Modeling of Residual Stresses Generated During Thermo-Mechanical Processing of Ni-Based Superalloy Turbine Disks and Effects on Plastic Growth Predictions.

by

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A Thesis Proposal Submitted to the Graduate Faculty of Rensselaer Polytechnic Institute in Partial Fulfillment of the Requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

Approved:

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ABSTRACT

The objective of the proposed work is to predict the residual stress state of a Ni-based superalloy jet engine turbine disk prior to operation, and determine the effect the bulk residual stress state has on plastic growth caused by room temperature pre-spin operations. Residual stresses resulting from the heat treatment and machining processes will be evaluated and incorporated into subsequent elastic-plastic residual growth models. The residual growth prediction will be compared to the Pratt & Whitney (PW) legacy prediction method, PW pre-spin historical growth data, and an elastic-plastic model completely neglecting the effect of residual stresses.

INTRODUCTION

During the operation of most modern jet engines, the combination of high temperatures and high rotational speeds result in a significant amount of plastic growth in high pressure turbine (HPT) disks. This plastic growth, commonly referred to as residual growth in the jet engine industry, can lead to undesirable effects during engine operation. Relative plastic growth between rotating components may lead to the loosening of radial pilot interference fits, generating excessive vibration and subsequent high cycle fatigue problems. Relative growth between rotating and static components may also negatively affect critical clearances needed to maintain secondary air system pressures and flow rates.

To reduce relative plastic growth between rotating components, and to eliminate relative plastic growth between static and rotating components, it has become common practice to pre-spin turbine disks, typically at room temperature and prior to finish machining. The pre-spin speed is targeted using the plastic growth results from an elastic-plastic finite element analysis of a representative flight cycle. If the pre-spin speed is targeted correctly, the majority of the deflections occurring during engine operation are elastic in nature. Due to historical limitations in FEM capability, residual stress effects have been addressed by debiting plastic material properties.
PROBLEM DESCRIPTION

The intent of the thesis is to develop a procedure to determine the residual stress state in a Ni-based superalloy turbine disk, and map the initial stress state into subsequent non-linear pre-spin models. The recently released version of ANSYS, version 12, claims to have introduced the capability of solving initial stress states in both linear and non-linear models, but a thorough investigation of the capability has not previously been performed. It is anticipated that the residual stress mapping technique will be applicable to a wide range of fatigue and fracture problems.

Additionally, sensitivity studies of the heat treatment and machining parameters specific to the thermo-mechanical processing of Ni-based superalloy turbine disks will be performed to determine a realistic bound of the residual stress values prior to pre-spin operations.

METHODOLOGY

The heat treatment and machining processes will be simulated using Deform FEA software to determine the turbine disk’s residual stress state prior to operation. Sensitivity studies will be performed on the heat treatment and machining parameters to identify potential sources for error in residual stress values. The residual stress state predicted by Deform will be mapped into subsequent ANSYS (or other software) finite element modeling of pre-spin operations. Initially, a simplified, uniaxial model will be used to troubleshoot and verify the residual stress mapping algorithm. The bulk of the work will be performed on non-specific disk geometry and publicly available elastic-plastic material data where possible, to allow for sharing with RPI. Information required for the correlation with production components, such as Pratt and Whitney material data and process parameters (i.e. heat treatment times and temperatures), will not be available in the publicly released document.
RESOURCES REQUIRED

- Access to Deform and Ansys software (available at PW or RPI)
- Heat treatment convection coefficients (PW)
- Thermal properties for select Ni based superalloy (PW)
- On-cooling tensile data for select Ni based superalloy (PW)
- Elastic-plastic data for select Ni based superalloy (PW)
- Turbine disk pre-spin residual growth data (PW)

EXPECTED OUTCOMES

It is expected that the thesis work will develop a procedure to incorporate the residual stress state developed during thermomechanical processing into a non-linear FEM residual growth model, and compare the residual growth predictions for the following scenarios:

- Legacy Pratt & Whitney residual stress approach
- Neglecting residual stresses
- Residual stresses fully modeled

A sensitivity study of the heat treatment and machining parameters will be performed to determine the potential range in residual stress values possible prior to the pre-spin operation.

MILESTONES

- Submit proposal. (1/7/2010)
- Complete literature research. (2/1/2010)
- Complete residual stress development - heat treatment (and sensitivities) modeling. (4/1/2010)
- Complete residual stress development - machining (and sensitivities) modeling. (5/2010)
- Complete integration of residual stresses into residual growth modeling. (6/15/2010)
• Complete comparison of growth predictions to production pre-spun disks.  
  (7/15/2010)
• Request thesis defense and submit copy to advisor.  (8/1/2010)
• Submit approved thesis.  (8/25/2010)
REFERENCES REQUIRED FOR THESIS


