BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVII (LXI), Fasc. 6, 2011
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

ANALYSIS OF FLOW INDUCED STRESS FIELD IN A FRANCIS TURBINE RUNNER BLADE

BY

RADU NEGRU[1,*], L. MARSAVINA[1] and SEBY MUNTEAN[2]

[1]“Politehnica” University of Timişoara
[2]Romanian Academy, Timişoara Branch

Received, May 31, 2011
Accepted for publication: July 26, 2011

Abstract. The analysis results of flow induced stress field in a Francis turbine runner blade is presented. The geometrical model was reduced to one blade, due to the periodical symmetry of the runner. The pressure field obtained from computational fluid dynamics (CFD) was applied as a mechanical load on the blade surface in the structural finite element analysis (FEA). The stress distributions obtained for different operating regimes are presented and sensitive areas to fatigue crack initiation are identified.

Key words: Francis turbine runner blade; finite element analysis; stress field.

1. Introduction

Using the energy of water, the hydraulic turbines contribute substantially to the generation of electricity worldwide. The advantages of hydroelectric power plants are: high efficiency rate, clean and renewable source of energy, high flexibility in operation required by the variable demand on the energy market. Consequently, hydraulic turbines are frequently operated at part load, with high pressure fluctuations generated by vortex rope in the draft tube (Kech & Sick, 2008). Therefore, strong vibrations are induced that can produce

[*]Corresponding author: *e-mail*: radun@mec.upt.ro

fatigue failures on the mechanical components of the hydraulic turbines.

Considering the failure mechanism as a combination of low-cycle and high-cycle fatigue (Huth, 2005), loads acting on the Francis turbine runner can be classified into these two categories: steady loading (fluid pressure, centrifugal force and runner own weight) and unsteady loading (high frequency pressure fluctuations due to stator–-rotor interaction as well as vortex rope phenomenon). The aim of this paper is the analysis of stress field induced in the runner blades by the steady loading at different operating regimes.

In the last years, the FEA of flow induced stresses in a Francis turbine runner through CFD was done by Xiao *et al*. (2008); Saeed *et al*. (2010); Sobrinho *et al*. (2009); Nava *et al*. (2006).

2. Analysis of the Operating Regimes

The data used in numerical simulation correspond to a medium specific speed Francis turbine with following characteristics: number of runner blades, N = 14, characteristic speed, n_q = 70, head coefficient, ψ = 1.264, hydraulic power coefficient, λ = 0.354, discharge coefficient, φ = 0.28, dimensionless characteristic speed, $\nu = 0.444$. The runner is a welded construction manufactured from martensitic–ferritic–austenitic stainless steel, T10CuNiCr180.

The nondestructive evaluation of runner structural integrity based on liquid penetrant inspection indicates that the fatigue cracks initiate in notches (Fig. 1), like the transition from blade to crown in area of the trailing edge, as in the case of a broken Francis turbine runner blade (Fig. 2) presented by Frunzăverde *et al*. (2010).

Fig. 1 – Fatigue crack in the runner blade.

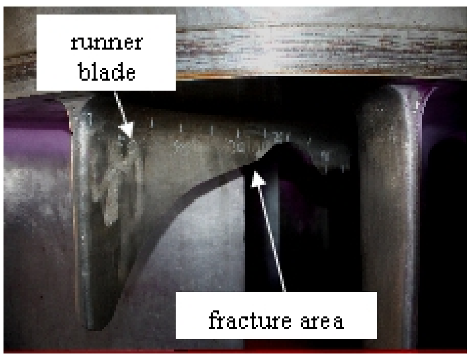


Fig.2 – Runner with the broken blade.

In order to determine the stress field induced in the runner blades, an analysis of operating regimes for the last ten years period (1999…2009) was made.

The results have shown an average operation time of 1,897 hours/year, with a balanced exploitation over each month and a relative peak for April-August period (Fig. 3). Moreover, the analysis of hydrodynamic conditions has shown the following distribution:

a) operation at part load (PL) representing 13.10% from total operation time, with the dimensionless guide vane opening less than 0.698;

b) nominal operation (NO), around best efficiency point, representing 37.2% from total operation time, with the dimensionless guide vane opening between 0.698 and 0.855;

c) operation at full load (FL) conditions over the nominal discharge, representing 49.7% from total operation time, with the dimensionless guide vane opening higher than 0.855.

