Development of an Acoustic Emission Test for the Detection of Anomalies in Hydroelectric Generator Stator Bars and Coils

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1 Introduction

To meet the ever-increasing demand for electricity, Hydro-Québec (HQ) is seeking to simultaneously increase the power of its generating stations while improving its service quality. HQ's research institute (*l'institut de recherche d'Hydro-Québec* - IREQ) has been tasked to investigate innovate methods to meet the aforementioned goals. Of interest in the current study, is the development of improved quality control (QC) to more objectively quantify the results obtained from the commonly used "Tap Test." Such methods must detect anomalies found between the insulation layers of stator bars and coils as these anomalies can result in partial discharges, which reduce the service quality of hydroelectric generators.

2 Test samples

Hydroelectric generators are either wound using roebel bars or multi-turn coils depending on the design. Bars/coils consist of copper strands and an insulation system comprised of five components : i) strand insulation, ii) inner-corona protection, iii) groundwall insulation (glass epoxy mica paper), iv) turn insulation (used only in coils), and v) outer-corona protection (or semiconducting slot coating-SSC). Like most composites, such insulation systems are subject to several types of anomalies including cavities or delamination between the insulation layers, and/or decohesion between the insulation and copper strands [1]. The aim of this study is thus to detect the most critical anomalies that will shorten the life expectancy of the stator bars or coils.

Two individual stator coils (C186 and C196) with deliberately introduced localized anomalies and a one stator bar (B156) were used to benchmark the detection methods of this study. The anomalies (identified X and Y) that were introduced within the groundwall insulation of each coil sample (C186 and C196) were amplified when compared to what is generally observed to facilitate their detection. Anomaly X consisted of inserting a machined epoxy cavity within the groundwall insulation of test sample C186. Anomaly Y consisted of inserting a significant delamination between the layers of the groundwall insulation of test sample C196. The results obtained on coils C186 and C196 were compared to an "ideal" bar (B156) to serve as a baseline for the detection methods. Bar B156 was considered as an "ideal" sample since partial discharge (PD) measurement revealed very low activities corresponding to the presence of little to no anomalies.

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3 Experimental Method

In the early 1980s, the tap test was commonly employed to detect anomalies found in composite materials utilized in the aviation industry [2,3]. Such tests are still being used today in the stator bar/coil industry [4]. Tap testing consists of an operator tapping a small metallic object (*e.g.* a coin) across the surface of a test piece in the goal of listening for a 'dead' (*i.e.* low frequency) sound corresponding to an anomaly [2–5]. However, such tests are subjective, and thus more quantitative impact testing methods have been proposed [3,5]. Efforts have been made to apply such methods to the stator bar/coil industry and this work is a continuation of those efforts [4].

The experimental method proposed in this study is an adaptation of the tap test, which consists of utilizing an instrumented striker [3]. The striker consists of a solenoid with a force gauge and steel striking tip attached at one end with retention springs on the other end to ensure the striker returns to its original position. The striker then impacts a given location across the straight portion of the bar/coil and this process is repeated from end-to-end of the test sample. To perform this test in an automated fashion a test bench was constructed, which consisted of an aluminium structure allowing the test samples to rest in a simply supported manner, and a motorized rail to systematically position the instrumented striker from the test sample. Furthermore, the test samples and test zone were instrumented with an accelerometer and several microphones, as illustrated in Fig. 1.

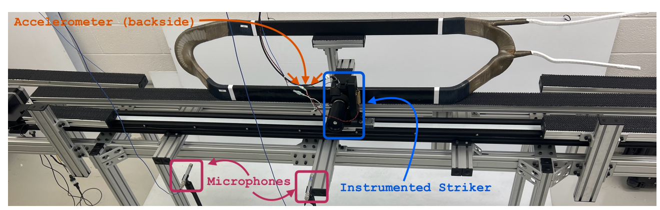

Figure 1 – Testbench utilized for anomaly detection on bars/coils using both impact and vibro-acoustic emissions tests

4 Anomaly detection methods

Two anomaly detection methods are proposed : i) impact time series analysis and ii) frequency analysis of both structure borne vibrations and acoustic emissions. For the former, the impact force and duration obtained from the instrumented striker were measured at each impact position along the stator bar/coil and compared. For the latter, an accelerometer attached to the backside of the bar/coil to measure the impact-generated structure borne vibrations and two microphones were positioned one meter from the test samples to measure the impact-generated acoustic emissions. Thus, both structure borne vibrations and acoustic emissions were analyzed during each impact with the striker allowing for the simultaneous investigation of both detection methods. Impacts in 10 mm intervals were considered assuming that the structure is identical from one interval to another, as the difference between an ideal zone and a defect zone is a shift in natural frequency and damping due to a change in local rigidity.

