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Influence of Working Environment on Fatigue Life Time Duration for Runner Blades of Kaplan Turbines

The papers present an analytical analyzes refer to influence of working environment on life time duration in service of runner blades of Kaplan turbines. The study are made using only analytical method, the entry dates being obtained from measurements made in situ for a Kaplan turbine. To calculate the maximum number of stress cycles whereupon the runner blades work without any damage it was used an analytical relation known in specialized literatures under the name of Morrow's relation. To estimate fatigue life time duration will be used a formula obtained from one of most common cumulative damage methodology taking in consideration the real exploitation conditions of a specified Kaplan turbine.

***Keywords**: fatigue, runner, blade, environment*

1. Introduction

Lately, the alternative sources of energy like energy provide by water became real analyzed and exploitive premises in actual socio-economical context. It is about a big rising of global energy consumption that in conditions of constant reduction of energy reserves impose a special attention for renewable source of energy.

The Kaplan turbines are used with maximal efficiency for small water fall and high flow, and lately have large-sized because the constant increase of power supplied.

Until this moment, the rotor of Kaplan turbines was the object of the most numerous theoretical and experimental studies. Actually, the runner blades of Kaplan turbines represent the most studied part of the rotor. For runner blades, besides stress cycles induced by exploitation regimes a very important role in life time duration are played by working environment.

In time are made a very large number of studies about the influence of sweet water on decrease of life time duration for different mechanism. Taking in consideration the difficulty of production technology, maintenance and repair for this kind of machine part it is easy to understand the necessity of high attention for designing such pieces.

For a real estimation of fatigue life time duration, in case of runner blades of Kaplan turbines, taking in consideration the water influence became an essential problem as will be shown in results part of this papers.

2. Initial consideration

History of exploitation for different machine parts which works corrosive environments, such as sweet water in our case, reveal the big influence that work conditions where having against their sustainability. The corrosion induced by water affect superficial layers of material, zone that are known like being fatigue crack initiation zone for over 90% of cases.

Under long time corrosion action, metallic pieces can be destroyed even on small stresses. Simultaneously action of corrosive environment and variable stresses it is much detrimental than the sum of them acting successively.

The experimental results reveals that the most unfavorable stress are the cyclical shear stresses, fatigue strength of metals in water being reduce with 2-5 times against fatigue strength of metals in air.

A relative recent papers [4] analyze the problem of correlation between tensile strength characteristics and fatigue strength for symmetrical alternant cycles , for a large area of steels having the ultimate tensile strength $\sigma_m(R_m)=370\div2330$ MPa. The relations that offer the moust closer results with reality (with a dispersion rage by ±15%) are:

$$\begin{aligned} \sigma_{-1air} &= 0,37\cdot R_m + 75\,[MPa]\ sau \\ \sigma_{-1air} &= 0,39\cdot R_m + Z\,[MPa]\ sau \\ \sigma_{-1air} &= 0,41\cdot R_m + 2\cdot A\,[MPa] \end{aligned} \tag{1}$$

where: Z - breaking bottleneck;

A – elongation at breack;

Taking in consideration a value of multiplication factor by 4 (in accordance with exploitation condition) we can find the new values for tensile strength under corrosive action of water like being:

$$\begin{aligned} R_{mwater} &= \frac{\sigma_{-1aer} - 300}{1,48}\,[MPa]\,sau \\ R_{mwater} &= \frac{\sigma_{-1aer} - 4\cdot Z}{10,256}\,[MPa]\,sau \\ R_{mwater} &= \frac{\sigma_{-1aer} - 8\cdot A}{1,64}\,[MPa] \end{aligned} \tag{2}$$

The relation used for determinate the maximum number of stress cycles that the runner blades of Kaplan turbines can endure until the fatigue macroscopic cracking network appear, on the surface of runner blades, is the Morrow equation. [1]. This relation are considered by world fatigue designers engineers being the most conservative from all relation used in that moment for the same scope. The Morrow equation (1) modified the elastic term of the strain life equation for introducing the local mean stress into the strain life equation:

$$\frac{\Delta\varepsilon}{2} = \left(\frac{\sigma'_f - \sigma_m}{E}\right) \cdot \left(2N_f\right)^b + \varepsilon'_f \cdot \left(2N_f\right)^c \quad (3)$$

where: $\Delta\varepsilon$ - total strain range;

σ'_f - true fracture strength (value of σ_a at one reversal);

σ_m - the mean stress;

E – modulus of elasticity;

ε'_f - fatigue ductility coefficient;

N_f - number of cycles to failure; therefore $2N_f$ is equal to the number of reversals to failure;

b - fatigue strength exponent;

c - fatigue ductility exponent.