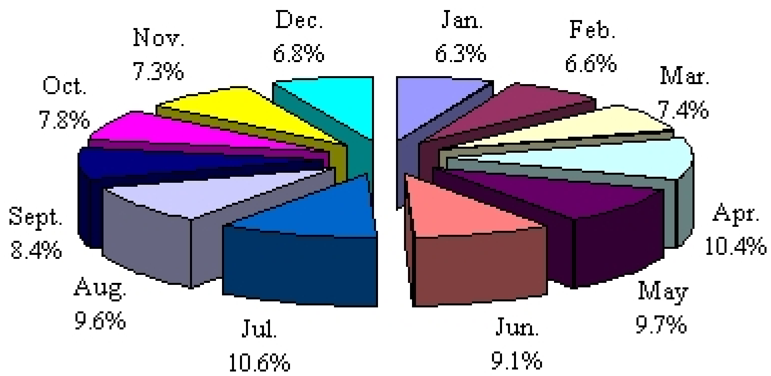


Fig. 3 – Percentage of monthly operation time in total operation time.

The operating points indicated in Table 1 were selected for the numerical simulation in order to determine the influence of the operating regime on flow induced stress field in the runner blade.

Table 1
Selected Operating Points for Numerical Analysis

Operating points	Operating regimes	Dimensionless guide vane opening	Dimensionless turbine power, PT
Case 1	PL	0.585	0.7949
Case 2	NO	0.707	0.8822
Case 3	NO	0.824	0.9346
Case 4	FL	0.882	0.9521

3. Stress Field Analysis in Turbine Runner Blade

For the finite element analysis, due to the periodical polar symmetry of the runner, the geometrical model was reduced to one single blade, of which the crown and band were removed, in order to reduce the required memory.

Firstly, 3-D turbulence steady simulation was performed, considering a coupled stator–rotor problem using mixing interface method (Muntean *et al*., 2004; 2007). For the meshing process of the model the 3-D structural solid SOLID185 finite element type was used, resulting the mesh shown in Fig. 4 with 61,140 elements and 38,186 nodes. To improve the precision of the results, the solid mesh of the runner and the finite volume mesh of the fluid domain were generated together to ensure the accurate transfer of the water pressure at the fluid–solid interface.

After the generation of the finite element mesh, the boundary conditions – displacements and loads were applied on the model (Fig. 5).

Thus, on the two ends of the blade, representing the transition areas to crown and, respectively, to band, zero displacements were assigned (fixed supports).

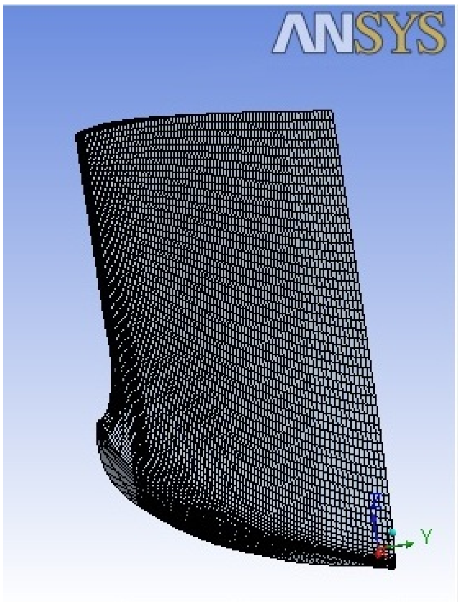


Fig. 4 – The finite element mesh of the blade.

