Assembly Fit-up Issue Investigation of a First Stage High Pressure Gas Turbine Rotor

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ABSTRACT

A Gas Turbine engine generates mechanical energy from a combustible fuel that could then be converted into electrical power by means of a rotating shaft as opposed to the pressurized thrust generated by a gas turbine engine. Within the different variations of gas turbine engines, the Turbofan is the configuration that is most commonly used in the commercial and military aviation field because it provides high thrust and good fuel efficiency.

A gas turbine engine can be break down onto five main modules: a) inlet/fan, b) compressor (high pressure and/or low pressure), c) combustor chamber, d) turbine (high pressure and/or low pressure), and e) outlet/nozzle. This investigation will focus on the high-pressure turbine module of a Turbofan engine, more specifically, the high-pressure Disk and Blades components.

The blades incorporate a dovetail design with surfaces that will load against parallel surfaces on the disk during engine operation to distribute loads due to the centrifugal force. These surfaces are called pressure faces. The intent of this Disk and Blade sub-assembly is to extract energy coming from the burner (compressed air mixed with fuel) and rotate the shaft that is linked to the compressor.

INTRODUCTION

This article will summarize the investigation of fit-up issues encountered during the sub-assembly of high pressure turbine blades and disk. The dovetail design of the blades incorporates 4 total pressure faces. These blades will slide in into the disk which will incorporate a similar dovetail design. This is shown on figure 1. The fitup issues occur during the installation process of blades and disk.

Each component (turbine blades and disk) is manufacture by different manufacturing sources and assembly is performed by the customer which adds up to the variables and potential factors influencing the fit-up issues.

A set of engine blades (92pcs) and Disk exhibiting this issue was made available by the customer to support this investigation. The affected hardware was segregated for detailed inspection and analyses.

Figure 1. Turbofan HPT Rotor Sub-Assembly

OBJECTIVES

The intent of this investigation is to identify the root causes and implement the corrective actions necessary to mitigate the current and any potential future fit-up issues between high pressure turbine blades and disk reported by a customer.

The corrective actions implemented here after will improve the quality of the affected products and reduce waste in the form of added cycle time during the assembly process which represents cost savings for the customer. Results will also be leveraged across multiple engine lines to prevent similar issues.

INSPECTION APPROACH

Preliminary engineering visual review of parts performed at the customer assembly facility indicated high risk of interference fit between blades and disk located along the MIN Neck region interface (see Figure 2).

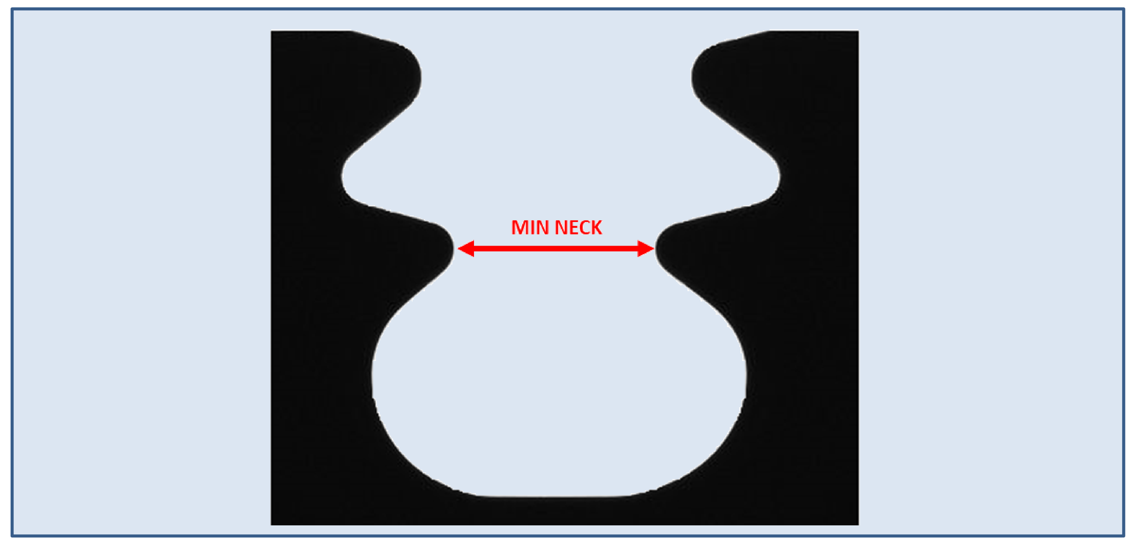

Figure 2. Disk Dovetail Sketch – MIN Neck

Historical inspection techniques were reviewed to determine the best approach to inspect the affected hardware.

