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ON THE EXCTITATION OF A SUBMERGED DISK-LIKE STRUCTURE WITH RSI PATTERNS

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ABSTRACT

Pump turbine runners are disk-like structures submerged and rotating that are excited with the well-known RSI excitation. To understand the dynamic behavior of the runner, it is necessary to study its structural response and the excitation characteristic. Simplified disk models have been widely used in the past to analyze this topic.

In this paper, the dynamic behavior of a rotating disk submerged and confined due to an RSI excitation pattern is analyzed experimentally. The structural response of the rotating disk is determined with an accelerometer screwed on the disk. For the excitation, several piezoelectric patches (PZT actuators) have been used. These are attached directly on the disk. Excitation and measurement signals are transmitted to the stationary frame with a slip ring system. Several excitation patterns that simulate the RSI excitation have been created with a properly calibration and set-up of the PZTs. In this way, the dynamic behavior of the rotating and submerged disk due to an RSI excitation pattern is determined experimentally.

KEYWORDS

Natural frequency, dynamic behavior, RSI excitation, Piezoelectric Patches

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1. INTRODUCTION

In order to avoid resonance problems in pump-turbine units it is important to study the dynamic behavior of the runner. This implies to determine the natural frequencies and mode shapes of the structure in their real operating conditions (submerged in water, confined and rotating) and also the excitation characteristic. Nevertheless the complexity of the structure (bladed-disk like structure with curved blades), the boundary conditions and associated effects (water rotating with respect to the runner) and the excitation characteristic (superposition of rotating excitation patterns) makes the study of the real case very complex. For this reason, simplified models are needed.

To study the dynamic response, i.e. natural frequencies and mode shapes, of pump-turbine runners and the influence of the boundary conditions, simple disk-like structures have been used in the past [1-3], since these kind of runners behave as simple disk-like structures in their first vibration modes. Furthermore, the characterization of the mode shapes that is used for disks is also widely used to describe the mode shapes of pump-turbine runners [1, 4-6]. Especially the first modes of PT runners are similar to the diametrical modes of a disk, i.e. modes with no nodal circles and N nodal diameters.

Most of the mentioned studies, deal with disks (or PT runners) submerged in standing water. Therefore this studies determine mainly the effect of the confinement, i.e. distance of the submerged structure to the rigid walls. Only in some of these studies [2, 3, 7], the influence of the rotation on the natural frequencies of the submerged and confined structure is analyzed.

The main excitation in this kind of runners is the well-known RSI excitation which has been also analyzed in the past [8, 9]. As the rotating blades pass very close from the standing guide vanes, the runner is excited with a complex pressure pulsation that can be discomposed as a sum of harmonic excitation patterns with different excitation shapes. According to these studies, a resonance of the runner can theoretically occur if the excited frequency coincides with a natural frequency of the runner and the excitation shape number coincides with the structural mode.

In this study, a rotating disk-like structure confined and submerged has been excited with different excitation patterns that simulate the RSI. The excitation patterns have been created with several Piezoelectric Patches attached on the disk. The response has been also measured on the rotating disk. In this way, the dynamic behavior of the rotating disk due to a RSI excitation pattern is determined.

2. NATURAL FREQUENCIES AND MODE SHAPES OF A DISK

The natural frequencies and mode shapes of circular plates have been studied in detail in the past [10]. For thin disks with high outer to inner radius, the several first mode shapes are characterized with the number of nodal diameters. Higher mode shapes in frequency corresponds to modes with higher number of nodal diameters.

The first mode shapes of pump-turbine runners behave as a simple disk-like structure and therefore they are also characterized with the number of nodal diameters [1, 4-6].

When a disk-like structure is in contact or totally submerged in water, the natural frequencies are generally reduced due to the added mass effect [1] (Eq. 1).

$$\delta_n = \frac{f_{air,n}}{f_{water,n}} \tag{1}$$

δ_n is the added mass factor of the mode *n*, which is the ratio between the corresponding natural frequency of the disk-like structure in air and the same natural frequency when the structure is in contact or submerged in water. The influence of the boundaries (especially the axial gap) on these factors has been analyzed in the mentioned studies.