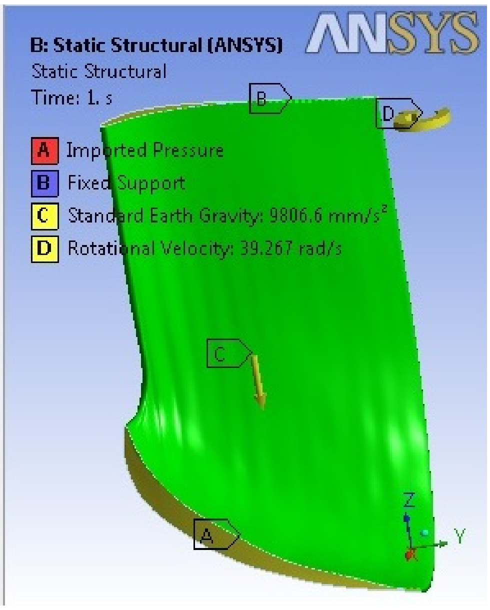
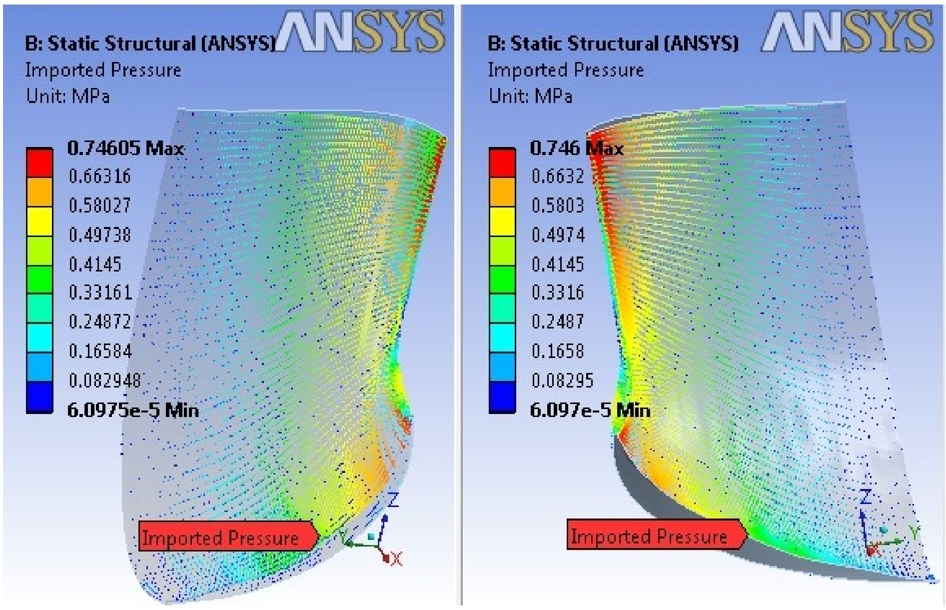


Fig. 5 – The boundary conditions.

In order to obtain the stress distribution on the blade the loads due to the water pressure, to the centrifugal force induced by rotation and to the own weight were considered, as shown in Fig. 5.

The water pressure imported from CFD and applied on the blade depends on the operating regime, being proportional with the dimensionless turbine power, PT. Thus, the maximum values of the pressure were obtained for case 4 and the minimum ones for case 1. In Fig. 6 is presented the water pressure distribution on the suction and pressure sides of the blade, at nominal operation conditions (case 2). The pressure decreases from leading to trailing edge, along the runner blade.



a *b*

Fig. 6 – Pressure distribution on the suction side (*a*) and pressure side (*b*) of the blade.

With these boundary conditions, the 3-D analysis of the runner blade was performed using software package ANSYS 12.1. Characteristic stress fields are presented in Fig. 7, for suction and pressure sides of the blade, in terms of von Mises equivalent stresses. For all four investigated cases the stress distributions indicate that the maximum stresses occur at the transition between the blade and the crown, in the trailing edge area, with a rapid decrease toward the transition to band. For the leading edge, the highest stresses occur at the transition to band.