Disk: Calibrated pins were selected to measure the maximum width of the MIN neck opening on the disk at all 92plc. The calibrated pins are precise to the third significant figure and provide an accurate measure for the disk

Blades: Coordinate measurement machine (CMM) inspection was concluded to be the best method to inspect blade thickness at the MIN neck region.

INSPECTION RESULTS

Inspection results for the high-pressure turbine disk are summarized on Chart 1. These shows that the MIN neck met the drawing requirements but process was targeted towards the lower end of the drawing tolerance band. However, measurements run consistently on the lower side which closes to a minimum the amount of room to install blades.

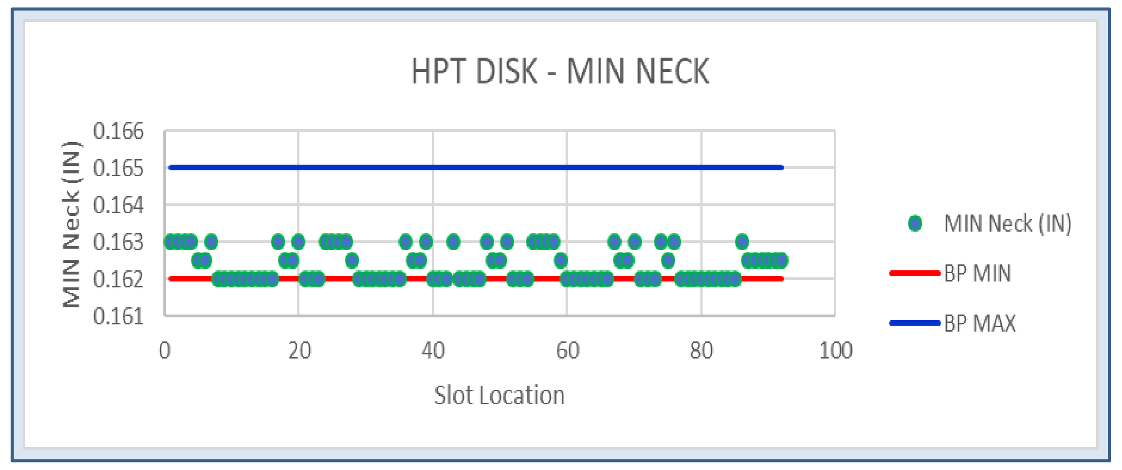

Chart 1. Disk Dovetail Sketch – MIN Neck

For the blades, results summarized on Chart 2 shows that MIN neck is conforming but running on the higher end of the drawing tolerance band. However, measurements run consistently on the higher side which closes to a minimum the amount of room for installation. Opposite to the disk, the blades were new make, meaning that they came right from the manufacturing source.

