RELIABILITY ANALYSIS OF KAPLAN TURBINE CRITICAL COMPONENTS

N.Grujić*, D.Momčilović*

Availability of Hydro-Electrical Power Plants mostly depends on safety of critical components of hydroturbines. Using data from maintenance's services of HEPP "Djerdap I", (nominal capacity 6x178 MW), technical diagnosis of materials, vibration and stress testing for reliability analysis of Kaplan turbines, paper presents now-a-days situation in safety analysis and gathered experience. Special attention is devoted to huge parts made by forging, casting and welding, exposed to fatigue, corrosion and cavitation.

INTRODUCTION

Hydro-Electrical Power Plant HEPP "Djerdap I" consists of 12 generator sets with Caplan turbines with total capacity 2136 MW. Six Yugoslav generator sets started with operation between 1970 and 1972. From that time up today some of those sets reached 150.000 operating hours with, in average, 7000 hours per year.
High equipment availability was ensured with service and maintenance measures according to the technical requirements for main components of turbine and generator. Operational and maintenance data, systematically collected, allowed creation of data base for ensuring optimal conditions for operation HEPP "Djerdap I", reliability evaluation of main compnents and timely planning measures of reconstruction and revitalization of HEPP.

Service and maintenance characteristics of generator sets

Characteristics of the first period of operation, from 1970 to 1973, were some intervention and reconstruction works. The purpose of those works was reducing

*Institute for Testing Materials of Republic Serbia, (IMS), Belgrade

cavitation damages and removing minor design and installation defects. In that time the overhauls were finished for 43 days and between-overhaul period was 6600 hours.
The main characteristic of second period (from 1974 to 1984) is high availability. In that time, the temporary stoppage of HEPP "Djerdap I" was 7-9 days with one major overhaul in every three years. Those overhauls were accomplished , in average, for 40 days and between-overhaul period was 20,000 hours.
Characteristic of the third period, after 1984, is decreasing of maintenance period. Main causes are occurrence of material destruction, reconstruction of corrosion protection cover and occurrence of cracks on stator. The average overhaul period, during that time, was 30 days per year and between-overhaul period 18,000 hours.
Typical reliability improvement diagram with maintenance measures (a) and planned revitalization (b) is shown in Fig. 1.

Condition diagnosis for generator sets

Condition of materials, welded joints vibration ranges, hydraulic pressures, dimension and geometry and operating characteristics was established for reliability preservations and life assessments of main components using the methods of technical diagnosis and analysis of damage mechanisms. Complex testing of parts exposed to fatigue stresses, including measuring of strains and variable pressure on turbine blades and rotating chambers, started recently as a first step in planned power increasing.
In last period testings were carried out according to programs for each set and component with critical status: rotating set (blades, hub and parts of driving mechanism), rotating chamber (armor and cover of control hatch), turbine stators (struts and their connections with stator rings), runner in gates (blades, their connections and servo motor), welded joints, axle bearings and shaft (flange parts and bolted joints with generator shafts). The inspections was carried out in overhaul period on parts that are exposed to fatigue stresses and corrosion environment.

Measures for reliability assurance of generator sets

Main requirements for high power HEPP service safety with minimum stoppages are:
- designed reliability assured by high technical level of equipment and construction;
- high quality standards in manufacturing, stocking and assembling;
- increasing of reliability in service establishing optimal operation conditions (1).

Rotating set blades are exposed to destruction caused by cavitation and fatigue, enhanced by presence of geometry and structural stress raisers. Critical zones, presented in Fig. 2, are root and outlet edge of blades according to stress and fitness for purpose criteria (2). In these zones it is possible to calculate only limited fatigue strength with the cycles number up to 10^{10}.

For the 13Cr - 1Ni steel, decreasing fatigue strength curves are presented in Fig. 3 for specimens ϕ 8 and 180x200, tested in water (3). Further decreasing fatigue strength is affected by the corrosion environment, inhomogenities of materials, surface quality and polyharmonical stresses, depended on amplitude as the main characteristic, established by measuring. Measured stresses with amplitudes σ_0, σ_1, ... σ_{n-1} and frequencies f_0, f_1, ... f_{n-1} can be reduced on equivalent fatigue stresses with amplitude σ_{aD} and frequency f_0 (4) as follows:

$$\sigma_{aD}=\frac{\sqrt{1+n_1\delta_1^2+\ldots+n_{n-1}\delta_{n-1}^2}}{1+\delta_1+\ldots+\delta_{n-1}}\left(\sigma_0+\sigma_1+\ldots+\sigma_{n-1}\right) \quad \ldots\ldots(1)$$

where is $\delta_i=\dfrac{\sigma_i}{\sigma_0}$ and $n_i=\dfrac{f_i}{f_0}$. (i = 1, 2, ...n-1)

