

WORLD-CLASS OUTSTANDING INTERNATIONAL  
PROGRAM | EXHIBITION | NETWORKING

**INNOVATIVE DESIGN IN EXPANDER WHEEL-SHAFT  
ATTACHMENT REPLACES HIRTH COUPLING  
FOR  
HIGH SPEED, HIGH TEMPERATURE AND HIGH POWER  
APPLICATIONS**

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**42<sup>nd</sup> Turbomachinery  
29<sup>th</sup> Pump SYMPOSIA**



GEORGE R. BROWN CONVENTION CENTER  
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# Abstract

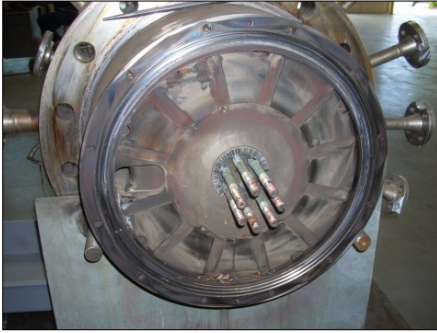
- Expander-Generator unit for a geothermal power plant application experienced ongoing failures during a ten year period. The longest run cycle for the machine was 18 months yet with less than 10 MW power production. The average time between failures was less than six months and with each failure; the wheel was completely damaged and separated from the shaft. A complete metallurgical study on previous failures showed the hirth coupling attachment was the first to fail in all cases.
- Using fully coupled non-linear contact point FEA analysis and benefiting from advancement in machining techniques, new four-lobe polygon shaft-wheel attachments were designed for high speed, high power and high temperature applications. The redesign reduced the hub centrifugal stress by 30 percent, allowed the shaft to be inserted inside the wheel to hold the wheel C.G. on the shaft, and increased the power transfer capacity of the rotary parts.
- By holding the wheel on the shaft, other problems like high vibration, electrical current passing through the unit, and incorrect blade resonance could be addressed and resolved. For more than two years, the redesigned machine has run continuously without any failures and with constant low vibration producing up to 12 MW, at minimum 20% above any previous operating points.

# Background

- An expander-generator unit for geothermal application was commissioned in 2000.
- The expander wheel failed continuously since commissioning of the machine.
- Machine experienced very high vibration (5 mils and higher) during operation.
- During a 10-year period, the machine was redesigned several times yet the problems remained.
- When the machine operated at the designed power, the average time between failures was less than three months.
- On one occasion, the unit ran for 18 months but on a lower power (less than 10 MW).

# History

2007



2009



2008



- Hirth coupling attachment was failing on all previous designs.
- Inconel 718 retaining bolt was also failing-either severely bended or completely cut off.
- Because of above reasons, in all failures the expander wheel was completely separated from the shaft, and it was rubbing to the follower and the housing, thus not much evidence was left for useful metallurgical analysis.

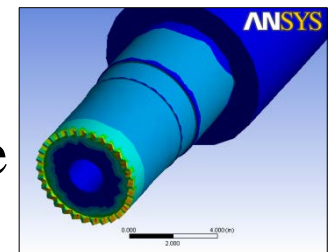
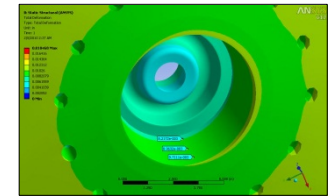
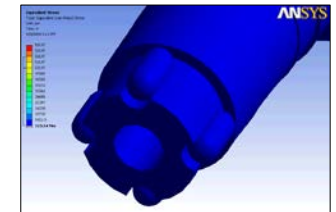
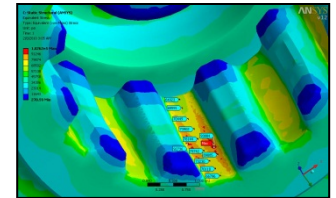
# First Stage of Re-design

- The first goal was to find a solution to keep the wheel on the shaft.
- To achieve this goal, a decision was made to insert the shaft inside the wheel and hold the center of gravity (C.G.) on the shaft.
- To successfully insert the shaft inside the wheel, challenging operational factors needed to be considered:
  - Weight: Very heavy wheel - 23.75” Titanium Wheel
  - Speed: Very high operating speed - 12,500 RPM
  - Performance: High horse power - 15 MW
  - Temperature: High operating temperature of 350F – 400F

