ANALYSIS OF FATIGUE CYCLES AND STRESS AMPLITUDE FOR THE LEVER PIN OF A KAPLAN TURBINE RUNNER BLADE OPERATING MECHANISM

Ana-Maria Budai, *Babeș-Bolyai University of Cluj-Napoca, ROMÂNIA*
Mihaela Molnar*, *Babeș-Bolyai University of Cluj-Napoca, ROMÂNIA*
Cornel Hațiegan, *Babeș-Bolyai University of Cluj-Napoca, ROMÂNIA*
Cristinel Popescu, *„Constantin Brâncuşi" University of Târgu-Jiu*, ROMÂNIA

ABSTRACT: The paper describes a numerical method that can be used to identify the number of fatigue cycles and the tests made to determinate the stress amplitude on the lever pin of a Kaplan turbine runner blade operating mechanism. For these purposes, were used measured data recorded for a period of two years, on the hydro units from a Romanian power plant. To process the fatigue cycles data obtained from measurements was used an algorithm specifically designed for this purpose. The number of fatigue cycles obtained by this method, can be used to analyze the fatigue lifetime of the lever pin from the runner blade operating mechanism.

KEY WORDS: fatigue, stress cycles, Kaplan turbine, numerical method, stress amplitude

1. INTRODUCTION

In the last period the interest in renewable energy is growing, the hydro-turbine becoming ones of the most studied mechanical structures. In this background, the optimization of hydropower plant operation [1] and identifying the failure causes [2,3] are important fields for research.

To determinate de fatigue lifetime duration for the most stresses pieces of Francis [4] or Kaplan turbine [5,6,7,8] (jet turbine), became lately an important desideratum in strength calculus into designing process.

Finding the real fatigue lifetime duration, assume, through others, to known or to estimate the real number of fatigue cycles resulting from operating condition [9,10]. Lately, the turbines components design included also the fatigue design, aspect directly dependent of fatigue cycles [11,12, 13]. Kaplan turbines represent an important research target in terms to fatigue lifetime [12].

In this paper is presented a numerical method applied to determinate the number of fatigue cycles number for a Kaplan turbine.

The second part of the paper shows a procedure used to identify the stress amplitude from hydropower plant in-situ measurements. This is a practical method that provides real data obtained from real operating conditions.

2. THE FATIGUE CYCLES COUNTING

In the experimental measurements, performed in hydropower plant, recordings were made from 10 to 10 seconds, the regulator being set to frequencies insensitivity of ± 40 mHz. The measurement was made for 6 hydropower plant groups. The processing dates, for each group, of studied hydropower plant included:

- Upstream level;
- Upstream level after left grate;
- Upstream level after right grate;
- Downstream level;
- Active power PA;

- Turbine flow.

For each file the measurement period starting to 7:00:10 (Romanian local hour) and stop to 7:00:00, in the next day.

The data base receive from measurements was processed using an algorithm designed for this purpose.

The line numbers of each worksheet were identically to the line numbers from the original data base, respectively 8640. In case of days with time change, the line number was 9000 (autumn hour) respectively 8280 (spring hour).

a. Creating Excel files with active power variation from unit HG5 that contained:
   - The time column, imported from files created on point b;
   - The power column at unit HG5, also imported from folders create on point b;
   - The graphic representation of power variation during 24 hours;
   - The column of maximum and minimum points. The number of cycles and the minimum and maximum points were determined by continuous comparing of PA_HG5 values, on a level of 13 point of succeeding measurements (6 previous points and 6 points positioned after the considering value). For this comparison was considering like peak point (maximum or minimum) the extreme value from analyzed interval, if the power difference between this value and another point from analyzed interval is minim 2 MW;
b. The cycle's number on one day, the maximum and the minimum point's number were centralized in Excel folders. In that folders were made and the graphical representation of daily variation number of cycles during a year.

