ULTRA-HIGH TEMPERATURE METALLIC SEAL/ENERGIZER DEVELOPMENT FOR AERO PROPULSION AND GAS TURBINE APPLICATIONS

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Ultra-High Temperature Metallic Seal Program
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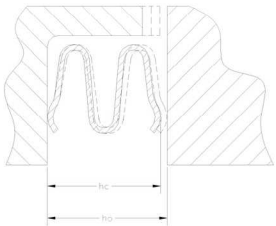
Ultra-High Temperature Metallic Seal Program

Program Overview

- Industry is requiring seals to operate at higher and higher temperatures.
  - Greater efficiency
  - Reduced cooling air requirements
  - Reduced emissions
- Traditional static seal designs and materials experience stress relaxation, losing their ability to maintain contact with moving flanges.
- Ultra High Temperature seal development program – Multiphase program with incremental increases in seal operating temperatures



Seal gap is created resulting from stress relaxation at elevated temperatures. The original seal height ho is reduced to hc creating a gap when the flange moves away from the compressed condition.

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Background of Problem

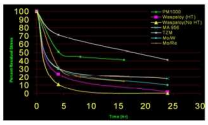
Ultra-High Temperature Metallic Seal Program

Program Review

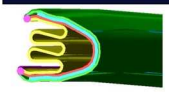
High Temperature Seal Development Program

Phase I : Improved traditional sheet metal seal design and analysis

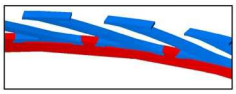
Phase II : Higher temperature sheet metal materials and improved thermal processing



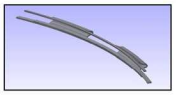
Phase III : Thermally insulated seals

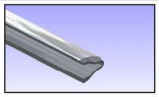


Phase IV : High temperature polycrystalline spring element development



Phase V : High temperature single crystal DFM and design optimization





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Material Comparison

Cast Blade Alloys Have Excellent High-Temperature Strength

Alloy	Temperature,° F	Yield Strength,ksi	Elongation,%
Mar-M-247, Single Crystal	1600	110	8.0
CMSX-4™, Single Crystal	1600	114	18.0
Waspaloy™, Polycrystalline	1600	60	12.0
René41™, Polycrystalline	1600	84	11.3

- Blade alloys also have superior creep and stress rupture strength compared to cold formable superalloys. Hence, blade alloys have higher resistance to stress relaxation.
- Manufacturing Challenge - Blade alloys are only available in the cast condition (poly or single crystal)

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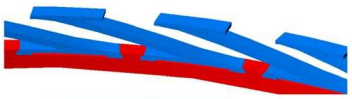
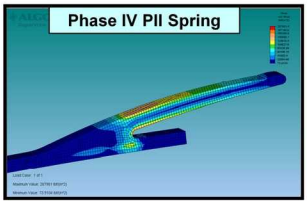
Single Crystal Spring Evolution – Phase IV

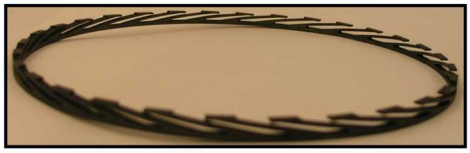
- Prototype I
  - Solid ring machined from a polycrystalline Mar-M-247 casting
  - Basic finger design, not optimized with FEA
  - Opportunities for Design for Manufacturability (DFM) enhancements
- Prototype II
  - Independent finger and support ring configuration
    - Improved DFM and lower manufacturing cost
    - Ability to fine tune spring load and total seal load
  - FEA optimized finger configuration
  - Improved dimensional relaxation characteristics