In some of these studies [1-3], the effect of rotation for a simple disk has been also analyzed. In [1, 3] the disk is supposed to be standing and the surrounding water rotating with respect to it, while in [2] the disk is rotating, which induces also the rotation of the surrounding water. The diametrical mode shapes of a standing disk are standing waves, which are the superposition of a forward and a backward wave. For this reason, there is a different added mass effect of the rotating water, with respect to the forward and to the backward wave and therefore each natural frequency in the standing case is split into two natural frequencies in the rotating case (Eq.2).

$$f_{water,n}(\Omega_{disk}) = f_{water,n}(\Omega_{disk} = 0) \pm \Omega_{disk} \cdot \gamma \tag{2}$$

γ is a parameter that depends basically on the diametrical mode n, the radius of the disk and the density of the surrounding fluid [11]. The lower natural frequency obtained with Eq.(2) is a travelling wave that rotates in the same direction than the disk, while the higher natural frequency is a travelling wave that rotates in the opposite direction.

3. RSI EXCITATION CHARACTERISTIC IN A PUMP-TURBINE RUNNER

The passing of the rotating blades of the runner in front of the static guide vanes with a short gap, causes the well-known RSI (Rotor-Stator Interaction) excitation. The combination of guide vanes, rotating blades and rotating speed of the machine define this excitation pattern [4, 8, 9].

The excited frequency on the rotating structure can be obtained as a function of the rotating speed of the runner and the number of harmonic i:

$$f_{excited} = i \cdot \Omega \cdot Z_v \tag{3}$$

Z_v is the number of guide vanes and Ω the rotating speed of the runner in Hz. i is an entire positive number.

The excitation shape or number k (which is a rotating excitation pattern with respect to the runner) can be calculated as:

$$k = j \cdot Z_b - i \cdot Z_v \tag{4}$$

Z_b is the number of rotating blades and j an entire positive number. It has to be mentioned, that the combinations of lower harmonics i, j producing lower values of $|k|$, give generally higher amplitudes of the pressure pulsation.

The magnitude of k gives the number of entire pressure pulsations in the outer part of the structure. Therefore a ressonance can occur if the excited frequency coincides with the natural frequency of the structure and this number k coincides with the structural mode n. The sign determines the spinning direction of the excitation.

4. EXPERIMENTAL TEST

To study the resonances of the rotating submerged structure due to a RSI excitation type a rotating-disk test rig has been used. It consists of a stainless steel disk inside a rigid casing. The casing is totally filled with water.

The speed of the disk is adjusted to 6Hz. When the disk is rotating in stationary conditions, it is excited with several excitation patterns that simulate the RSI created with PZTs (Piezoelectric patches) attached on it. Patches are previously calibrated as explained in [6]. The response of the disk is measured with a miniature accelerometer attached to it. The excitation and measured signals are transmitted to the stationary frame through a slip ring system. Fig.1a shows the test rig and Fig.1b the position of the patches and of the accelerometer.