The above mentioned stress acts by mean static stress value σ_m and could be reduced to the stress caused by reversed loading, according to equation:

$$\sigma_{nD}=+\sigma_{aD}+\psi_{\sigma e}\cdot\sigma_m; \quad \ldots\ldots(2)$$

Coefficient $\psi_{\sigma e}$ depends feom influence of mean static stress on fatigue strength of material. Using Heigh's diagram, can be obtain:

$$\psi_\sigma=\frac{2\sigma_{Dn}+\sigma_{Dj}}{\sigma_{Dj}} \quad \ldots\ldots(3)$$

Reliability generally depends on existing of cracks on rotor shaft and their propagation rate to a critical value depending on actual stress and crack length (a). For 13Cr-4Ni steel following equation was derived (5):

$$da/dN=6{,}733\cdot 10^{-11}(\sigma-\sigma_0)^{4{,}493}(e^{2{,}97a}-1) \quad \ldots\ldots(4)$$

Good correlation of equation (3) with experimentally obtained data in diagram log(da/dN) - log(da) presented in Fig. 4, was found (4). Critical element of rotating chambers is the armor made of stainless or cladded steel. Characteristics of armor damage are fatigue defects in blade rotating zone. Measurements of pressure pulsations indicated high level of variation. Reliability increasing of armor could be achieved, according to (6) with injection of elastic material between metal and concrete. Decreasing of rotating sets hub reliability may cause intensive cavitation during deflection of blades. Protection of critical zones on blade, made of low-alloy

steel, could be accomplished with stainless layer covering (by metallizing) or repair welding (surfacing), Fig. 5.
Measuring of residual stresses in welded joints of struts exhibits increased values which during the time facilitate crack initiation. This problem could be solved with replacement of old and repaired weldments by new material during major overhauls.

CONCLUSIONS

During the whole operation period of HEPP "Djerdap I" there was no unexpected stoppages, but in several kinds of damages were observed:
- destruction of materials by cavitation and corrosion;
- local deformation;
- initiation of cracks on turbine stator and blades of rotary set;
- local leakage, and
- destruction of metallizing cover on axle bearings.

However, in practice known cases of unexpected stoppages are caused by exceeded vibrations, fatigue fracture caused by long-term reversed stresses, brittle fracture as a result of overloading, stress corrosion and increasing of temperature in axle bearings. With adequate maintenance measure and timely diagnosis, unexpected stoppages are reducing significantly.

SYMBOLS USED

σ_{aD}	– amplitude of reduced fatigue stress by acting of σ_m
σ_m	– mean static stress
σ_{nD}	– amplitude of fatigue stress by reversed loading
$\Psi_{\sigma e}, \Psi_\sigma$	– influence coefficient of average static stress on fatigue strength
σ_{Dn}, σ_{Dj}	– fatigue strength by reversed and repeated stress for N
N, a, f	– number of cycles, crack length and frequency of fatigue stress

REFERENCES

(1) Hydropower Reliability Study Nr. 1745-5, EPRI-Palo Alto, California, USA
(2) Richtlinien für Werkstofe in hydraulischen Machinen (RWhM), Wien, 1989
(3) A.J. Aronson, Problemi pročnosti, 1988, No. 10, pp 21
(4) P.Terzić, Speed of fatigue cracks propagation in iron castigs with 14Cr-4Ni, IV Czechoslovak Conference on crack detection in castings, Bratislava 1979, pp 159
(5) V.I. Artenijev, G.Z.Zajcev, J.V.Kaširski and E.V. Rjazanov, Energomasinostroenie No. 10, 1988 pp 22
(6) E.M.Džubanov, N.J.Dmitriev, L.I.Polnikov, T.I.Šamsonova, Fatigue analysis and reliability of runner chambers for Kaplan turbines, AHR Symposium, Belgrade Yugoslavia, 1990.

