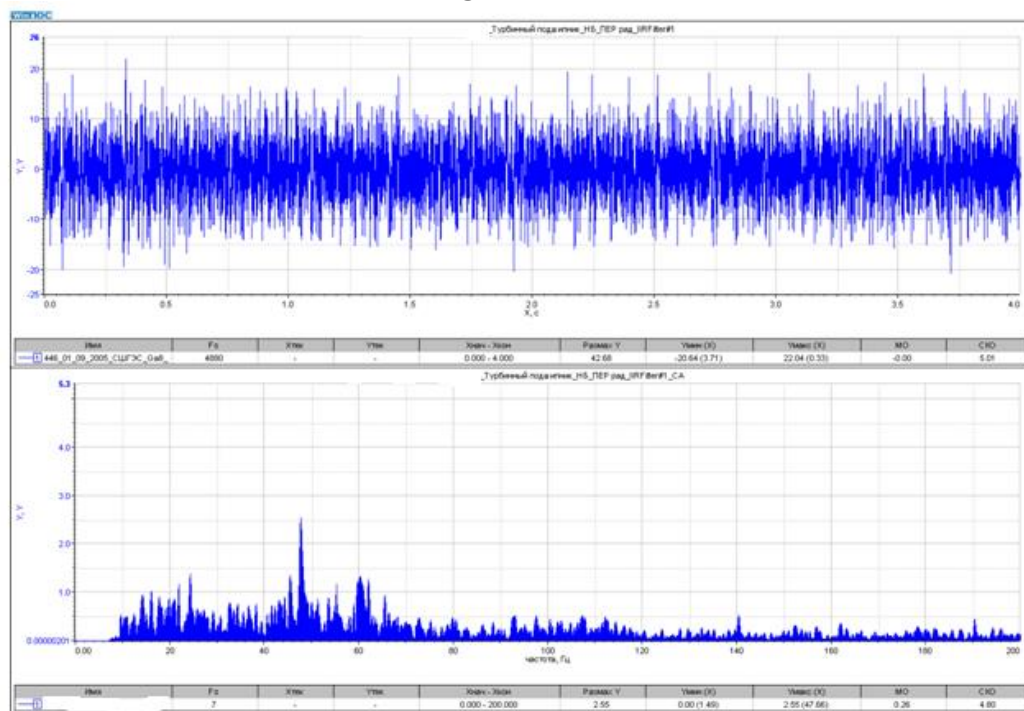


Figure5. Case3.

## 5. Problem 4

The average range does not take into account the fact the small range impact of high-frequency vibration can significantly exceed the impact of low-frequency vibration, which has a several times larger range (Figure 1). We pay less attention to high-frequency oscillations when they are presented against the background of low-frequency oscillations. We offer to divide a frequency band 1-350 Hz into two ones.

Low-frequency vibration range of 1-15 Hz is to be controlled according to the occurred vibro-displacement. The range should be divided in the norms into frequency bands, possibly into octaves. The limit value of the double amplitude of the movement is to be determined for each range. This will clearly allow to identify causes of increased vibrations and to eliminate them.

The frequency band 15-350 Hz is best represented on the amplitude frequency characteristics of vibro-velocity. Using the experience of operating the turbine units as a normalized vibration parameter is to set the average square value of vibro-velocity. At the same time we increase the accuracy of measurement by removing one integration step.

Technical diagnostics is based on the vibration analysis of the object being diagnosed. The objects of analysis are specific frequencies or narrow frequency bands recording a certain mechanical impact. The diagnosis is not looking for the defect at the middle frequency.

## 6. Conclusions

Assessing the vibration level by the vibro-displacement parameter, errors arise as a double integration result of the signal and penetration of cavitations interference into the signal components.

It is proposed to divide the frequency of the hydraulic machine into bands and create standards for the operational control of the vibration state for each band.

- The operating frequency band of the sensor does not cover on the vibro-displacement parameter the frequency range of 0.1-200 Hz. There is no such vibration sensor. Technically, we can not get a complete picture of the vibration state of the hydraulic unit and according to the norms determine its evaluation. Therefore, the frequency band 0.1-2 Hz is proposed to be separately controlled by pressure pulsation sensors. This will require standards for acceptable pulsations.
- We have not to appreciate as it was 60 years ago on the time waveform the vibration state of the units. That is reasonable to evaluate more specifically the amplitude-frequency characteristic of the vibration signal. At the same time, the frequency band 1-15 Hz should be divided into frequency ranges, possibly per octave, according to the standards. We should determine the limit value of the movement double amplitude for each range. This allows clearly to identify the causes of increased vibrations and to eliminate them.
- The frequency band 15 -350 Hz is to be controlled on the parameter – vibro-velocity, it is more clearly represented here. This will require the creation of standards for vibro-velocities.

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