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Calibration of blade tip-timing sensor for shrouded 40″ last stage blade

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ABSTRACT

Today's power generation market requests steam turbines of high efficiency, reliability and wide operation range. The last stage moving blades are designed with integral shroud, mid-span, and fir-tree dovetail. The blades are continuously coupled by the blade untwist due to the centrifugal force, and thus the vibration control and increased structural damping are provided. Unfortunately this shroud complicates the blade vibration measurement using contactless methods. This paper describes in detail the Blade Tip-Timing measurement and calibration provided in test rig and in steam power station where the new eddy-current and optical sensors were used together to measure blade vibration in various conditions. Detail calibration procedure for Blade Tip-Timing sensors will be presented as well as the results of the measurements and comparison to FEM Maxwell calculation and to FEM stress analysis.

1. Introduction

Since 1999 Doosan Skoda Power has been interested in Blade Tip-Timing. First Blade Tip-Timing system (BTT) was installed in power station Prunerov II [11,12] where free standing blades were installed. At that time the main focus was on synchronous vibrations and first installation of BTT system itself.

In 2008 after 10 years of smooth operation of a steam turbine with large output power there was an accident during the turbine run-up. One of rotating blade fell off. All 6 LP rotors (two machines) were checked and many cracks on the L-1 blades were found. Tip-timing measurement was installed on two L-1 stages to monitor and protect the blades [10]. The new age of Tip-Timing in Doosan Skoda Power has begun as well as the age of new contact elements (shroud, snubber).

In 2009, a new 48″ steam turbine last stage blade (LSB) was developed by Doosan Skoda Power [2–4] and in 2013 a new 54″ LSB for 3000 RPM was developed with applying of new design features [5,13]. Using modern computational instruments, airfoils with high flow efficiency were designed. The successful detuning of natural-frequencies with respect to the harmonics of rotational frequency has been achieved for both blades by using interconnecting elements near the mid-span and at the tip of the blades. The forces among the contact elements result from the constraint of the blade untwisting induced by the centrifugal force. The mechanical properties of LSBs were measured under rotation in the Cambpell testing rig. It was proved that blades are out of synchronous resonances up to 7th harmonic frequency.

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The first BTT installation in 1999 was performed to monitor the natural frequency of the blades, because the numerical frequency tuning was quite demanding task that time. The synchronous excitation was the cause of blade vibration when the natural frequency was close to this excitation frequency. On the other hand, nowadays the asynchronous vibrations seem to be a bigger problem because of hardly expected phenomenon like a flutter, that is more common for high loaded blades.

The synchronous excitation is the most common excitation in terms of the steam turbine blades. This excitation is closely related with the circumferential asymmetry, blade passing, unbalance etc… On the other hand, resonances with non-synchronous excitation can occur by an aerodynamic excitation. To avoid it is a quite demanding task, because even very small aerodynamic excitation forces with wide frequency range can excite the blades if the damping is insufficient. Large vibrations during the ventilation conditions were presented several times as well as the unstalled flutter observation during power output increase [10]. The 3D unsteady CFD methodology under ventilation condition was published by Megerle in 2012 [1]. Rotating aerodynamic excitation was measured and confirmed by CFD code, unfortunately cells motion are still uncurtaining in numerical prediction. Previous study made by Shnee in 1974 shows that there is a dynamic stress 2–3 times larger in the range of 30–60% of the nominal volume flow.

To avoid unpredictable excitation, dynamic stress and reduction of blade lifetime, it was decided to measure blade vibration during a wide operation condition range in the power station because mechanical stress reduces service life of rotating blades.

Damage of the blades causes changes in their frequency characteristics, which are measured using a contact or contactless method. The contact measurement by strain gauges provides direct information about the blades stress during the whole revolution [6]. However, this method is not suitable for long-term measurements, because the sensor service life is short in a corrosive environment. Furthermore, it is very difficult and expensive to monitor all blades of the bladed disk.

Noncontact measurement methods based on the analysis of time differences between blade tip passages are used for the blade vibration measurement – blade tip-timing. This method was firstly used in 1970's. The manufacturers use abbreviations NSMS (Non- Intrusive Stress Measurement System), BSSM (Berührungslose Schaufelschwingungsmessung) or usually Blade Tip Timing. The BTT method is a cheaper alternative with a long-term instrumentation in comparison with the strain gauges which offer a direct measurement of the blade stress but with a very short instrumentation lifetime. The BBT approach is based on the sensors which are located circumferentially around the stator and in the plane of the bladed wheel. This arrangement enables the measurement of the blade tip passages. The system measures and analyzes the time differences of blades passing around the sensor position. The sensor itself is placed very closely to the blades (order of ones-tens of millimeters depending on the technology of the sensor), to be able to interact with the passing blade fast enough and with the proper sensitivity. The passing blade generates a pulse on the output of the sensor which is captured by the high resolution time counter. All the data or timestamps are analyzed and blade vibration information is provided as the output of the system.

The contactless method BTT is based on the measurements using sensors oriented radially on the circumference of the stator above the rotor blades [7–9]. The time instances of blade tip passages under the sensors are analyzed. Changes of the frequency characteristics, which are associated with normal blade wear and tear, are reflected very slowly. We cannot measure these changes using conventional methods. In contrast, immediate blade damages are manifested by rapid changes, which enforce the immediate shutdown and repair of the turbine.

It is important to monitor the blades frequency characteristics, during the turbine run-up, run-down and power changes. The measurement of vibrations gives us the information about the blade deflection and blade residual lifetime. Based on this information, we monitor the state of the blades and other parts of the turbine. The long-term measurement of the blade deflections is important for the planning shutdowns and optimization of the cost of maintenance and operation of the turbine.

The blade deflections are determined by the difference between the real and expected passage times of the blades under the sensors. The deflection of the specific blade is sampled once per revolution. An antialiasing filter cannot be used in the measurement chain, because the turbine rotation frequency is in fact the sampling frequency of the blade rotation movement and furthermore, the rotation speed changes. For these reasons, the vibrations of the specific blade are measured in the limited frequency bands with lot images of higher frequencies and the low frequency resolution. Increasing the number of sensors does not often bring results adequate to expended resources.

Instead of single blade behavior analysis, the behavior of the whole bladed disk could be analyzed. The deflections are sampled by the passages of all blades. Then, the width of the frequency band is sufficient and the aliasing effect is not contained in the signal. The all-blade spectrum, which is the spectrum involving all blades of one disk, is calculated for each sensor from deflections measured for all the blades passed under the sensor using the short-time Fourier transform. Consequently, cross spectra are calculated from the couples of the all-blade spectra from different sensors.

Nevertheless the single or all blade spectrum cannot be used when the input signals are not at high quality. To obtain correct information on vibrations of shrouded blades, it was necessary to develop reliable measuring equipment for the shrouded blades. The key factor was indicated to be using of adequate sensor and determination what part of blade shroud is measured.