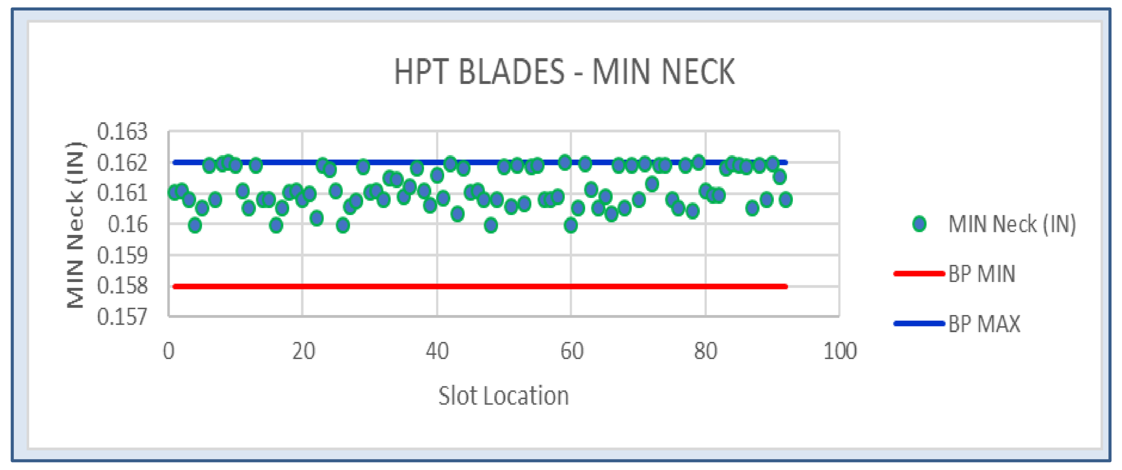

Chart 2. Blades MIN Neck Measurements. Data collected using CMM

INSPECTION RESULTS

Chart 3 shows the resultant circumferential clearance at the MIN neck region between the disk and blades (92pcs) based on the individual data collected for each component. It is evident that on many slot locations the clearance is almost zero or close to.

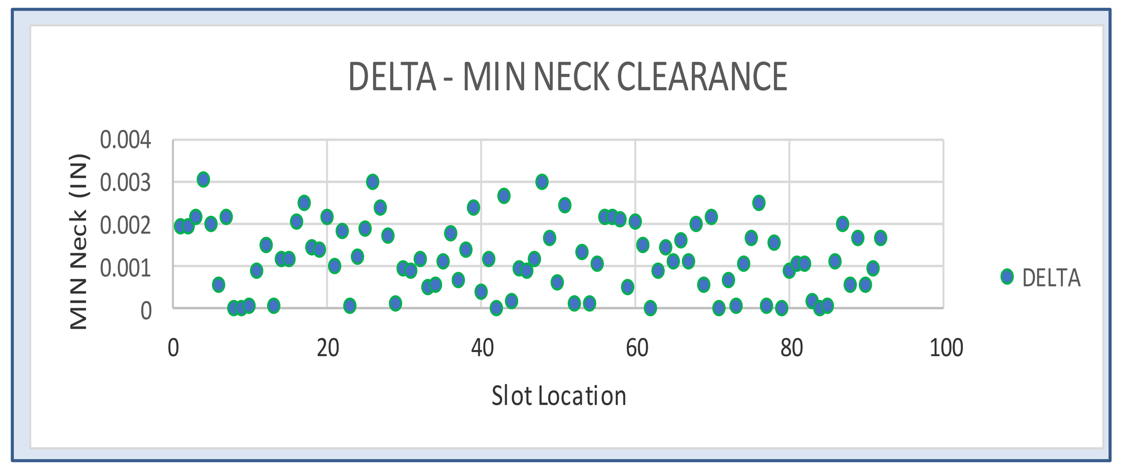

Chart 3. MIN Neck Resultant Clearance

ANALYSIS OF RESULTS

Inspection results indicated that both components met the drawing requirements and should assembled together. Looking back at the inspection results it can be seen that the fielded disk and new make blades ran at the low and high side of the tolerance band respectively. As a result, some of the disk/blade slot combinations would provide a line on line fit during the disk/blades sub - assembly and any other factors that may occur during the assembly process might contribute to the fit-up issues that were localized on this MIN Neck interface.

Customer highlighted that during the inspection of the fielded disk the pin checks exhibited a tight fit meaning that inspector had to exert some force and rotation at some slot locations to fit the pins in. Afterwards, pin checks were performed over again and measurements were identical but no force or rotation on the pins was needed. Same blades exhibiting the fitup issues were tried again after the pin checks and were successfully assembled.

Review of the cleaning process at engine overhaul showed that no detailed cleaning was performed on the MIN Neck. Lack of detailed cleaning at this location in addition to the line to line fit at the MIN neck would influence fit.

