Limitation in the design of cooling systems for Gas Turbine Blades

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Cooling design – as planned

Typical cooling design for a Hp turbine blade

Makes use of:
- Ribbed turbulators'
- Pedestals (Pin-fins)
- Over-size pin-fins
- Plain passage

Other features include:
- Impingement
- Matrix
- Pimples / Dimples
Correlations used for design derived from research rigs

**RIG design**
- Uniform linear inlet flow
- Passage Aspect ratio ~1.0
- Rotation perpendicular to passage axis
- Smooth Walls Ra = 1.6
- Square section ribs
Cast Turbine blades

Cooling flow enters blade passages via a series of bends, plenums with flow mixing.

Rotation axis from $0^\circ$ to $45^\circ$ to passage axis

Passage shape varies from ‘D’ shape, square, rectangular, to aspect ratio = 10.

Casting fillet radius of 0.4mm & 85° draw angle turns square ribs to rounded bumps.

Cast surface finish $Ra = 3 - 4$
Pin-fins
Casting compromises

Wall thickness measurement pads

Replacing cooling features

½ pin-fin close to hub wall – ensures turbulent flow and robust ceramic close to wall
Cross-over hole location

Cross-over feed hole, small diameter & easily broken
Trailing edge ejection
Tip Cooling & Seal leakage
Casting Compromises (2) – Thin training edges

Ceramic at trailing edge not held securely –
Slot moves relative to trailing edge
Coating application
Overall Effect on internal heat transfer

FIG 10
Correction needed on Internal HTC's

Per centage correction
0
100
-100

Region 1
Region 2
Region 3

Pasage number
1 2 3 4 5 6

Pressure side
Suction Side
SUMMARY

• Heat transfer coefficients derived from Cooling correlation are compromised:
  • Correlations for ‘ideal’ passage (square, rotation along axis, Uniform inlet flow etc)
  • Actual cast blades have fillets, rough surfaces, blends
  • Casting requirements cause compromise features (wall thickness pads, mods to features close to wall, blends, cross-over feeds)
  • Aerodynamic effects may dictate how cooling air is ejected into mainstream
  • R.T.D.F. / O.T.D.F. errors, Seal leakages cause unexpected hot-spots
  • Casting errors cause cooling compromises (thin t/edge, core shift, deformed cooling features)

• Coating application not constant thickness / limited control.

Overall effect:

Internal HTC’s not as high as predicted
External boundary conditions may be more extreme than predicted

Measured metal temperatures greater than predicted
SUMMARY (2)

Based on the one test case examined, at mid section, in order to compensate for internal heat transfer errors:

• Suction Side heat transfers need greater compensation than pressure side

• Mid-chord region requires a moderate degree of compensation

• Trailing edge region needs considerable compensation as passages have high aspect ratio, and greatest off-axis rotation
Conclusion

Difference between predicted and actual operating temperatures can be resolved into two groups

**Effects that can be predicted**
- Correlation errors,
- Rotation,
- Casting limitations

**CORRECTION FACTORS SHOULD BE DERIVED**

**Effects that can only be estimated**
- Actual RTDF/OTDF
- Leaks, seal flow,
- Casting errors – thin wall, deformed features, etc

**DESIGN SHOULD HAVE A GOOD TEMPERATURE MARGIN OVER THAT REQUIRED** [\(~25-30°C\)]