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ANALYSIS OF SERVICE LIFE OF CYCLICALLY SYMMETRIC STRUCTURAL ELEMENTS

Smetankina Natalia
DSc., Professor
A. Pidgornyi Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine

Misura Serhii
Ph.D., Senior Researcher
A. Pidgornyi Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine

Misiura Ievgeniia
Ph.D., Associate Professor
Simon Kuznets Kharkiv National University of Economics

Requirements to effectiveness and reliability of power generating plants have been raised significantly. Utilization of power generation potential in many countries in the world resulted in a necessity to modernize and replace hydraulic turbine equipment at hydroelectric power plants that are in operation for a long time [1]. In connection with exhausting of a resource of many hydraulic turbines, at their modernizing there is a question on extension of life expectancy of their separate sets and details and changing out-of-date equipment at raise of power and operate reliability of hydraulic turbines. The estimation of efficiency and redesign volume needs for operative techniques and programs for strength analysis of hydraulic turbines at various operating conditions.

When taking decision as to a scope of modernization, due consideration shall be given either to necessary replacement or service life prolongation of a turbine head cover because it is one of its most metal intensive sets. The variety of used materials and designs have led to the big number of papers in which destruction criteria, methods of faults summation for different materials, loadings and real service conditions of structures are observed. However, it is not enough works which integrate improved techniques for investigation of the static and dynamic stress-strained state of power machines taking into account real service conditions, experimental data about materials and analysis of longevity and the residual resource at modernizing of the hydraulic turbine equipment, and it demands the further development [2].

The present work deals with development of an estimation technique of a service life of welded cyclically symmetric structural elements of hydraulic turbines.

The head cover of a hydraulic turbine is a stationary annular part limiting from above the turbine water passageway, and being used for placement of guide vanes and other assemblies [3]. The head cover is the space cyclically symmetric structure consisting of thin-walled revolution shells integrated with meridian plates with a complex configuration. For investigation of the stress-strained state of such structures we construct the sector model of the prototype system. On boundary lines of the next sectors cycle symmetry conditions are satisfied. The main requirement to it at designing stage consists in that strength and stiffness are to be provided at a minimum specific metal content. The head cover structure of hydraulic turbine represents a combination of thin-walled bodies of revolution, which are stiffened with a system of closely-spaced multiply connected meridian plates.

However, structural features of the head cover are determined by entire layout of a turbine and its type and size. When in operating condition, the head cover is affected by significant axis-symmetrical loads both from mass forces and from hydrodynamic pressure acting on its surface in contact with water, as well as by radial load from the turbine rotor. As concerns previous design versions, the head covers were made as iron castings, whereas nowadays they are made as welded structures of carbon steel.

Calculation of a service life of hydraulic turbine covers demands determination of maximum stresses under static and dynamic loadings. For the problem solution of the stress-strained state analysis we applied the finite element method [2, 3] and analytical approach [4, 5].

The cover structure includes ring details, seven types of the radial edges and four types of straps. These structural elements are regularly arranged in the peripheral direction. Edges and straps have different width and a configuration. The cover is a welded construction of sheet carbon steel. It consists of six parts connected among themselves by fixture. In the peripheral direction in a butt joint twenty-seven bolts and six tight fitting screws are installed. Cover bolted connections are installed with a tightness which force ensures to the cover work as the uniform construction.

It is to note that elastic properties of those grey cast iron types as used previously for casting purposes are dependable on amount of graphite inclusions: elasticity modulus of these cast iron types makes up 40-75 % of elasticity modulus for steel qualities, Poisson's ratio about 67%. Cast iron density makes up 90-95% of steel density. The material mechanical characteristics are as follows [6]: $E = 2.1 \cdot 10^5$ MPa (Young’s modulus), $\nu = 0.3$ (Poisson's ratio), $\rho = 7850$ kg/m^3 (material density), $\sigma_u = 380$ MPa (ultimate limit), $\sigma_y = 240$ MPa (yield strength).

Calculation results have displayed that stresses attained the maximum value $\sigma = 45$ MPa at the vibration frequency of the cover $f = 27.57$ Hz. The cover service life has been determined with such mechanical and fatigue material characteristics [7]: $\sigma_{-10} = 95$ MPa (the fatigue limit of the sample at base number of symmetric cycles), $N_0 = 10^7$ (base number of cycles), $m = 3.78$ (curve fatigue slope). Level of residual stresses for a steel taking into account an actual metal condition makes from 160 to 170 MPa.

Table 1 shows the cover residual resource defined by the proposed technique.

Table 1.
The cover residual resource

Assembly number	Operating time, hours	Residual resource, years
1	286914	45
2	281677	46
3	177356	55
4	187344	57
5	178469	56
6	181029	55
7	184539	56
8	174841	58

Thus, the method to estimate a residual life of cyclic symmetric structures was proposed. To analyze the stress-strained state the finite element method with high degree approximation was applied. For residual life estimation the high-cycle fatigue theory was used. The calculation results can be used at creation of new hydraulic turbines and on modernization of the existing structures.

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