Development of Compressor Blade Prognostics and Health Management for Large Gas Turbine Engine

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ABSTRACT

DOOSAN has been developed large gas turbine since 2014 as a national project in Korea. Recent researches showed that one of major risk item in gas turbine development is compressor rotor blade failure. There are several events of compressor rotor blade failure which have occurred over the last few years, in some cases causing catastrophic damage to the entire compressor. In response to these issues, DOOSAN started to develop compressor monitoring system to prevent failures and diagnose blades to assess the structural integrity of each blades. This paper presents the ideas and plans how DOOSAN will develop the system with latest sensors. Additionally, validation methods will be presented using sub-scaled test rig in 2018 and real scale engine test in 2019, respectively.

1. INTRODUCTION

A gas turbine for power generation consists of a compressor used to supply compressed air, a combustor used to burn compressed air with fuel and a turbine used to convert the expansion of high-pressure, high-temperature combustion gas into rotational force to produce electricity. Doosan successfully completed developing of 5MW gas turbine in 2011 and has started developing 270MW class large gas turbine as national project since 2013. The gas turbine has high-flow, high-efficiency compressors, low NOx combustors and high-temperature, long-life turbines applicable to the gas turbine market where large-sized, highly efficient gas turbines capable of using multiple types of fuel increasingly gain popularity. Detailed design has been finished and several component tests such as compressor rig test, full scale engine test are under preparation to validate performance, structural integrity and life to meet requirements. Figure 1 shows the 3D whole engine model with locations of main components and main specifications of Doosan's gas turbine engine are shown in Table 1, respectively.

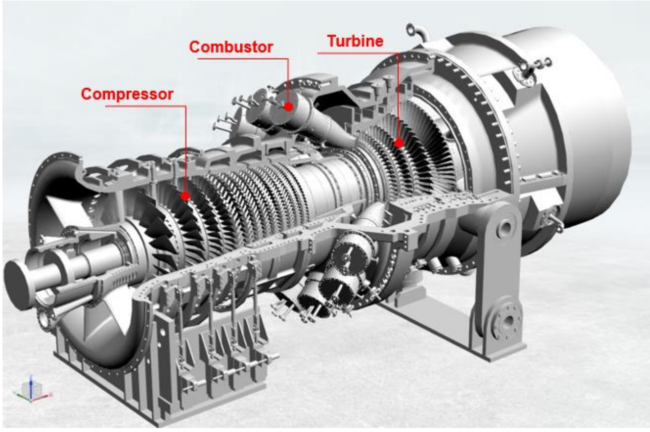

Figure 1. Doosan 270MW class gas turbine 3D model.

Table 1. Specification of Doosan's gas turbine engine.

Item	Specifications
Efficiency	40% ↑ (Simple cycle)
	60% ↑ (Combined cycle)
Environment	NOx 15 ppm, CO 10 ppm ↓

1st stage of compressor blade is considered to be critical component because it has largest size, mass and heavily loaded. HCF (High Cycle Fatigue), FOD (Foreign Object Damage) and rubs makes blade liberation and could cause significant secondary damage for gas turbine engine. Figure 2(GE, 2012) shows the example of a gas turbine compressor blade liberation followed by extensive secondary damage.

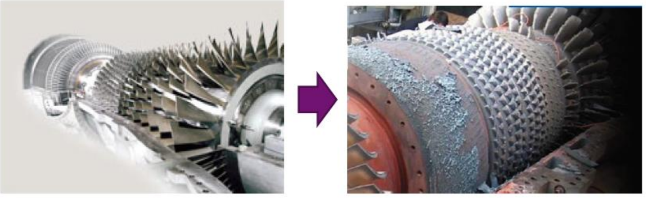

Figure 2. Examples of compressor blade secondary damage.

To prevent such a damage, compressor health monitoring system is required to mitigate unexpected downtime which causing power plant losing millions of dollars.

2. COMPRESSOR PROGNOSTIC AND HEALTH MANAGEMENT

Figure 3 shows the schematic process of developing blade's PHM(Prognostics and Health Management). It is basically based on physics-based-approach and therefore, various and sufficient database will be required to maximize accuracy.

