Power Systems Division is Manufacturer of Wide Range of Turbomachinery Products

Turbomachinery Products Designed for Diverse Applications

Gas Turbine & Compressor Packages

Process & Gas Compressors

Air Compressors

Turbo-Compressors

Over 30 years experience of compressor technology originally derived from gas turbine business...
Aero-Mechanical Optimization of Turbomachinery
Influence of Manufacturing Technology on Turbomachinery Design

- **Goals for commercial gas turbines and compressors are consistent ...**
  - ✓ Increasing efficiency
  - ✓ Increasing reliability
  - ✓ Decreasing maintenance cycle
  - ✓ Reduced delivery time

  - **End users drive need for reduced OPEX**
  - **Competition amongst OEM’s fosters lower CAPEX**
  - **Regulations drive reduced environmental impact**

- **Each manufacturer has slightly different approach ...**
  (but all really based on similar philosophies)

- **Discussed herein is the following ...**
  - ✓ OEM’s approach to turbomachinery optimization
  - ✓ How additive manufacturing can alter that paradigm significantly.
  - ✓ Example case to illustrate the impact additive manufacturing can have on turbomachinery design.
Within Turbomachinery Multiple Engineering Disciplines are All Coupled

FEA - Stress

CFD - Flow

Rotor-Bearing Dynamics

Cooling

Iterative Constraint

One-way Constraint

Structural

Rotor-dynamics

Cooling

Mechanical Design

Stage Aerodynamics

Piping Connections

Diameter and Speeds

Impeller Mass and Inertia

Volute Sizes

Scaling and Aero C.C.

Geometry and Dynamic Coefficients

Power Transmission

Bearings

Gearing (if Present)

Shaft Diameters

Gear Diameters
Example ... in part from Joint Program between Hanwha Techwin and Southwest Research Institute
DMLS in Turbomachinery

- Stationary and rotating parts
- Published application of DMLS to rotating parts limited mostly to development test rigs
  - 100,000 rpm 1380 °F Inconel GT wheel (Inconel 718)
  - SwRI experience with micro-turbomachine closed impellers and turbines
    - Overspeed test successful at 1140 ft/s
    - Overspeed test to failure at 1403 ft/s

Flow Straightener for Helicopter Engine (Killian 2013)

EOSINT M 280 (Source: EOS)

100 krpm GT wheel (Killian 2013)
DMLS Impeller Design Considerations

The Direct Metal Laser Sintering process works best to minimize:
- Thicker parts can build internal stresses that lead to fracture during build.
- Excellent rotordynamic characteristics as weight and inertia are minimized.
- Reduced material minimizes build time and cost.

Ribbed Design Produces Non-uniform Seal Clearance and High Stresses in Ribs – Tested Inconel 718 Part Instead.
**Tensile Test Results**

**DMLS Ti 6AL-4V**

- **Under 200 X magnification micro-porosity is present:**
  - Investigated implication on fatigue strength
  - Investigate dimensionality

- **Reduced grain size:**
  - Slight increase in yield and ultimate strength
  - Increased material hardness
Test Results Show Reduced Fatigue Life

S-N Diagram for DMLS Ti 6Al-4V
Manufacturing Flexibility Significantly Outweighs Fatigue Limit

DMLS Ti 6AL-4V

- 15% decrement due to strength
- 35% reduction in stress due to increased design flexibility.
Relationship to
Integrally Geared sCO$_2$
Advanced 10 MW<sub>e</sub> Integrally Geared Compressor-Expander Configuration

Compressors

Re-Compressors

Expanders

Generator

Turbine

Gearbox

Technology Demonstrator

Hanwha Techwin
Conclusions and Future Needs
Conclusion

Advantages of Direct Metal Laser Sintering:

- Process lends itself to reduced material waste
- Process lends itself to minimize weight ... improved rotordynamics.
- Process removes some previous constraints ... can reduce “effective” stress and improve component life.
- Or with lower effective stresses it becomes possible to re-stagger the design optimization and achieve high efficiency and/or high compressor ratios.

Opens Up New Design Possibilities:

- Can we build in new and advanced forms of integrated blade damping mechanisms?
- Can we develop internal flow paths that were not feasible before?
- Add ability to add internal cooling passages in novel ways
Some of the practical issues facing OEM:

- **Inspections ...**
  - QA practices are lagging technology.
  - Technology allows ability design components with internal structures that are difficult to inspect.

- **Material Properties ...**
  - Fatigue properties are key to design process.
  - Some vendors are using “propriety” powder blends

- **Build Process ...**
  - Fractures can develop during build process.
  - Surface roughness has drastically reduced.
  - Substantial post build work required.