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Experimental investigation on the effect off near walls on the eigen frequency of a low specific speed francis runner

Petter T.K. Østby [a,b,*], Kjell Sivertsen [a], Jan Tore Billdal [a], Bjørn Haugen [b]

[a] Rainpower Norge AS, 2027 Kjeller, Norway
[b] NTNU, Richard Birkelands vei 2B, 7491 Trondheim, Norway

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A B S T R A C T

The importance to correctly predict the natural frequency of a turbine runner have been demonstrated several times. It is now common practice to include the added mass effect of the surrounding water when calculating the natural frequencies. In this paper the added mass effect of water on a simplified low specific speed francis turbine runner is experimentally investigated. Three cases are investigated. 1: The runner hanging in air. 2: The runner hanging in a tank of water. 3: The runner installed into the turbine housing. The measurements reveal a frequency reduction of about 40% when the runner is hanging in water. Installing the runner into the turbine housing does not significantly change the natural frequency of the main blade modes. Modes which vibrate heavily on the outside of the runner are visible in the water tank but becomes dampened when installed into the turbine housing.

1. Introduction

The importance to correctly predict the natural frequency of a turbine runner have been demonstrated by several authors [21,5,4]. Some turbines have failed very quickly due to resonances in the runner. The 250 MW Svartisen A1 turbine failed in only hours after being put in operation [11]. It is now common practice to include the added mass effect of the surrounding water when calculating the natural frequencies.

Nearby ridgid structures are known to increase a fluids added mass and thereby reducing the eigen frequency of the oscillating structures. Fritz [7] showed that the added mass is inversely proporsional to the clearance between a cylinder and a rigid outer wall. Rodriguez et al. [15] showed that for a thin plate submerged in water both the plate thickness and distance from nearby walls affect the added mass effect, while also showing that numerical models can predict this effect on simple structures. Bossio et al. further expanded on the numerical calculation of a disc submerged in water [3]. This is especially important for hydro turbines where the relative clearance (clearance divided by seal radius) between the runner and the surrounding components in the seal areas are in the range of 0.1%. Tanaka [18] showed through experiments that reducing the clearance radially and axially on a high head pump turbine reduce the eigen frequency of the runner. Valentín et al. [22] showed numerically a clear reduction of the natural frequencies of a low head Francis runner as the gaps around the runner was reduced.

* Corresponding author at: Rainpower Norge AS, 2027 Kjeller, Norway
E-mail address: petter.oestby@rainpower.no (P.T.K. Østby).

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Whether or not the a runner will be affected by the nearby walls is dependant on the shape of its eigen modes. These mode shapes will differ between runners of different designs. Several authors have published mode shapes of actual Francis and pump turbine runners with different specific speeds. [23,10,8] The overall trend seems to be that low head runners have more radial motion on the runner band near the outlet, while high head runners have larger disc like mode shapes. These runners may thus be affected differently by the walls.

In this article, the effects of water and covers are experimentally investigated on a simplified low specific speed runner. The effects are evaluated for the first harmonics of the different nodal diameters of a high head runner. The novelty of this article is the measurement of the runners natural frequency while installed in the turbine housing. This article may provide some insight to the questions asked by Trivedi [21,20]; how the runner housing influences the natural frequencies and damping of a turbine runner. Further, the excitation method, controlling which nodal diameter to excite, is new. At least for hydro turbine runners. The results are then compared to the numerically calculated values using commercial software.

2. Experimental setup

The experiment was conducted in Rainpowers Turbine Laboratory in Trondheim, Norway.

2.1. Geometry

The geometry tested is based on a real low specific speed hydro turbine runner ($N_{QE} = 0.066$) with some simplifications to the blade design. It is scaled to a model size with a outlet diameter (D_2) of 300 mm. The runner is made of 6 full blades and 6 splitter blades and is CNC machined out of a single block of stainless steel. Model turbines are often made with bolted connections between the runner vanes and the hub/shroud. Fabricating it from a solid block removes uncertainties due to such bolt connections. See Fig. 1 for a cross section of the runner.

$$N_{QE} = \frac{nQ^{0.5}}{(gH)^{0.75}} \tag{1}$$

Each vane is a straight foil placed vertically between hub and band. Each 8.3 mm thick near the inlet and taper down to 4.0 mm at the trailing edge. Both the leading edge and trailing edge is profiled with a smooth hydraulic profile and the blades have a 2 mm fillet towards hub and band. The full and splitter blades have cord length 184.7 mm and 93.9 mm respectively. The geometry resemble the simplified model in which Huang et al. [9] investigated the added mass effects of water.

To test the effect of water on the resonance frequencies of the runner, three different experimental setups were used. First, the runner was suspended on chains hanging in air. In the second test series, the runner was still hanging on the chains but submerged in a tank full of water, as shown in Fig. 2. Only one runner position in the tank was tested. The last test was performed with the runner installed in the water filled turbine housing. A Francis turbine has regions on the outside of the runner called labyrinth seals, where the clearance towards the stationary covers is small. This is done to limit the flow going around the runner. For this turbine the radial clearances towards the stationary seals were 0.17 mm and 5.4 mm towards the upper and lower cover, as shown in Fig. 2 and Fig. 3.

2.2. Excitation

Each full vane is equipped with two Piezoelectric pads, one which excites the vane and one which senses the vibrations. Both pads are glued into cavities machined into the runner vane and covered with epoxy. The setup is similar to the setup used by other authors investigating added mass and damping of submerged structures [17,24,2].

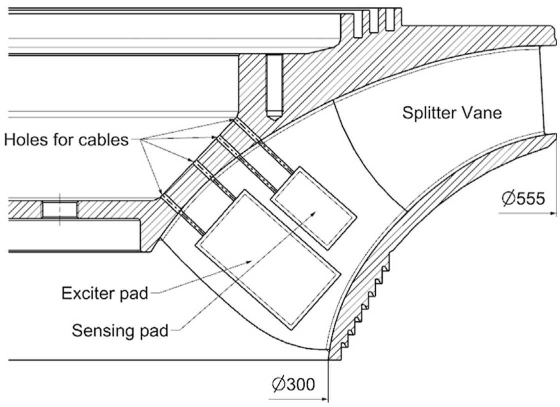

Fig. 1. Runner Cross Section.