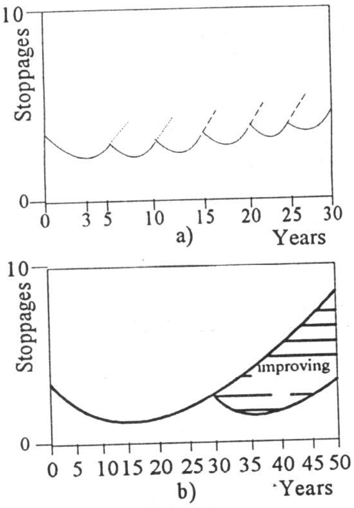

Figure 1. Reliability improving diagram by a) mantenance b) revitalization

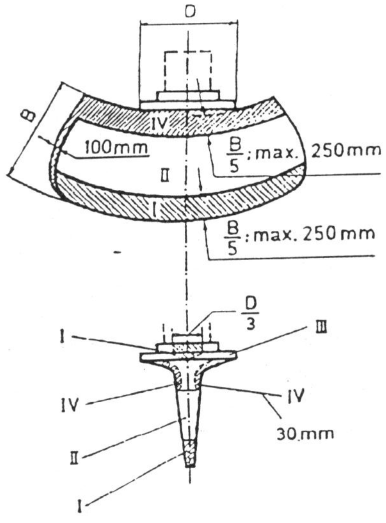

Figure 2. Position of critical zone on rotary set blade (I - IV)

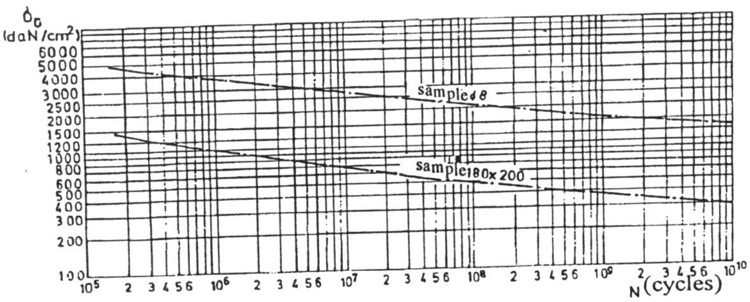

Figure 3. Decreasing of fatigue strength for 13Cr-1Ni steel

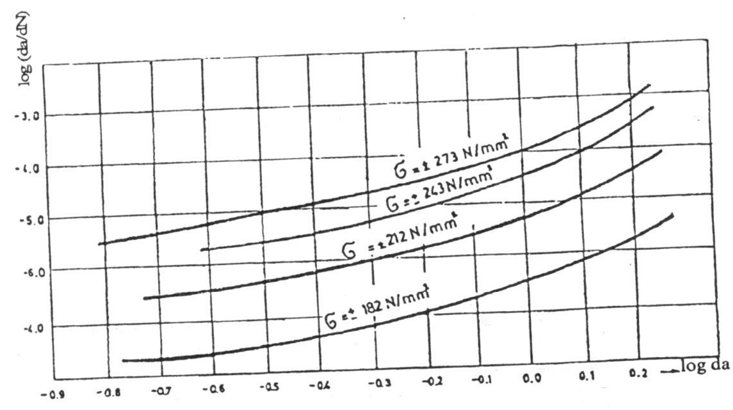

Figure 4. Curves obtained from formula (3) for 13 Cr-1Ni steel samples

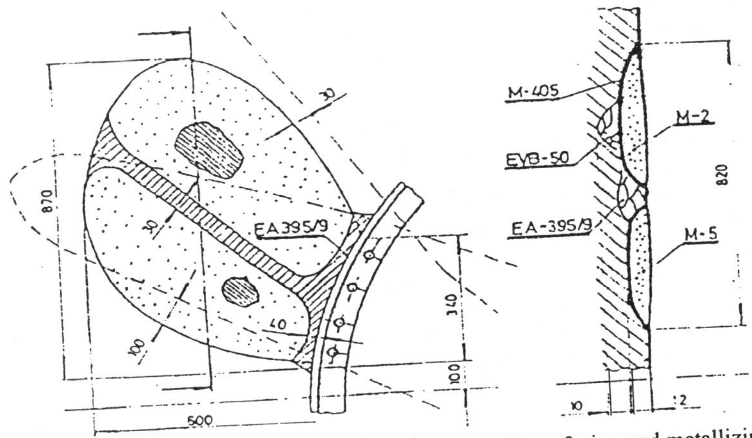

Figure 5. Protection of cavitation zone on hub with surfacing and metallizing