For processing and subsequent analysis were used an MSExcel macro programmed in Visual Basic. In Table 1 is given an example of summary table for fatigue cycles calculated for a power deviation higher than ± 1 MW.

Table 1. Fatigue cycles summary table

Read files	Create files	Fatigue cycles number	Minimum points	Maximum points
PF060101.xls	_PF060101.xls	811	462	466
PF060102.xls	_PF060102.xls	763	462	469
PF060103.xls	_PF060103.xls	800	450	463

The processing and graphical representation for a power deviation higher then ± 1 MW (interval 2 MW) respectively for a power deviation higher then ± 0,5 MW (interval 1 MW) are given in Table 2. In Figure 1 is given the fatigue cycles diagram calculated for a power deviation higher then ± 1 MW, for first year of measurements.

Table 2. Fatigue cycles

<table>
<tr><td>Power deviation</td><td colspan="2">Year "n"</td><td colspan="2">Year "n+1"</td></tr>
<tr><td rowspan="4">higher then
± 1 MW</td><td rowspan="2">Average / hour</td><td>Cycle's number</td><td rowspan="2">Average / hour</td><td>Cycle's number</td></tr>
<tr><td>9,53</td><td>7,77</td></tr>
<tr><td colspan="4">Cycle's average / 2 years</td></tr>
<tr><td colspan="4">8,65</td></tr>
<tr><td rowspan="3">higher then
± 0,5 MW</td><td rowspan="2">Average / hour</td><td>Cycle's number</td><td rowspan="2">Average / hour</td><td>Cycle's number</td></tr>
<tr><td>22,8</td><td>17,41</td></tr>
<tr><td colspan="4">Cycle's average / 2 years</td></tr>
</table>

	20,105

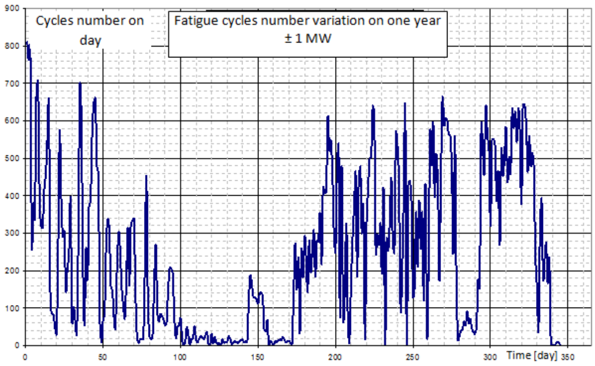

Figure 1. Fatigue cycles calculated for a power deviation higher then ±1 MW, year “n”

2. TEST TO DETERMINATE STRESS AMPLITUDE ON THE LEVER PIN OF RUNNER BLADE OPERATING MECHANISM

To determinate stress amplitude on the lever pin of operating mechanism were made measurements on two hydropower plant units:

- Operating tests to charging – discharging slow and sudden with power by 10, 15 and 20 MW;
- Operating test in secondary control;
- Operating tests in primary control.

The purpose of these tests was to determinate the loads and respectively the stress state that occurs on lever pin in different cases of turbine operating. In this tests were also measured the pressure on servomotor sides of the runner, in order to calculate the force that is applied on connecting rod of operating mechanism. In the same time was followed verification of fatigue cycles of turbine operating on secondary control, having a frequencies insensitivity of ± 40 mHz, and determination of fatigue cycles in operation on primary control having a frequencies insensitivity of ± 10 mHz.
Taking about primary control, the turbine governor can operate with an insensibility in frequency by minimum ± 10 mHz. The volume of data processed on tests is very big so is not possible to present all of them. In this paper are presented only the most significant diagrams rise by measured dates.