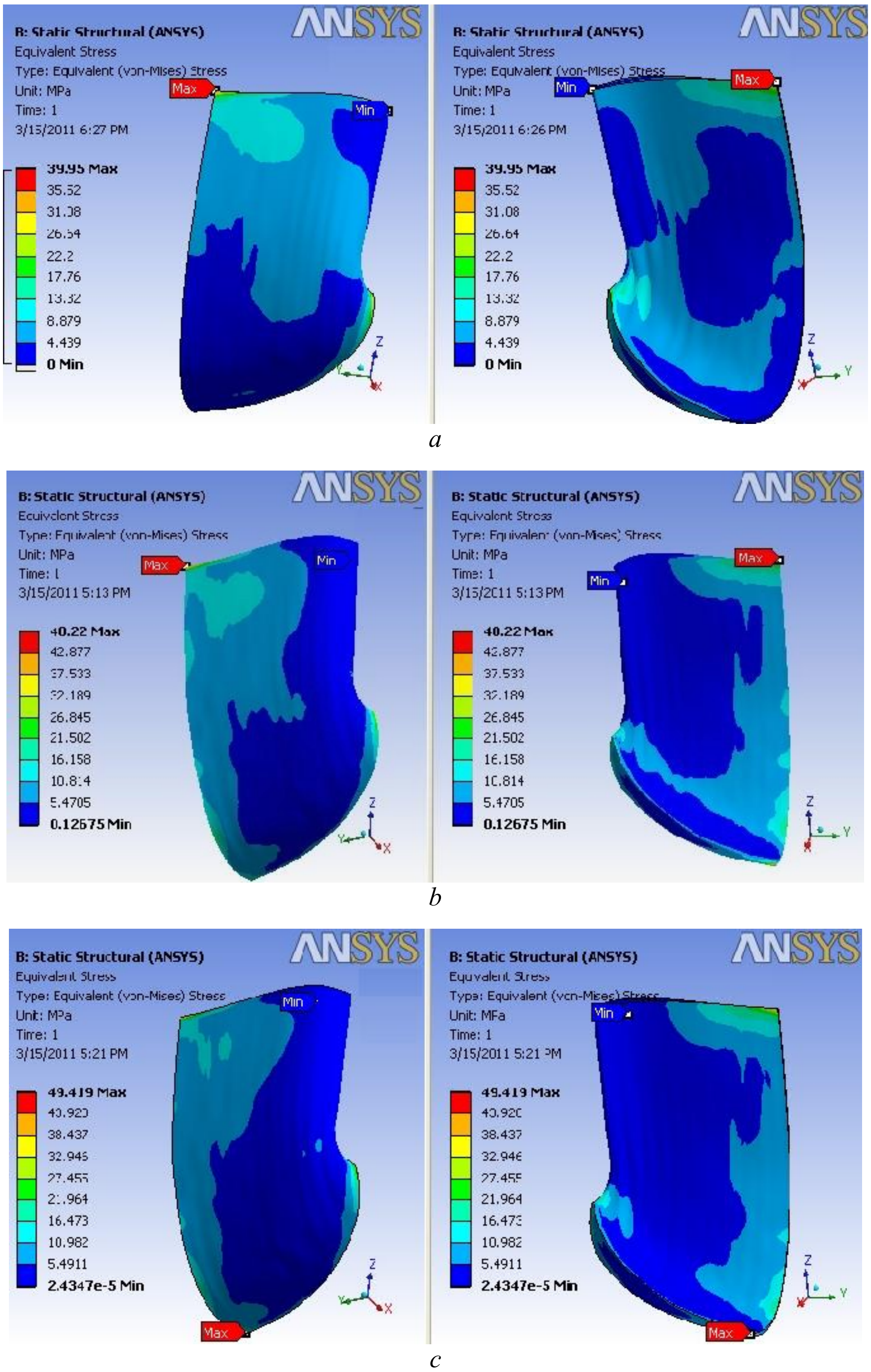


Fig. 7 – The flow induced stress field in the runner blade at nominal operation regime (*a* – case 2, *b* – case 3, *c* – case 4).

4. Conclusions

Using the obtained results with the CFD model, the flow induced stress field in a Francis turbine runner blade has indicated that the maximum static stresses occur at the transition between the blade and the crown, in the trailing edge area, where the fatigue cracks were observed (Fig. 1). These maximum values depends on the operating regime, being proportional with the dimensionless turbine power, PT, as shown in Fig. 8. Due to their low level these static stresses could not explain the failure of the turbine blade.