5 Results of the force and impact duration

In Figs. 2(a-b), both the force and time signatures over the normalized position (*i.e.* impact position over the total length of the sample) at each impact for the samples are shown. Nearly constant impact force and delay values are observed in the signature of the ideal bar (black curve), which confirms the similarity in the structure's rigidity between impact intervals when no defects are present. However, in the force signature of coil C186 (green curve) shown in Fig. 2(a), a lower amplitude zone is present between 0.50-0.55 highlighting the cavity zone. Moreover, a zone of lower amplitude in the force signature of coil C196 (blue curve) is also present between 0.024-0.23 highlighting the delamination zone. A similar effect is also present for both impact delay signatures where an increase in impact duration is present in both the delamination and cavity zones.

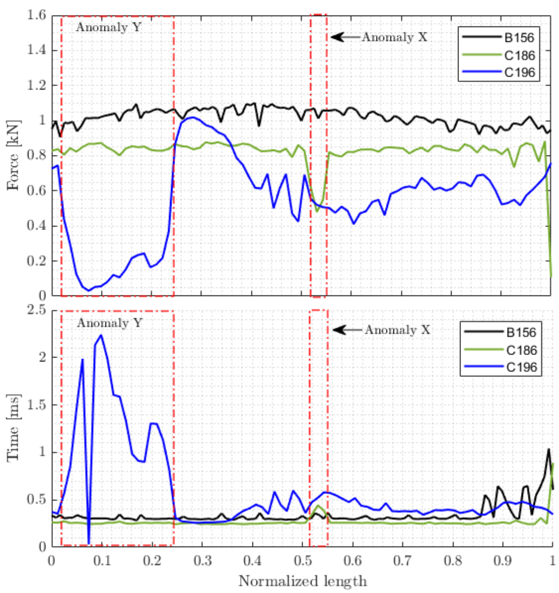

FIGURE 2 – (a) Force and (b) impact duration over the normalized length of the ideal bar (B156) and coil samples (C186 and C196).

6 Results of the natural frequencies

In Figs. 3(a-c) contour plots of the log-amplitude of the frequency response of the structure borne vibrations at each position along the sample for the ideal bar and both coils samples (C186 and C196) are shown. Similar to Figs. 2(a-b), no variations between each position are shown for the ideal bar in Fig. 3(a). However, a shift in natural frequency is highlighted between 0.50-0.55 (Fig. 3b) and 0.024-0.23 (Fig. 3c) for the cavity and delamination zones, respectively. Similarly, contour plots of the log-amplitude of the frequency response of the acoustic emissions from the left-most microphone obtained from impacts at each position along the sample for the

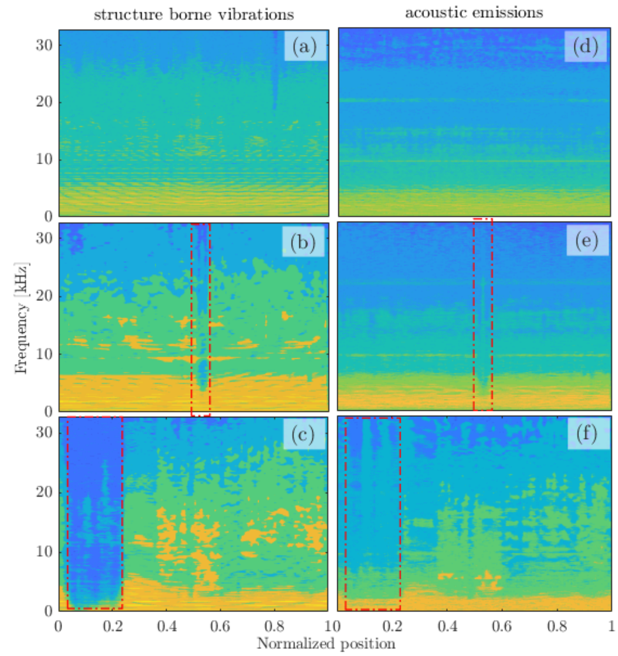

FIGURE 3 – Log-amplitude contours of the frequency response of both structure borne vibrations (a-c) and acoustic emissions (d-f) for (a,d) the ideal bar B156, (b,e) coil C186, and (c,f) coil C196 over their normalized position.

ideal bar (B156) and both coils samples (C186 and C196) are shown in Figs. 3(d-f). In the same aforementioned regions (0.024-0.23 and 0.50-0.55) where both anomalies (X and Y) are present, a shift in natural frequency is observed.

7 Conclusions

Both methods (impact time series analysis and frequency analysis of both structure borne vibrations and acoustic emission) were capable of identifying cavities and delamination within the test samples. However, more investigations are required on samples with more realistic anomalies to evaluate each methods effectiveness in automatically identifying defects of varying sizes and locations to generalize any potential anomaly identification/classification method.

Acknowledgments

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