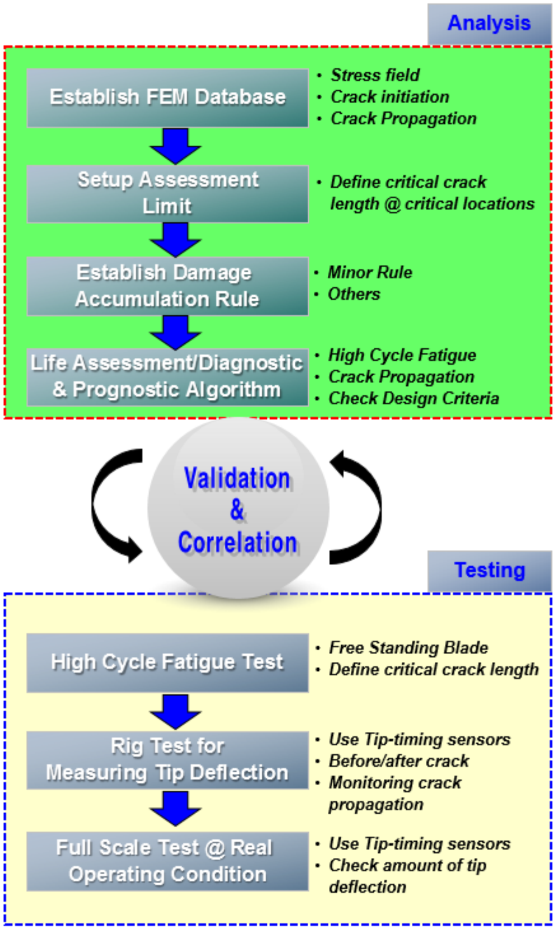

Figure 3. Schematic process of developing PHM of blades.

2.1. Tip timing method

Tip timing sensor is the fundamental enabler of the compressor health monitoring system. Tip timing sensor is suitable for measuring tip deflection by calculating blade TOA (Time of Arrival). The theoretical TOA of each blade to a sensor is defined by the sensor position, the number of blades in the compressor and the rotational speed.

$$TOA_{measure} = TOA_{expect} + \delta_{static} + \delta_{vibration} + \varepsilon \quad (1)$$

Equation (1) is shows schematically how the system calculate the time of arrival of each blade in real time. Expected TOA establishes at start of resonance and steady state condition, δ_{static} measures static deflection, $\delta_{vibration}$ checks dynamic deflection and lastly epsilon represent noise from signal. By filtering blade passing signal, deflections of all blades can be obtained as shown Figure 4(Garcia et al. 2016)

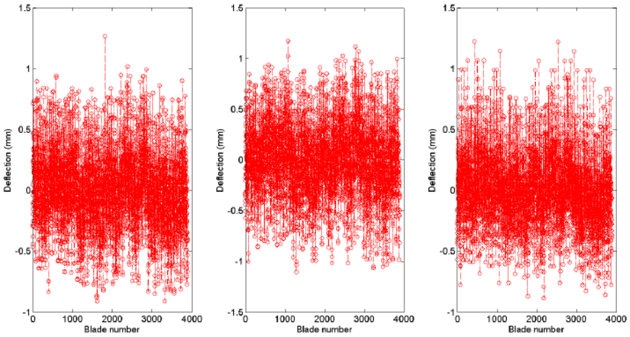

Figure 4. Examples of blade deflections through TOA.

It shows the blade deflections obtained by 3 different sensors when turbine is rotating at high rpm. Four different types of sensors are now under consideration which are optical, eddy current, capacitance and microwave sensors. During development stage, optical sensors are best suitable because it offers the highest spatial resolution but prone to signal loss due to the accumulation of contaminants. Eddy current sensors typically have the relatively lowest resolution but are suitable commercially because of lowest cost and minimal maintenance.

2.2. Crack propagation vs. Tip deflection

Minimum detectable deflection will be calculated in advance with compressor blade before selecting the type and size of the tip timing sensors(David et al. 2012). In order to check the sensitivity between crack size and deflections, quick analysis has been performed by FEM (Finite Element Model). Simple geometry has been created and arbitrary crack models has been made. Depth and width are constant and but length of crack size varies 0 to 140 mm. Figure 5 shows the geometry, crack location/size and load/boundary condition for analysis.

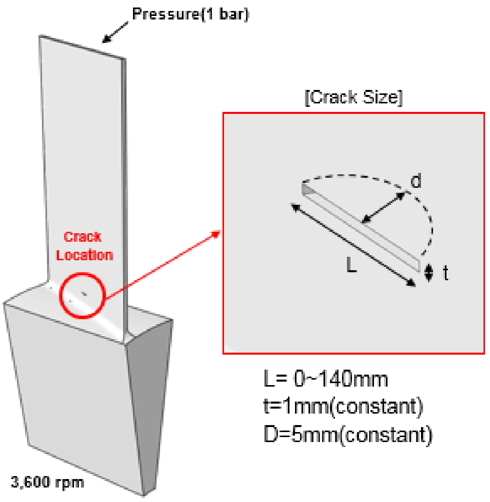

Figure 5. Simplified FE model for analysis.

Figure 6 shows the amount of deflections along with crack sizes. The results implicates that by measuring blade deflection and magnitude, crack size can be estimated and therefore, total life (before crack initiation/crack propagation) can be calculated.