2.1. Operating tests to slow and sudden charging – discharging with power by 10, 15 and 20 MW.

Within the allowable limits of automatic speed governor, from a constant power by 190 MW, were made power slow and sudden charging – discharging in domain limits by 10 – 20 MW. To a constant power operating were prescribed slow and sudden decrease and increase of power to track the force evolution that load the crack pin.
For both changes of power, slow or sudden, the force that load the pin remain approximately constant, inside the limits 3100-3200 kN (Figure 2 and Figure 3).

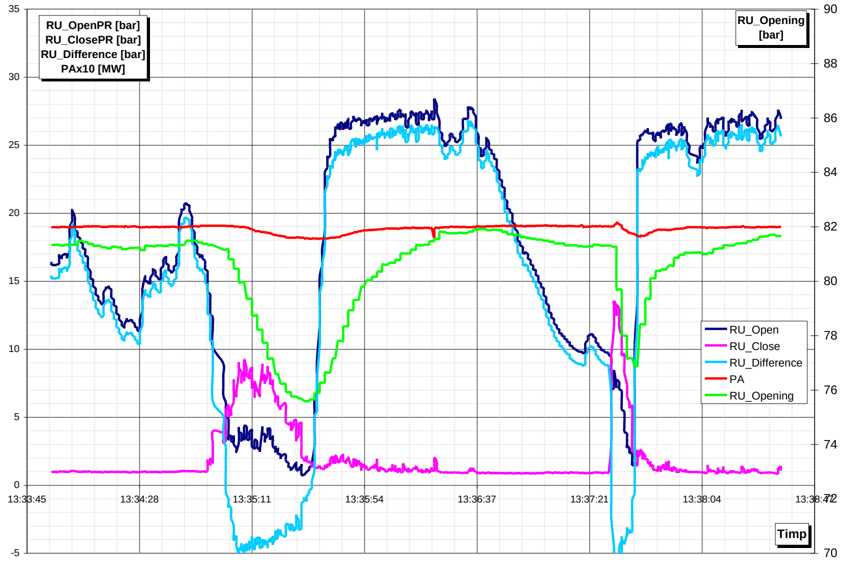

Figure 2. Operating tests to slow and sudden charging and discharging with a 10 MW power

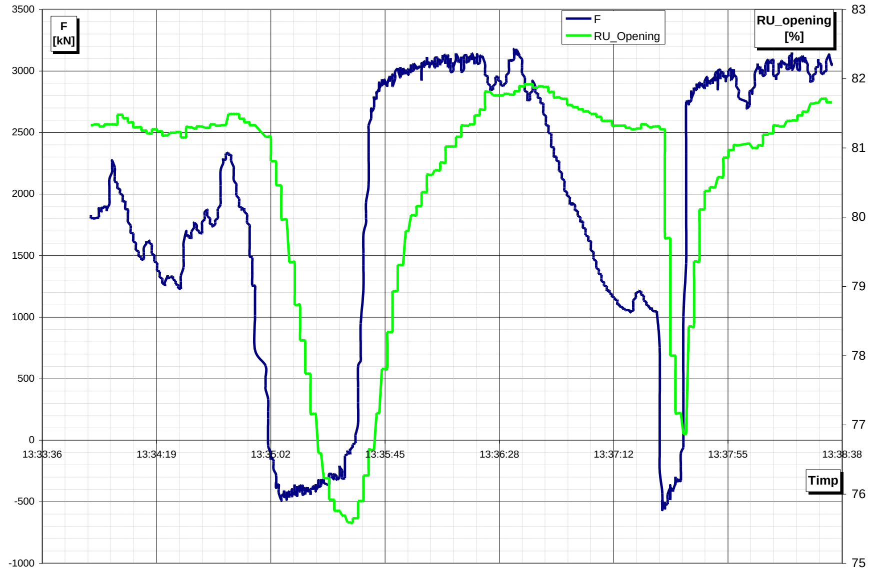

Figure 3. Operating tests to slow and sudden charging and discharging with a 10 MW power

2.2. Operating tests in secondary control regime

To obtain the secondary control fatigue number of cycles were made measurements for approximately 50 minutes. The fatigue cycle's numbers were obtained from charging cycles results by forces diagrams (Figure 4).