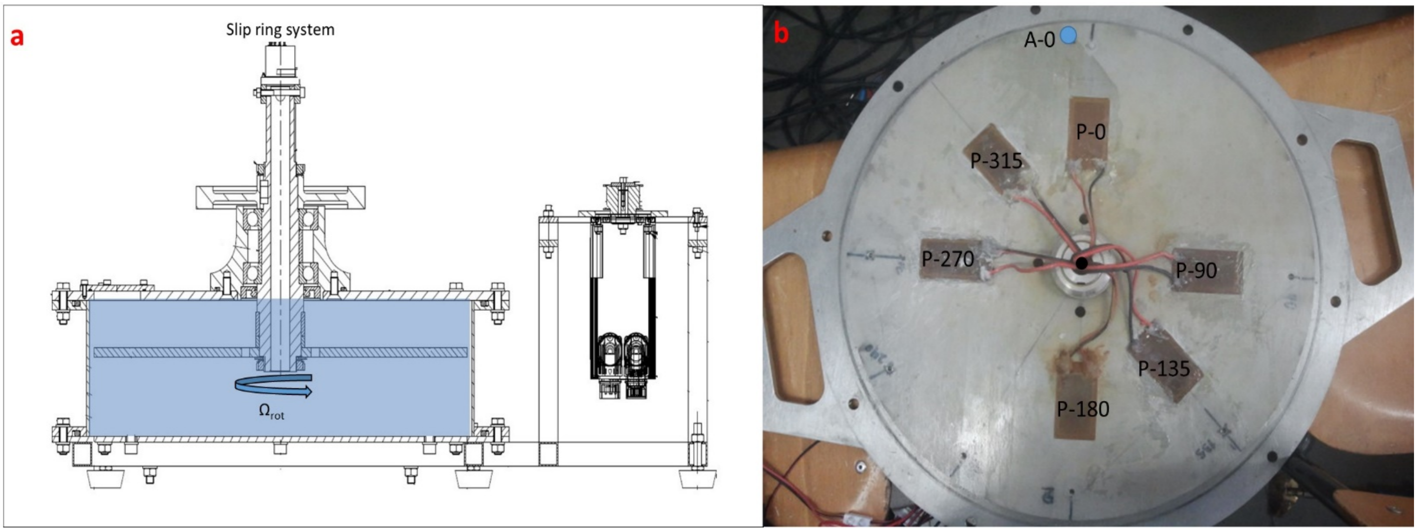

Fig.1 a) Test rig. b) Disk with attached patches and accelerometer

Due to the limited number of slip ring channels only four patches are used simultaneously. With these patches and adjusting properly the phase shift between them, the excitation shapes k= +2, -2, +3, -3 can be created on the disk.

5. RESULTS

Sweep excitations with excitation number k=+2, -2, +3, -3 are applied on the rotating disk around the structural resonances n=±2 and n=±3. The disk is also excited with only one patch, which is the reference situation Fig.2 shows the excitation around the resonances n=±2.