Phase IV PI Spring



Phase IV PII Spring



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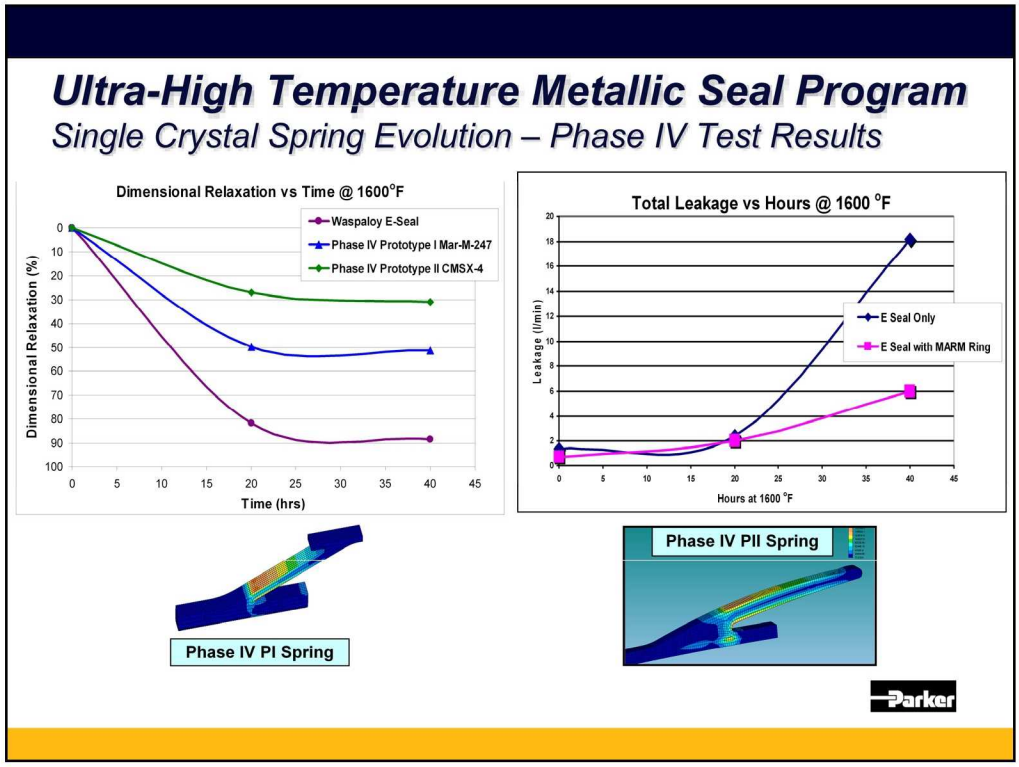

Stress relaxation testing on Phase IV prototypes showed very positive results compared to polycrystalline Waspaloy and Rene41. Follow-on leakage testing showed a strong correlation between improved stress relaxation and improved leakage results.

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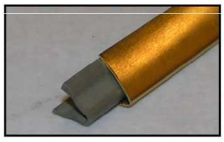
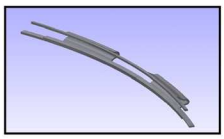
Single Crystal Spring Evolution – Phase V

- Prototype I – "Wishbone"
  - Linear "V" shape machined from a single-crystal rod of CMSX-4™
  - Secondary machining operation required to allow parts to interlock
  - Positive stress relaxation results
  - Opportunities for design and manufacturability enhancements



- Prototype II – "Chevron"
  - Radial "V" shapes cast in both Mar-M-247 and CMSX-4™ using a prototype SLA mold
  - Cast part thickness held to .020"
  - Optimized profile for reduced stress and simplified assembly (eliminated need for secondary machining operation)



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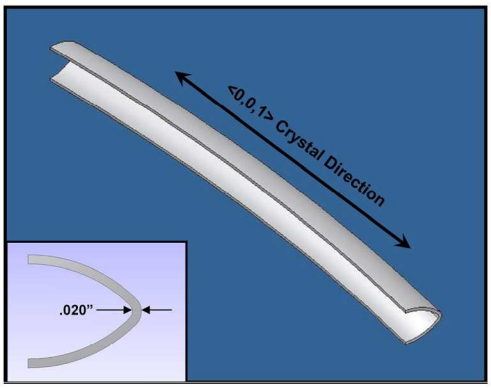
Single Crystal Spring Evolution – Phase V



- V-Spring is cast with <0,0,1> crystal orientation *approximately* along the circumference of the part
- This orientation improves the stress relaxation properties of the part, and maximizes the range of elastic compression

