NUMERICAL MODAL ANALYSIS OF A KAPLAN TURBINE RUNNER

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Abstract The aim of the research has been to investigate the change of 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 have been determined. The results show that the typically assumed invariance of all the mode shapes of a structure when submerged in a dense fluid is not fully accomplished in this particular geometry. And regards to the frequency reduction ratios, they are found to be similar for the first six modes with an average value of about 37%.

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

Methods

Assuming that the calculation of the added mass has been performed considering:

- Small displacements
- Small variations of density

And using a flow:

- Irrotational
- Without mean velocity

The discretized acoustic wave equation coupled to the structural one is used to do the modal analysis of the Kaplan turbine as described with:

$$\left.\begin{aligned}[M_s]\ddot{u} + [K_s]u &= [R]p \\ [M_f]\ddot{p} + [K_f]p &= -\rho[R]^T\ddot{u}\end{aligned}\right\}$$

The frequency reduction ratio (FRR) is computed according to:

$$\mathrm{FRR}\ (\%) = \frac{W_v - W_w}{W_v}100$$

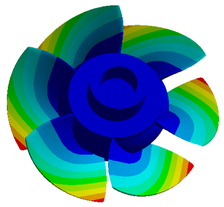
And the modal assurance criterion (MAC) is computed according to:

$$\mathrm{MAC}\ (\mathrm{r,q}) = \frac{\left|\{V_r\}^T\{V_q\}\right|^2}{(\{V_r\}^T\{V_r\})\left(\{V_q\}^T\{V_q\}\right)}$$

Results

Table 1: Runner natural frequencies in vacuum, air and water, and FRRs.

	Natural Frequency (Hz)			
Mode	**Vacuum**	**Air**	**Water**	**FRR (%)**
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



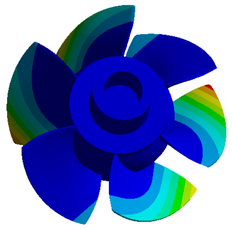


Table 2: MAC values of mode shapes: vacuum-water and vacuum-air.

		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

Conclusions

- The FRR for the first runner blade bending mode are slightly lower than those provided by other authors.
- This difference could steam from the fact that the added mass depends on multiple factors such as dimensions, geometry and boundary conditions.
- The typically assumed invariance between mode shapes in vacuum and water is lost specially for M6.

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