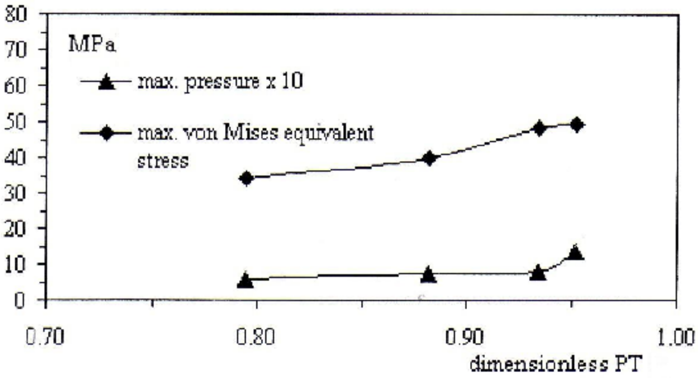


Fig. 8 – The variation of maximum pressure and von Mises equivalent stress.

Thus, a future investigation of the dynamic stresses induced by the unsteady loading is necessary for fatigue cracks initiation studies and for runner integrity assessment.

Acknowledgment. This paper was supported by the project "Development and Support of Multidisciplinary Postdoctoral Programmes in Major Technical Areas of National Strategy of Research – Development – Innovation" 4D-POSTDOC, contract no. POSDRU/89/1.5/S/52603, project co-funded by the European Social Fund through Sectoral Operational Programme Human Resources Development 2007-2013.

REFERENCES

Frunzăverde D., Muntean S., Mărginean G., Câmpian V., Marsavina L., Terzi R., Şerban V., *Failure Analysis of a Francis Turbine Runner*. IOP Conf. Series: Earth a. Environ. Sci., **12**, 012007, 2010.

Huth H.-J., *Fatigue Design of Hydraulic Turbine Runners*, Ph. D. Diss., Norwegian Univ. of Sci. a. Technol., Oslo, 2005.

Keck H., Sick M., *Thirty Years of Numerical Flow Simulation in Hydraulic Turbomachines*. Acta Mechanica, **201**, 211-229 (2008).

Muntean S., Baya A., Susan-Resiga R., Anton I., *Numerical Flow Analysis into a Francis Turbine Runner with Medium Specific Speed at Off-Design Operating Conditions*. Acta Tehn. Napoc., S. Appl. Math. a. Mech., **2,** *52*, 325-334 (2009).

Muntean S., Susan-Resiga R., Bernad S., Anton I., *3D Turbulent Flow Analysis of the GAMM Francis Turbine for Variable Discharge.* Proc. of the 22nd IAHR Symp. on Hydr. Mach. a. Syst., June 29–July 2, 2004, Stockholm, Sweden, Part A., paper A11-2, 1-12.

Nava J.M.F., Gomez O.D., Hernandez J.A.R.L., *Flow Induced Stresses in a Francis Runner Using ANSYS*. Internat. ANSYS Conf. Proc., 2006.

Saeed R.A., Galybin A.N., Popov V., *Modeling of Flow-Induced Stresses in a Francis Turbine Runner*. Adv. in Engng. Software, **41,** *12*, 1245-1255 (2010).

Sobrinho E., Sanomya R., Ueda R., Tiba H., Tsuzuki M.S.G., Adamowski J.C., Silva E.C.N., Carbonari R.C., Buiochi F., *Development of a Methodology for Evaluation of a Structural Damage in Turbine Blades from Hydropower Generators*. Proc. of the 20th Internat. Congr. of Mech. Engng., November 15-20, 2009, Gramado, Brazil.

Xiao R., Wang Z., Luo Y., *Dynamic Stresses in a Francis Turbine Runner Based on Fluid-Structure Interaction Analysis*. Tsinghua Sci. a. Technol., **13,** *5*, 587-592 (2008).

ANALIZA DISTRIBUȚIEI TENSIUNILOR INDUSE DE CURGERE ÎN PALETA UNUI ROTOR DE TURBINĂ FRANCIS

(Rezumat)

Se prezintă rezultatele analizei distribuției tensiunilor induse de curgere în paleta unui rotor de turbină Francis. Modelul geometric este redus la o singură paletă, pe baza simetriei periodice a rotorului. Câmpul de presiune obținut din analiza numerică a curgerii a fost aplicat ca o încărcare mecanică pe suprafața paletei pentru analiza structurală cu elemente finite. Sunt prezentate distribuțiile tensiunilor obținute pentru diferite regimuri de exploatare şi sunt identificate zonele sensibile la inițierea fisurilor de oboseală.