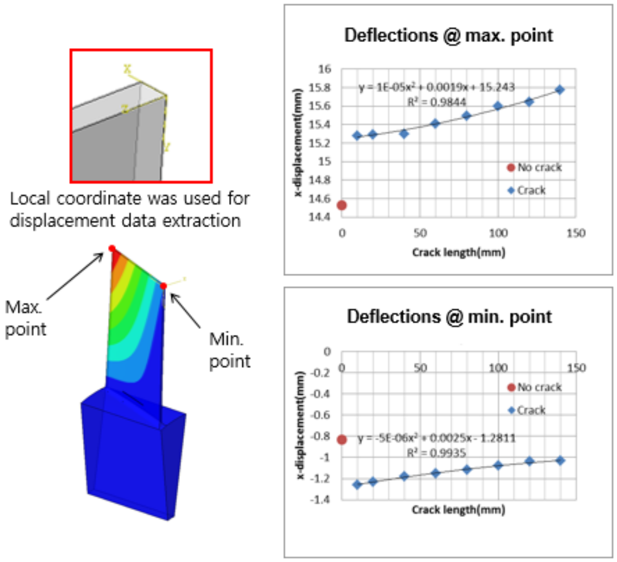

Figure 6. Deflections depending on crack sizes.

2.3. Residual life estimation

In order to create lifing tool for compressor blade, surrogate regression model will be applied. The concept of the model is similar to a one-dimensional polynomial regression, but is capable of handling non-linearity through the use of ANN (Artificial Neural Networks). Stress for crack initiation, or stress intensity factor for crack propagation, as a function of RPM, peak to peak deflection and crack size will be used for surrogate model.

2.4. Validation Methods

Validating FEM results through tests is essential to secure the accuracy of PHM for compressor blade. Three (3) tests are in preparation for validation.

1. High Cycle Fatigue Test – In order to define critical crack length, arbitrary crack size will be applied in real blade and excite at critical mode. Once it fails, number of cycles and crack size will be recorded as shown in Figure 7(Witek et al. 2015).

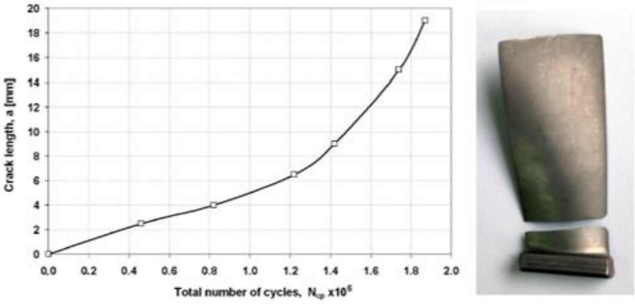

Figure 7. Number of cycle and crack sizes when fails.

2. Sub scale rig test – Scaled down compressor blade with disk will be installed in rig test and tip deflection will be measured with/without crack. Crack propagation and tip deflection will be monitored and measured until it reaches critical crack length. Results will be used for correlations. Figure 8 shows typical compressor rig test facility for one stage of compressor.

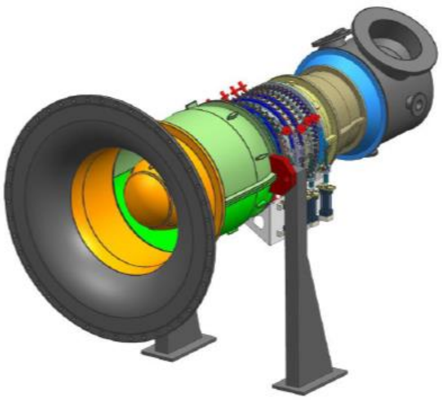

Figure 8. DHI scaled compressor rig

3. Full scale engine test – Doosan is preparing for FSFL (Full Scale Full Load) test at Changwon facility in middle of 2019. PHM for compressor blade will be installed in real scale engine and finalize the validation of diagnostic and prognostic algorithm for compressor blade. Crack propagation cannot be monitored due to the risk of failure. However once abnormal signals are

detected, engine will be stopped and examined to mitigate any failures. Figure 9 shows example of full scale test facility for gas turbine engine.

Figure 9. DHI FSFL test facility

3. CONCLUSION

The paper proposed the process to use the diagnostic data from tip timing sensors to estimate the impact of blade vibration on remaining life. FEM technique will be used to translate blade deflection and magnitude measured from tip timing into life consumption. A regression model will be used to predict blade life as a function of blade condition. Validation methods which are under preparation also introduced for validation.

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BIOGRAPHIES

Luke Park is currently a Lead Research Engineer in Doosan Heavy Industries & Construction since 20005. He had joined 5MW class gas turbine development project for five years and since then, he developed assessment method of steam generator in nuclear power plant and operational flexibility for steam turbine and boilers. His research interests are condition based monitoring system and prognostic and health monitoring system for gas turbine. He received the B.S. in mechanical engineering from Hanyang University in Korea and M.S. in aero-space engineering from ChungNam National University in Korea.

Donghyeon Hwang received the B.S.,M.S. and Ph.D. in mechanical engineering from Hongik University in Korea. He is currently a Lead Research Engineer in Doosan Heavy Industries & Construction. His research interest is fretting fatigue durability assessment in gas turbine and steam turbine blades.

Samsik Nam received the B.S. and M.S. in mechanical engineering from Konkuk University in Korea. He is currently Senior Research Engineer in Doosan Heavy Industries & Construction. His research interest is gas turbine testing and validation.