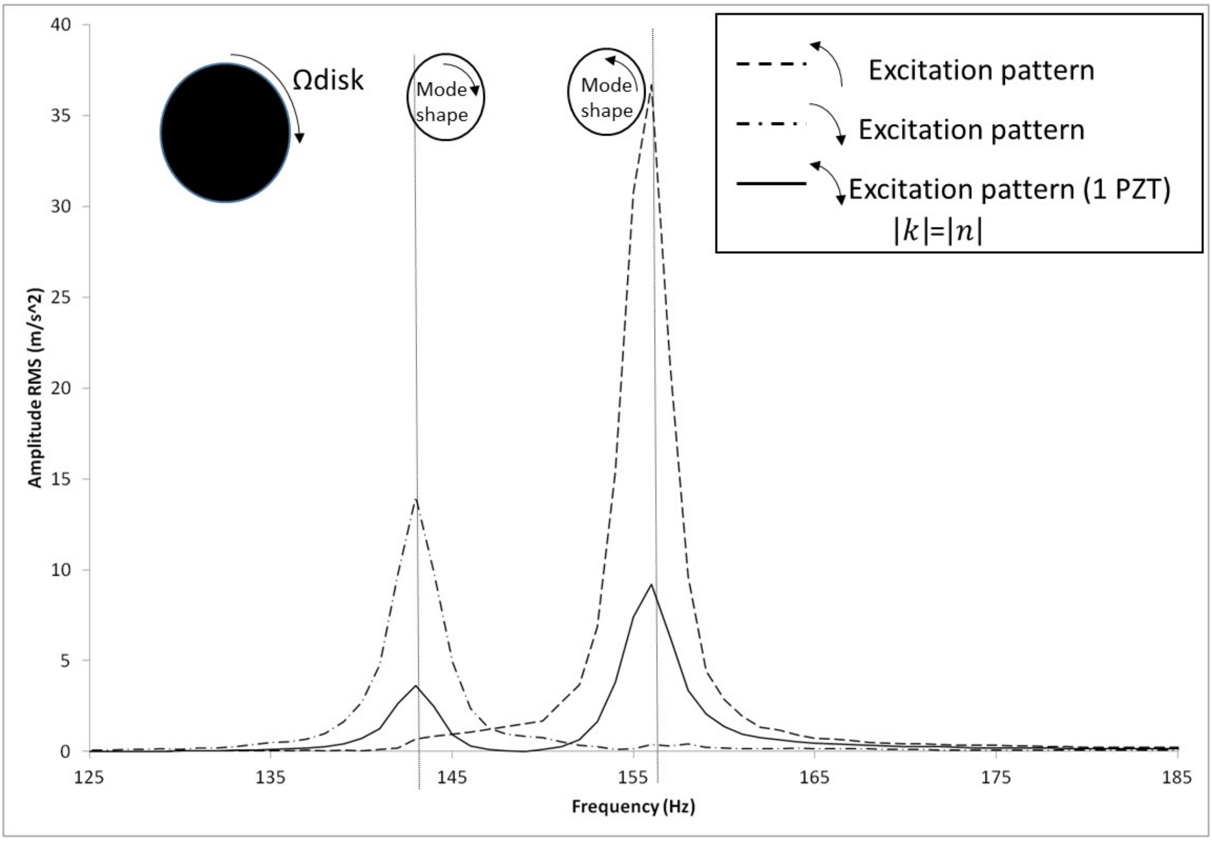

Fig.2: Excitation of the disk around the resonances n=±2

As shown in this figure, with one patch both resonances are excited, which confirm the results obtained in [7]. Nevertheless, when the excitation has a spinning direction, only the structural mode that has the same direction than the direction of the excitation is excited. Other excitation shapes (different number of excitation) do not excite the disk. For the mode $n=3$ the conclusions are equivalent.

6. CONCLUSION

In this paper a rotating disk confined and submerged in water has been excited with several excitation patterns that simulate the RSI.

Firstly, it has been shown that, viewed from the rotating frame, the disk has two natural frequencies for each mode shape in the standing case. The first one is a travelling wave rotating in the same direction than the disk and the second one in the opposite direction.

Secondly, a rotating excitation k excites only the natural frequency corresponding to the structural mode shape with same number and spinning direction. Other excitation numbers or spinning direction do not excite the disk.

As a consequence of these two conclusions, if an excitation shape rotates in the same direction than the rotating direction of the disk-like structure the resonance will occur at a lower frequency than the natural frequency of the standing structure (if the excitation shape coincides with the structural mode shape). If the excitation rotates in the opposite direction the resonance will occur at a higher frequency.

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8. REFERENCES

[1] Y. Kubota, H. Ohashi, A study on the natural frequencies of hydraulic pumps, 1st ASME Joint International Conference on Nuclear Engineering, (1991) 589-593.

[2] A. Presas, Analysis of the dynamic behaviour of rotating disk-like structures submerged and confined, in: C. Universidad Politécnica de (Ed.), Universitat Politècnica de Catalunya, 2014.

[3] J.A.N. Hengstler, Influence of the Fluid-Structure Interaction on the Vibrations of Structures, ETH Zurich, Zurich, 2013.

[4] E. Egusquiza, C. Valero, X. Huang, E. Jou, A. Guardo, C. Rodriguez, Failure investigation of a large pump-turbine runner, Engineering Failure Analysis, 23 (2012) 27-34.

[5] X. Huang, Contribution to the Dynamic Response of Hydraulic Turbomachinery Components, CDIF, UPC, Barcelona, 2011.

[6] A. Presas, C. Valero, X. Huang, E. Egusquiza, M. Farhat, F. Avellan, Analysis of the dynamic response of pump-turbine runners-Part I: Experiment, IOP Conference Series: Earth and Environmental Science, 2012.

[7] A. Presas, D. Valentín, E. Egusquiza, C. Valero, U. Seidel, Experimental analysis of the dynamic behavior of a rotating disk submerged in water, IOP Conference Series: Earth and Environmental Science, 2014.

[8] H. Tanaka, Vibration Behavior and Dynamic Stress of Runners of Very High Head Reversible Pump-turbines, International Journal of Fluid Machinery and Systems, 4 (2011) 289-306.

[9] C. Nicolet, N. Ruchonnet, F. Avellan, One-Dimensional Modeling of Rotor Stator Interaction in Francis Pump-Turbine, 23rd IAHR Symposium - Yokohama, (2006).

[10] R. Belvins, Formulas for natural frequency and mode shape, Krieger Publishing Company, 1984.

[11] A. Presas, D. Valentin, E. Egusquiza, C. Valero, U. Seidel, Influence of the rotation on the natural frequencies of a submerged-confined disk in water, Journal of Sound and Vibration, 337 (2015) 161-180.