It was obtained approximately number by 22 cycles / hour.

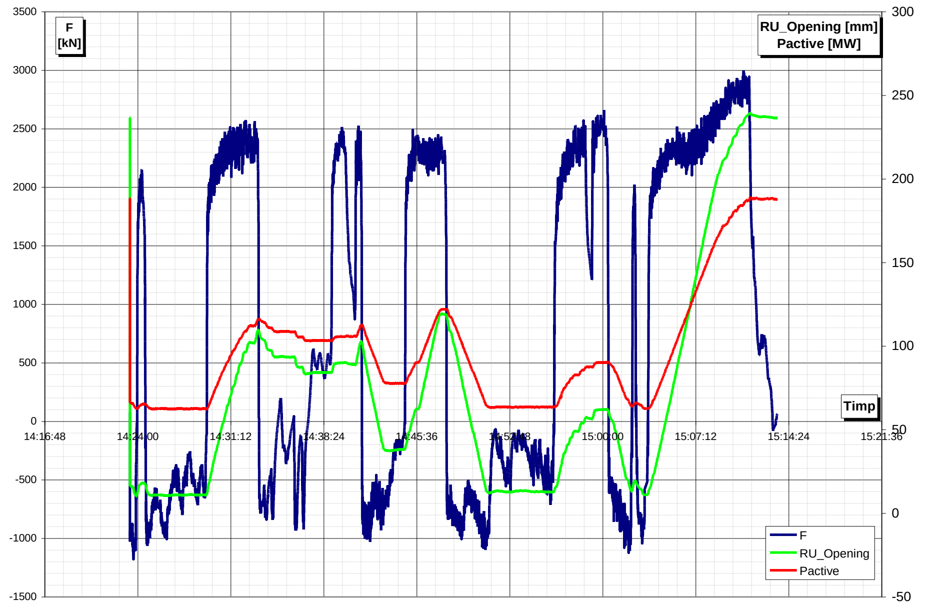

Figure 4. Operating tests to secondary control regime

2.3. Operating tests in primary control

The load of runner blade link when the turbine operating in frequency control regime, was measured at active power 191,5-192 MW.

In Figure 5. can be observed the existence of a pressure variation on opening side of runner servomotor piston. In the same time the pressure remaining approximately constant on the closing side of runner servomotor piston. This pressure variation induces a stroke oscillation with a half period which varies from 2-3 minutes to 7 minutes and maximum amplitude by approximately 1% (3 mm).

The same evolution can be also observed to the force that acts on lever pin (Figure 6.). This force varies inside limits 0-3200 kN.

