EXPANDER BLADE ROOT DESIGN TO PREVENT FATIGUE AND CREEP FAILURES

By Eric Dunlap, Senior Engineer

Hot gas expander blades are expected to provide long term, reliable operation in a very demanding service environment. The rotor blades are expected to survive operating campaigns of up to six years at inlet temperatures up to 1400° F. In this environment the design of the expander blade attachment root becomes a particularly challenging problem. The root geometry must be carefully designed to minimize operating stresses to avoid fatigue and creep rupture failures.

Fatigue is weakening of the metal caused by cyclic loading that results in crack initiation, growth, and rupture at stresses below the ultimate tensile strength of the metal. The concept of fatigue strength is necessary to predict and avoid this failure mechanism. The material fatigue strength is the magnitude of completely reversing alternating stress under which the material will not rupture below a certain high number of cyclic loadings, usually 10^7 cycles at a minimum. In hot gas expander applications, the primary cyclic loading is due to alternating gas bending loads as the rotor blades pass behind the upstream nosecone struts and stator vanes during rotation. However, there are also constant, steady loads applied to the blades due to gas bending forces as well as centrifugal loading as a result of rotor rotation.

The material's resistance to fatigue decreases as the steady state stresses increase. A design tool called a Goodman Diagram is used to visualize this relation. On the Goodman Diagram, alternating stress is plotted on the vertical axis, and steady stress is plotted on the horizontal axis. A line is drawn connecting the material fatigue strength on the vertical axis to the material ultimate tensile strength on the horizontal axis. This line is known as the Goodman Line; high cycle fatigue failures are not expected for the combination of alternating and steady stresses beneath this line.

Typically, the area under the Goodman Line is further reduced to form a "design envelope" by applying a safety factor to the material fatigue strength and limiting the steady stress to the material yield strength. Blade stresses inside the design envelope are considered acceptable to prevent fatigue failure for the life of the rotor blades.

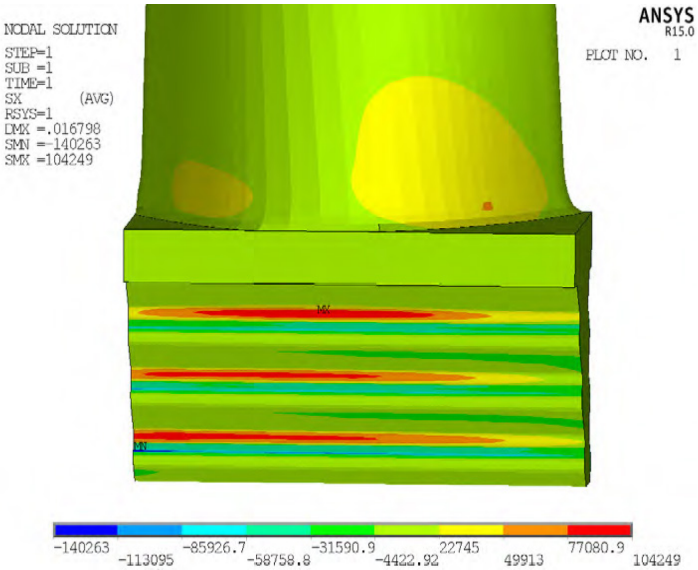

Figure 1: Example ANSYS Rotor Blade Attachment Stress Analysis. Peak stresses (red) must be minimized to avoid fatigue and creep failures

Rotor blade stresses must also be limited to prevent creep rupture. Creep is time dependent permanent deformation of a material under the influence of a persistent applied load, typically occurring at elevated temperature. Eventually the material will rupture if the deformation is allowed to continue for a long enough time. Critically, creep damage can occur at stresses well below material yield strength.

Creep damage accumulates in the material over time, and the rate of damage accumulation is dependent on both blade stress and operating temperature. Creep damage accumulates more quickly at higher stress levels and at higher temperatures. The challenge for the designer is to minimize blade stresses so as to maximize the expected blade lifetime before creep rupture is expected to occur. Experimentally determined creep rupture curves are used to predict blade life for a given stress level and operating temperature. Typically, hot gas expander blades are designed for at least a 100,000 hour operating lifetime, but can often have creep rupture lives much longer than that.

Successful blade attachment designs minimize operating stresses to prevent creep and stress rupture failures. The blades typically become life limited by other factors such as erosion, corrosion, or metallurgical degradation.

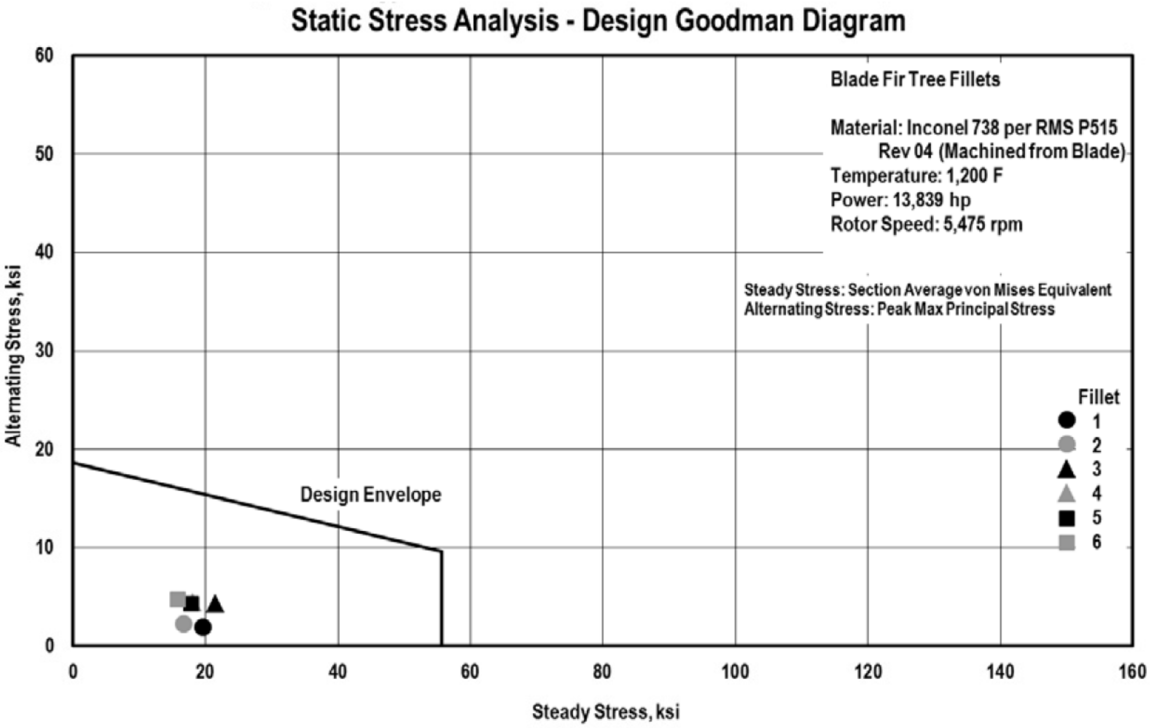

Figure 2: Example Goodman Diagram and Design Envelope

For more information:
Eric Dunlap, Senior Engineer
Email: edunlap@rotatingmachinery.com
Tel: 484-821-0702

Headquarters
2760 Baglyos Cir.
Bethlehem, PA 18020

Houston Office
16676 Northchase Dr., Ste 400
Houston, TX 77060

rotatingmachinery.com
Tel: 484-821-0702
Parts: rms@rotatingmachinery.com

Rotating Machinery Services, Inc.