NUMERICAL MODAL ANALYSIS OF A KAPLAN TURBINE RUNNER

RAFEL ROIG, OSCAR DE LA TORRE, ESTEVE JOU, XAVIER ESCALER

Universitat Politècnica de Catalunya, Barcelona, Spain
e-mail rafel.roig@upc.edu

ABSTRACT

The aim of the research has been to investigate the dynamic behavior of a Kaplan turbine runner when submerged in still water. More specifically, the effects of the added mass on the modes of vibration have been quantified. For that, the modes of vibration of the runner in vacuum, in air and in water have been simulated with a coupled Acoustic-Structural modal analysis and from their comparison the reduction of the natural frequencies and the possible changes of the mode shapes of the runner have been obtained. The results show that the typically assumed invariance of all the mode shapes of a structure when submerged in a fluid is not fully accomplished in our case. And regards to the frequency reduction ratios, they are similar for most of the first modes with an average value of about 37%.

Keywords: Kaplan runner, modal analysis, fluid structure interaction, frequency reduction ratio, mode shape.

1 METHOD

The numerical model is based on a coupled Acoustic-Structural Finite Element Model (FEM), where the fluid is modeled using acoustic elements and the runner using structural elements. The acoustic elements are based on the Helmholtz equation so that a potential flow modeling approach is used. Consequently, the added mass due to viscous effect is not taken into account. Other considerations are that despite of the fact that the flow velocity affects the fluid-added stiffness value in a way that it increases for higher flow velocities, it can be considered negligible in the case studied here and that the mode shape can be assumed not to be affected by the additional stiffness introduced by the flow (J.P. Gauthier et al., 2017). So, taking into account the above considerations, it can be concluded that an Acoustic-Structural approach is valid to calculate natural frequencies and mode shapes of the Kaplan turbine runner.

The frequency reduction radio (FRR) between the natural frequencies of the structure in vacuum and in water has been computed using the following formula:

$$FRR(\%) = \frac{Wv - Ww}{Wv} \cdot 100 \qquad [1]$$

Where *Wv* is the natural frequency of the structure in vacuum and *Ww* in water.

Once the mode shapes have been computed, the Modal Assurance Criterion (MAC) has been used to compare the modal vectors between the runner in vacuum, in air and in water. The MAC is calculated as the normalized scalar product of two sets of vectors *{Vr}* and *{Vq}* (M. Pastor et al., 2012).

$$MAC(r,q) = \frac{|\{Vr\}^T\{Vq\}|^2}{(\{Vr\}^T\{Vr\})(\{Vq\}^T\{Vq\})} \qquad [2]$$

Where *{Vr}* is the mode shape of the structure in vacuum and *{Vq}* is the mode shape of the structure in air or water. The MAC can take a value between 0 (representing no consistent correspondence) and 1 (representing perfect correspondence). Values larger than 0.9 indicate a consistent correspondence whereas small values indicate a very poor resemblance of the two shapes.

2 RESULTS

2.1 Frequency Reduction Ratio

In table 1, the frequencies of the first modes in vacuum, in air and in water are indicated. It can be observed that the natural frequencies decrease when the density of the fluid increases. Because of the fact that the added mass effect of the air is almost negligible, it has not been computed.

Table 1. Natural Frequencies of the runner in vacuum, air and water; and the frequency reduction ratio (vacuum-water).

MODE	VACUUM (HZ)	AIR (HZ)	WATER (HZ)	FREQUENCY REDUCTION RATIO (VACUUM-WATER) (%)
M1	1081	1081	736	32
M2	1257	1257	768	39
M3	1262	1261	775	39
M4	1269	1268	779	39
M5	1280	1279	833	35
M6	1285	1284	836	35

2.2 Mode Shapes

Despite of the common assumption that the mode shapes are invariant between structures in vacuum and water, it seems that this correlation between mode shapes is lost for complex structures which are submerged in a dense fluid (with lower correspondence for higher mode shapes). As an example, Figure 1 shows M5 of the Kaplan runner in water.

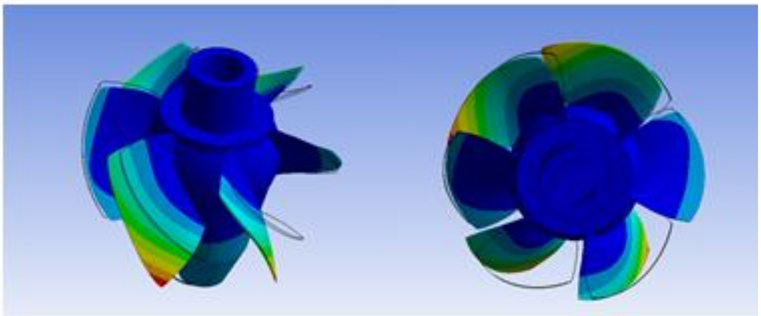

Figure 1. Isometric view (left) and top view (right) of the M5 of the Kaplan runner in water. The wireframe shows undeformed geometry.

Table 2 indicates the MAC values for the first vibration modes and it can be observed that they are exactly 1 between vacuum and air as expected, but they are significantly lower between vacuum and water especially for M6.

Table 2. MAC values for mode shape: vacuum-water and vacuum-air.

		water					
		M1	M2	M3	M4	M5	M6
vacuum	M1	0,8	0,7	0,7	0,6	0,7	0,6
	M2	0,5	0,9	0,4	0,2	0,3	0,2
	M3	0,9	0,8	0,9	0,3	0,7	0,3
	M4	0,5	0,4	0,6	0,8	0,6	0,3
	M5	0,8	0,5	0,9	0,4	0,8	0,3
	M6	0,3	0,4	0,3	0,7	0,3	0,4

		air					
		M1	M2	M3	M4	M5	M6
vacuum	M1	1	0,5	0,8	0,7	0,7	0,6
	M2	0,5	1	0,6	0,2	0,3	0,3
	M3	0,8	0,6	1	0,6	0,8	0,3
	M4	0,7	0,2	0,6	1	0,7	0,5
	M5	0,7	0,3	0,7	0,7	1	0,2
	M6	0,6	0,4	0,4	0,5	0,2	1

3 CONCLUSIONS

It can be concluded that a coupled Acoustic-Structural FEM model is a valid method to estimate the natural frequencies and mode shapes of complex submerged structures such as Kaplan turbine runners. It has been found that the FRR are around 37% for the first modes and that the mode shapes when submerged in water present differences with the ones in vacuum.

REFERENCES

Gauthier, J.P., Giroux, A.M., Etienne, S., Gosselin, F.P., 2017. A numerical method for the determination of flow-induced damping in hydroelectric turbines. *J. Fluids Struct,* 69 (2017), 341-354.

Pastor, M., Binda, M., Harcarik, T., 2012. Modal Assurance Criterion. *Procedia Engineering,* 48 (2012), 543-548.