To obtain more approach results from real exploitation conditions must calculate the number of cycle for every representative regime that occur in time on service. To select these regimes is necessary to have a good loads history usually obtained from monitoring process that always exists in modern industry.

After we have all the number of cycles the last problem is to apply a cumulative damage methodology for calculating the fatigue life. The cumulative damage methodology choused for this determination are Palmgren-Miner linear aggregation criterion [3].

The formula used to estimate fatigue life time duration is:

$$\Pi = \frac{N_{mc}}{a \cdot N_{AD} + b \cdot N_{O/P} + \kappa \cdot N_e} \quad (4)$$

where: N_{mc} - common denominator of (N_1, N_2,…,N_i): N_1,…,N_i represent the num ber of cycles for the "i" regimes of works taking in consideration for the analyze;[cycles]

N_{AD} - cycle's number induced by device manager's blades; there are obtained from measurements made in situ;[cycles/year]

$N_{O/P}$ - cycle's number induced by stop and start operates on turbine; there are obtained from measurements made in situ;[cycles/year]

a, b - coefficients result from common denominator operation;

κ - mediate cycles coefficient result from exploitation regimes; it is de pendent on material properties and intensity and different weighting schemes in to the operating overview.

The κ coefficient could be define like in relation (5):

$$\kappa = c \cdot y + d \cdot z \tag{5}$$

where: c, d - coefficients result from common denominator operation;

y, z – coefficients that express the different weighting schemes in real operating overview (percentage).

The expression for κ is variable function of the real operating overview. Relation (4) describes exactly the operational conditions for the case used to exemplifier the theoretical part.

To resolve equation (1) will be used specialized software capable to obtain real answers from equations with a high degree of difficulty. It is about software named Mathematica a fully integrated software environment for technical and scientific computing. As we already said without such of software actually the problem can not be solved.

2. Results and comments

The study system is represented by runner blade of Kaplan turbines from PDF I. Material of runner blades is G-X5CrNi 13-4 and his mechanical properties are in accordance with current standards (σ_r=760 MPa after EN 12073/ASME) .

In Fig.1 are presented the experimental results, represented by a diagram with two durability curves, for a CrNi steel, with mechanical proprieties similar with the one of our material, having the ultimate tensile strength σ_r=900 MPa.

From Fig.1 can be observe that with how the corrosive action of water is more persistent only that the fatigue strength of material is smaller and the Wőhler curve is not longer tend towards a asymptote.

In Table 1 are given numerical results of tensile strength for some usual material used for pieces that are working in corrosion condition induce by sweet or salty water.

As is shown in Table 1 the higher fatigue strength in corrosive environments are manifests by stainless steel. That is reason way the turbine constructors chooses this kind of materials for realize the runner blades.

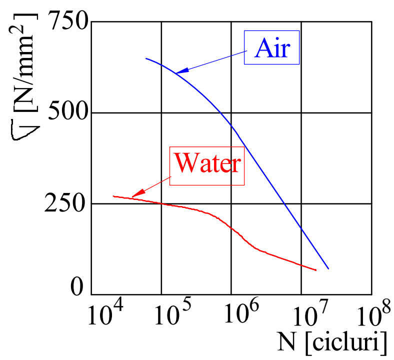

Figure1. Experimental curves σ – N for Cr – Ni steel with durability σ_r=900 MPa, in air and water

Table1.