Furthermore, the engine manual instructions prevent the use of any force to install blades that are slide in manually into the disk. This means that if there is any sign friction during the installation process these are not acceptable for use and would need to be called unacceptable.

ROOT CAUSE AND CORRECTIVE ACTIONS

CLEANING: Short-term solution for potential future fitup events will be to incorporate a detailed cleaning of the MIN neck area of the disk. However, performing this detailed cleaning process require additional time that will translate into cost-in for the customer. This was determined to be acceptable on the short term until the long term fix was implemented.

DRAWING TOLERANCE STACKUP: The final fix to eliminate any future fitup events is to reduce the MIN neck thickness of the blades by 0.002in. This change will increase the current worst-case minimum clearance from line on line (0.000 clearance) to 0.002in. This minimum limit will provide adequate clearance to prevent future fitup events.

During the investigation process it was determined that the current line on line minimum allowable fit between disk and blades at the MIN Neck area is not practical and represents a risk regardless of cleaning process on the disk given that inspection techniques utilized on both the blades and disk manufacturing sources combined with the level of stackup tolerances provide room for deviations that increases risk of an interference fit.

EVALUATION

The circumferential clearance increment at the MIN Neck region will be achieved by reducing the MIN Neck radius on the blades. This change will increase the minimum clearance from line on line (0.000 clearance) to 0.0020in.

Analysis were completed following a comparative approach. The current, proposed and successful designs were compared to validate the change.

Results shows that the proposed design will exhibit P/A stresses 0.2% higher than the current design but 4.4% below legacy experience.

CALCULATIONS

CURRENT BLADE	PROPOSED BLADE	LEGACY BLADE
wt	wt	1.045 * wt
W^2	W^2	W^2
R_{CG}	R_{CG}	R_{CG}
G	G	G

Table 1. Centrifugal Force Variables

Centrifugal Force: Fc

$$Fc = \frac{wt * W^2 * R_{CG}}{G}$$

Where:

R_{CG}-Radius @ Center of Gravity

W-Rotational Speed

Wt-weight

G=Gravity

	CURRENT BLADE	PROPOSED BLADE	LEGACY BLADE
$P = .5F_C$	P	P	1.045*P
Axial Length	A_L	A_L	A_L
Circumferential Length	C_L	$C_L - 0.002$	$C_L - 0.002$
A	$A_L \cdot C_L$	$A_L \cdot (C_L - 0.002)$	$A_L \cdot (C_L - 0.002)$
P/A	$P / (A_L \cdot (C_L - 0.002))$	$P / (A_L \cdot C_L)$	$1.045 * P / (A_L \cdot C_L)$
% DIFF P/A	+0.2% (current vs. proposed)	-4.4% (proposed vs. legacy)	

Table 2. P/A Comparison

CONCLUSION

It was concluded that both blades and disk met the drawing requirements and it was the lack of cleaning on the fielded disk that drove the interference fit. In addition, it was also determined that the tolerance circumferential stackup also contributed to the fitup issue with a worst-case scenario that creates a line to line contact.

Short term corrective actions were implemented consisting of detailed cleaning of the MIN neck area of the disk.

The long term and final fix for the fitup issues consisted of redefining the blades MIN neck area to provide additional circumferential room on a worst-case tolerance stackup.

Changes were validated by comparative analyses. The smaller radius translates into a smaller MIN neck cross sectional area that will carry the same centrifugal load. This constitute a stress increment. Three different blades geometries were compared: a) Current Design, b) Proposed Design and c) Legacy Design. In summary, stress on the proposed blade configuration is 0.2% higher than the current but still 4.40% below legacy. Successful experience of the legacy blade operating on the same disk under a harsher environment validated the proposed change.

Final change to the blade MIN neck design will provide adequate circumferential clearance at the MIN neck region and will mitigate future fitup issues.

REFERENCES

[1] "Gas Turbines. Learn about the history and development of the gas turbine", Edison Tech Center.

[2] "Types of Gas Turbines", Glenn Research Center. National Aeronautics and Space Administration.