On variations in turbine runner dynamic behaviours observed within a given facility

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Abstract. When confronted with cracks or high stresses in turbine runners, we often wonder if the behaviour observed on one specific runner will be present on all other similar runners. In this case, we have a facility with 19 runners having the same blade geometry. In order to answer the question, we selected three runners for measurement campaigns. First, the runners were divided in groups using band length, materials and wicket gate geometries. We then examined two runners with different wicket gate geometries and were thus able to explain why one runner exhibited recurrent fatigue damage problems and not the other. However, even within a given group, significant reliability differences were found when comparing with a third runner. The observed data shows that an important turbine characteristic was overlooked. Our conclusions point toward eccentricities and imperfections in the discharge ring attributable to only the upper part of the labyrinth seal being refurbished in this facility. This may generate a significant imbalance in the force produced by the flow in the runner side chamber. The paper underscores the impact of such imbalance, which could be present in older refurbished facilities.

1. Introduction
It is generally believed that turbine runners having similar geometries will exhibit similar behaviour in terms of fatigue life and overall reliability. Yet, historical maintenance data collected from a large run-of-river generating station at Hydro-Québec shows that not all turbines exhibit the same behaviour. This phenomenon has puzzled the maintenance staff for some time. By studying all turbine characteristics rather than just runner geometries, seven different turbine groups were identified within the 19 Francis turbines in this facility. Note that all the runners have the same blade profiles but, because of some of this facility’s specificities, they require different runner band lengths resulting in a different blade overhang. We also considered that some runners are manufactured in different materials and have different wicket gate geometries.

To understand the dynamic behaviour of these different turbines, strain measurements were carried out on 3 of the 19 Francis runners in the facility. The first runner, Runner A, was chosen from within a very reliable group that exhibits no fatigue cracking. The second, Runner B, was chosen from within a group prone to fatigue cracking. The third, Runner C, was chosen from within the same group as Runner B, but it has historically exhibited significantly more fatigue damage.
2. **Comparison between Runner A and Runner B**

As previously mentioned, Runners A and B belong to two different groups of turbines having the same blade profiles. They differ in term of materials, band lengths and wicket gate geometries. The differences between these two runners in terms of dynamic behaviour were first exposed in a previous study by Gagnon et al., 2017 [1]. The conclusions of this study showed that the differences in dynamic behaviour were mainly attributable to wicket gate geometries that generated much more rotor-stator interactions (RSI) during operation for Runner B, as shown in Figures 1 to 3. Often, small differences in wicket gate geometries are neglected by maintenance staff. However, the impact of such differences was obvious from a hydraulic standpoint and was later confirmed using numerical simulations. Notice that for all the runners, the strains measurements were taken at the same critical location, known from prior finite element analysis (FEA).

![Figure 1. Measured strain on Runner A (left) and Runner B (right).](image1)

![Figure 2. Measured dynamic strain at maximum opening on Runner A and Runner B (right).](image2)

Nonetheless, an important characteristic of the dynamic behaviour of Runners A and B could not be explained by the difference in wicket gate geometries. If we look at Figure 3, we can see an imbalance in the strain distribution over one rotation. While this imbalance is slightly different for each runner, it was not deemed to be important during our previous study [1] as the amplitude was similar on both. As we will see below, this is not the case for all runners.
Figure 3. Strain synchronous average at maximum opening for Runner A (left) and Runner B (right) with an arbitrary static strain of 100 microstrains used for comparison purpose.

3. Comparison between Runner B and Runner C
One of the characteristics of the imbalance observed on Runner B is that if the RSI is neglected, the amplitude does not change significantly with the opening of the wicket gates. Given that this imbalance was not significantly different in Runners A and B, similar results were expected for Runner C. However, the measurements obtained for Runner C proved to be much larger than expected, as shown in Figure 4.

Figure 4. Measured dynamic strain at SNL on Runner B (left) and Runner C (right).

Looking at the synchronous average in Figure 5, the highest deformation observed is always at the same angular position during the rotation, and this position is identical for measurements made on two different blades. The difference between Runners B and C is attributable to a localized imbalance that does not change significantly with the opening of wicket gates and cannot be explained by any of the characteristics that were used to differentiate the runners in this facility. Furthermore, the difference is quite significant, such that it fully explains why Runner C always exhibited more fatigue damage than Runner B.
4. Discharge ring and runner dynamic behaviour

The source of this imbalance was not obvious, and a review of the work by Doerfler et al., 2013 [2] helped us to identify two potential imbalances, both linked to some form of casing asymmetries. The first is attributable to asymmetric flow in the spiral case. Here, we have an old facility for which such asymmetry might be expected. However, by examining the average pressure distribution at maximum opening for Runners A and B in Figure 6, we found no correlation with the imbalance observed in the strain measurements presented in Figure 3. Furthermore, if the imbalance stems from the flow, the amplitude should change with the opening of the wicket gates, which was not observed in this case.

The second type of imbalance is related to the flow in the side chamber adjacent to the runner. This chamber is just below the labyrinth seal at the band and is formed by the gap between the runner band and the discharge ring, as shown in Figure 7. Here, the original design of the facility is presented, but the refurbished runners do not have a fretted ring at the band, leaving a significantly larger gap. During refurbishment, only the labyrinth seal was machined and rebuilt as it was believed that a larger gap would provide more tolerance for imperfections and eccentricities.
The main characteristics of an imbalance related to flow in the side chamber are localized angular position, unaffected by the flowrate, and amplitude, which scales proportionally to the square of the rotating speed. We easily confirmed the first characteristic, but the second could not be verified because of the nature of the measurement campaign that did not include constant over speed measurements. Figure 8 shows a simple numerical simulation to illustrate the phenomenon. Here, the rotating cylinder represents the runner operating in an ovalized and slightly eccentric cavity. The result is a significant imbalance in the force acting on the cylinder with a maximum located where the gap is minimal due to flow acceleration.

5. Conclusions
The strains and pressure measurements on three runners were compared and numerical simulations were used to explain the different dynamic behaviour linked to recurrent fatigue damage on certain runners in the facility under study. Understanding the nature of this variability proved to be important for future refurbishment projects. Usually, only the labyrinth seal at the top of the discharge ring is refurbished in order to align the runner with the generator. Because the gap between the band and the discharge ring is generally large, this area is usually considered tolerant to eccentricities and imperfections. Strain measurements at the same location on three runners demonstrated that such a presumptive belief might be false and the cause of significant strain fluctuations leading to recurrent and extensive fatigue damage. Furthermore, such differences in dynamic behaviour might also be
present and overlooked in many other facilities, hence the importance of better understanding the many factors that influence the behaviour of a specific runner.

References

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