Material	Fatigue strength $\sigma_{-1}\left[N/mm^2\right]$ in base of 5x10^7 cycle		
	In air	In sweet water	In salt water
Carbon steel (OL 37)	150	140	65
Carbon steel (OL 42)	165	120	-
Carbon steel (OSC 10)	280	150	-
Chromium-manganese alloyed steel (51VMnCr11)	465	130	-
Chromium-nickel alloyed steel (0,28%C, 5%Ni, 0,73%Cr)	470	115	95
Stainless steel (10Cr130)	380	260	210
Stainless steel (40Cr130)	360	250	250
Nickel-silicon steel (0,5%C, 3,1%Ni, 1,6%Si)	770	120	-

Having dates about the last two years of turbine's function we select the entry dates. The work regimes taking in considerations for this analyze are:

- $H = 26{,}4\ m\ and\ \varphi = 12{,}9^\circ$;
- $H = 31{,}4\ m\ and\ \varphi = 9{,}849^\circ$.

H are the head waterfall and φ represent the angular positions of runner blades. In accordance with work history of turbine will be consider that 70% of time the turbine work on first regime and the rest 30% she work to second regime. It is also known the medium number of stress cycles that stress the lever button over one year.

The value of measured stress data are [2]:

- $N_{O/P} = 365 \times 0,75 = 274 \ cycles/year$; for turbine having a duty factor of 0,75;
- $N_e = 86724 \ cycles/year$.

The entry dates necessary to apply relation (5) are:

- characteristically dates for regime one necessary to calculate the number of stress cycles N_{f1}: - $\sigma_a = 205,205 \ MPa$;

  - $\sigma_m = 119,105 \ MPa.$

- characteristically dates for regime two necessary to calculate the number of stress cycles N_{f2}: - $\sigma_a = 259,735 \ MPa$;

  - $\sigma_m = 119,105 \ MPa.$

- characteristically dates for stop/start operations necessary to calculate the number of stress cycles N_{f3}: - $\sigma_a = 124,84 \ MPa$;

  - $\sigma_m = 124,84 \ MPa.$

- characteristically dates for device manager (AD) operations necessary to calculate the number of stress cycles N_{f3}: - $\sigma_a = 20 \ MPa$;

  - $\sigma_m = 256,9,84 \ MPa.$

Using relation (2) and (3) can be determinate the value of maximum cycle stresses for both cases, not taking and taking in consideration the influence of work environment. The results are given in Table 2.

Table 2.

No.	The rolling case	No. of stress cycles in air N_{fi} [cycles]	No. of stress cycles in water N_{fi} [cycles]
1	Regime I ($H = 26,4 \ m \ and \ \varphi = 12,9^\circ$)	N_{f1}= 3,58 x 10^8	N_{f1}= 5,08 x 10^6
2	Regime II ($H = 31,4 \ m \ and \ \varphi = 9,849^\circ$)	N_{f2}= 5,65 x 10^6	N_{f2}= 1,58 x 10^6
3	Stop/start operations	N_{f3}= 1,05 x 10^8	N_{f3}= 5,65 x 10^6
4	Device manager operations	N_{f4}= 2,61 x 10^{15}	N_{f4}= 2,61 x 10^{15}

After we apply formula (4), using dates from Table 2, result an estimated fatigue life duration that are given in Table 3.

Table 3.

Estimated fatigue life time duration for runner blades $\Pi\left[year\right]$	
without taking in consideration water influence	taking in consideration water influence
130	3,5

As is shown in Table 3 the influence of water against reduce fatigue life time duration in service are drastically.

4. Conclusions

The paper reveals the importance of water influence in fatigue life time duration for runner blades of Kaplan turbines. It is absolutely necessary for designer engineers to make a real evaluation regarding the effects of work environments against real behavior of runner blades in time. Ignoring the influence of water represents a big error of designing process with real consequences on estimation of fatigue life time duration.

In the same time we can conclude that in corrosive medium is not exist a physical fatigue limit, but only a conventional one, strictly dependent by numbers of stress cycles until the experimental attempt continue.

The precision of results are also influence by the how better are known the real operating pictures, the existence of o specialized software necessary to resolved the high difficulty equations, and in last but not the least, the experience of design engineers.

The relation (4), obtained from Palmgren-Miner linear aggregation criterion, is the result of personal point of view about the way in which a cumulative damage criterion can be adapted to resolve the problem of estimating fatigue life time duration for a mechanical system, component of Kaplan turbine.

It is necessary to specified that relation (4) was developed to be used only for Kaplan turbines components, being adapted for characteristically exploitation system. For any other mechanical system it is necessary to be developed different relation, having like start point, their specific operation conditions.

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