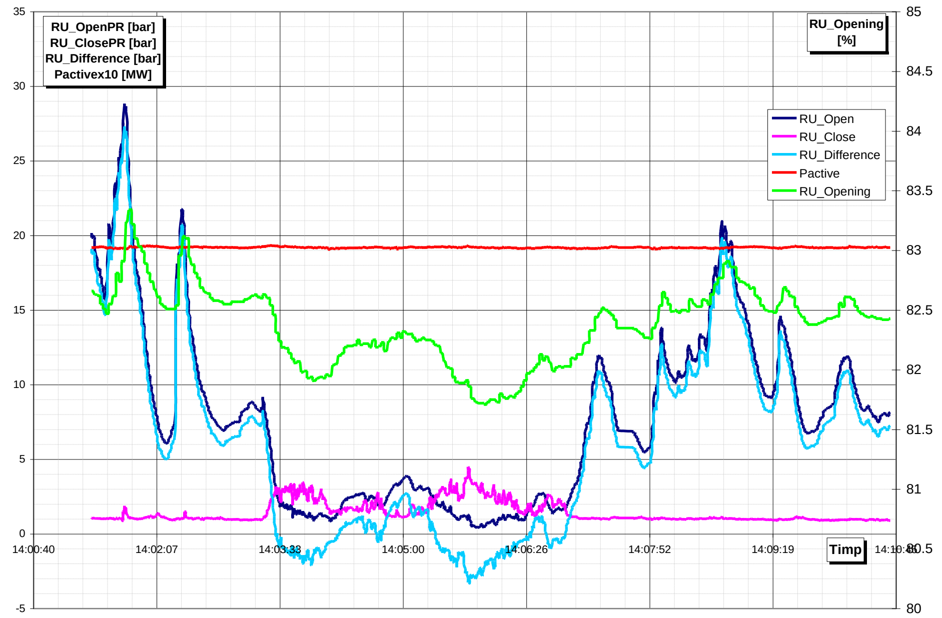

Figure 5. Operating tests on primary control regime

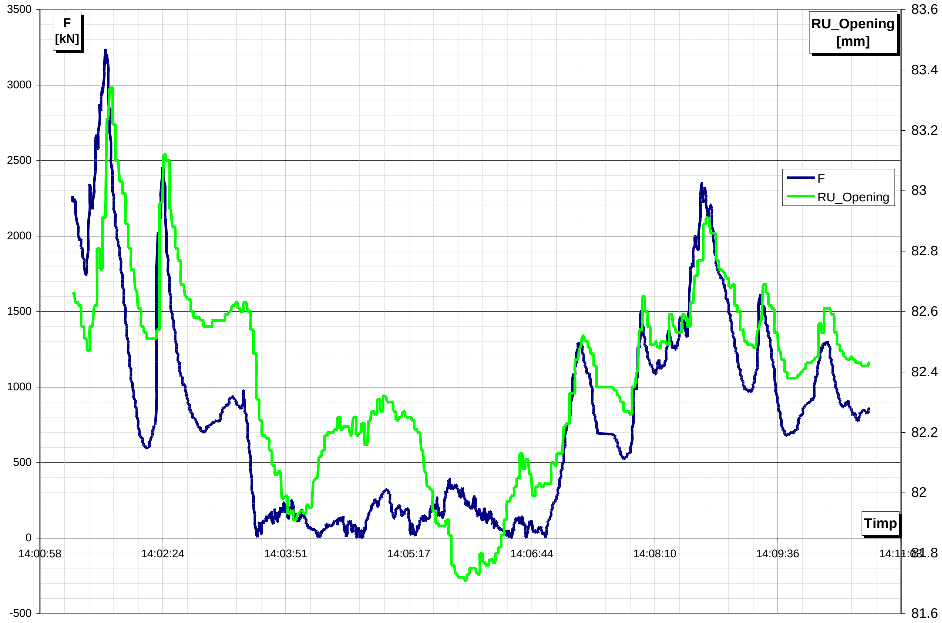

Figure 6. Operating tests on primary control regime

3. CONCLUSIONS

One of the most important problems for fatigue calculus of hydro-turbines components is to know the real number of fatigue cycles that, as is shown, are strictly depending on turbine operating condition. Also, the stress amplitude has a major influence on the fatigue lifetime.
The experimental investigations performed in a Romanian hydropower plant, the data processing, and the results analysis leads to the next conclusions:

- The number of stress cycles were obtained by processing the measured dates from a period of two years;
- A fatigue cycle is obtained by changing the sign and value of machine power, in the range of ± 1 MW, range obtained from accuracy class of power measuring devices. To analyze this power range influence over the cycles number were made calculations for ± 0,5 MW power range;
- To determine the number of fatigue cycles was used an Excel macro, created for this application;
- From measurements was revealed that slow and sudden power changes not lead to sudden jumps of force capable to generate stresses amplitude increases over the value obtain by calculus from linear static analyzes;
- The measurements reveal a force variation between 0 and 3200 kN, the charging – discharging cycles number being by approximately 110 cycles / hour.

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* corresponding author