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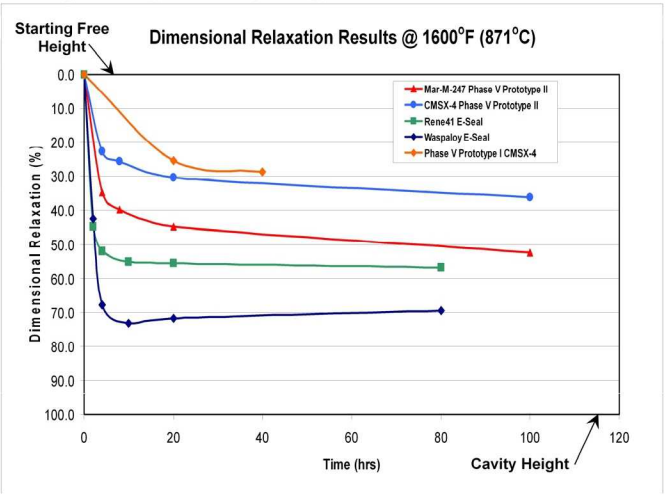
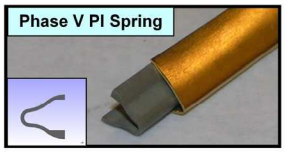
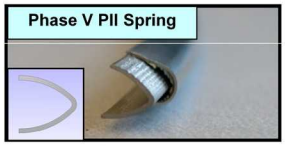
Single Crystal Spring Evolution – Phase V Test Results



CMSX-4™ exhibits approximately 34% better dimensional relaxation than Mar-M-247, and 76% better than Rene41™ @ 1600°F.





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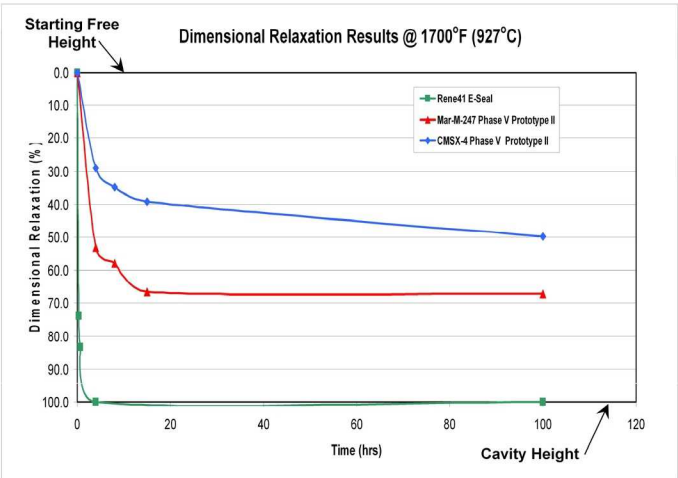
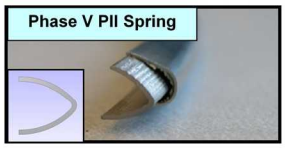
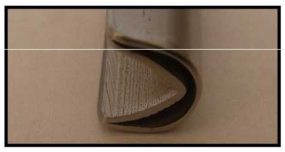
Single Crystal Spring Evolution – Phase V Test Results



Rene41™ 100% relaxed after 4 hours at 1700°F. CMSX-4™ retains approx. 54% of it's starting free height after 100 hours at 1700°F





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Single Crystal Spring Evolution – Phase V Summary

- DFM has been the primary program goal since 2006
  - Convert the fundamental concept into a commercially / economically viable design while retaining stress relaxation gains
  - Through FEA analysis and DOE an improved design configuration was developed
- Modular manufacturing approach was developed
  - Standard V-Spring configuration nests within a relatively thin, oxidization resistant sheet metal jacket (Haynes® 214®, Haynes® 230®, PM2000, etc.)
  - Jacket serves as primary pressure barrier and structural support
  - V-Springs are brazed into position using standard techniques
- Standard V-Spring configuration allows for cost effective linear seals and hoop seals
  - V-Springs are cast near net shape to keep manufacturing costs low
  - Cast as a single crystal material with [0,0,1] crystal orientation along the part circumference
  - By joining multiple V-Springs, any diameter seal can be cost effectively produced

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Conclusions & Future Work

- Single-crystal blade alloys can be cast in thin sections (.020") for use as high-temperature energizers for static metal seals
- Single-crystal CMSX-4™ V-Springs have significantly better stress relaxation resistance than single-crystal Mar-M-247 and polycrystalline Rene41™
- The Ultra-High Temperature seal program has successfully progressed and developed a commercially viable, high temperature static seal solution.
- Moving forward
  - Continue long-term stress relaxation testing (up to 200 hrs)
  - Perform comparative leak testing of latest prototypes
  - Perform testing at 1800°F and above
- Future activities
  - Finalize details of manufacturing process
  - Develop a product-specific, technical performance data sheet
  - Identify a launch customer / application and build first production pieces for on-engine testing

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Questions?

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