# First Stage of Re-design

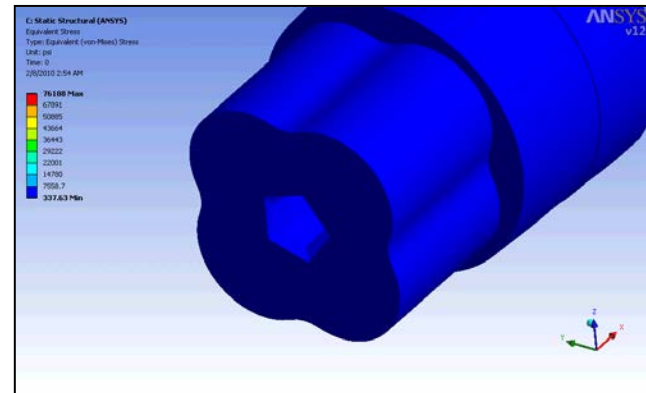
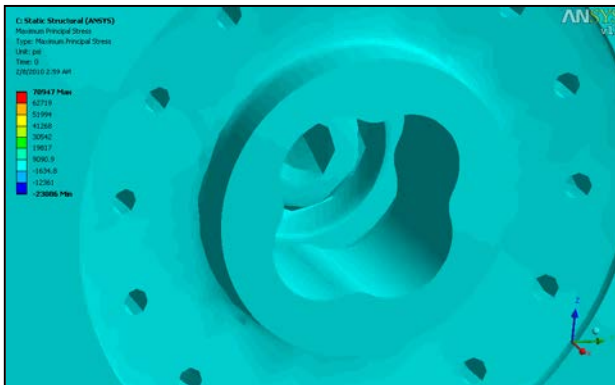
Other considerations:

- Combination of heavy wheel weight and high operating speed causing very high stress on any opening inside the wheel.
- Traditional keyway design ruled out as key's weight would apply additional stress to the hub.
- Centrifugal force opens up the hub diameter by a minimum of 20 mils and reduces effective contact area to transfer the torque.
- High temperature plus centrifugal force make it difficult to locate the wheel on the shaft and hold the imbalance.



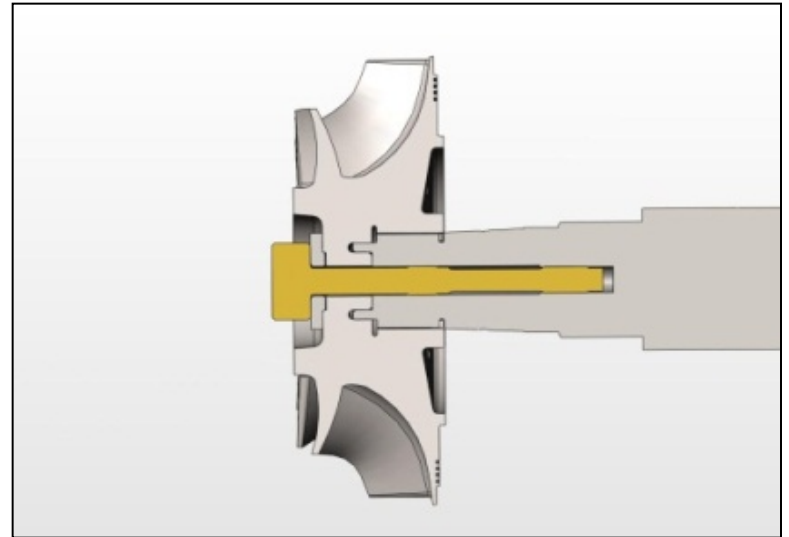
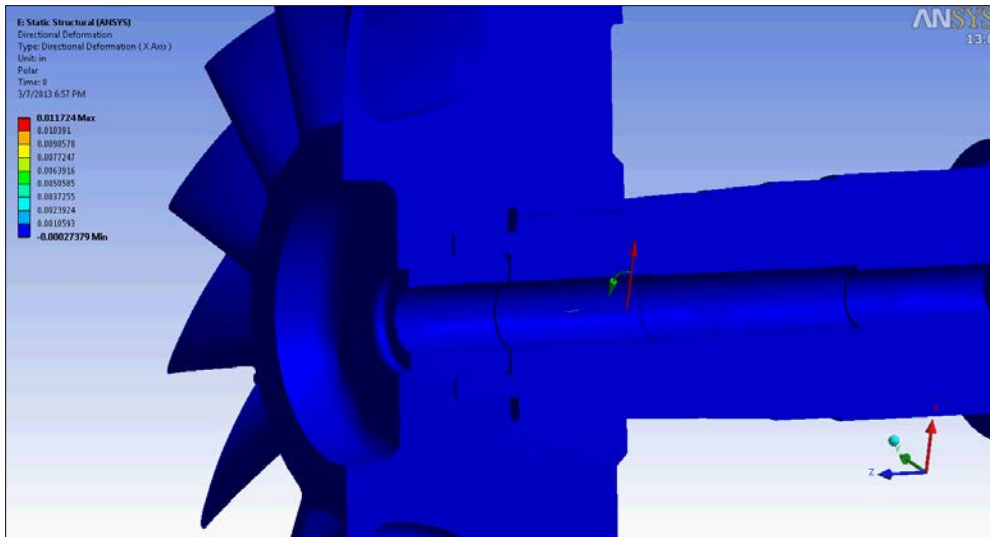
# First Stage of Re-design

- A unique four-lobe polygon attachment was designed.
- To reduce the centrifugal stress further, the hub diameter was increased by one inch.
- With this new design, stress at the hub at no point exceeds more than 60% of expander wheel's material yield stress.
- To increase the effective contact area, advanced lobe geometry with very tight tolerances were used. CNC machining advancement allowed for machining shaft and hub assembly to a tight tolerance of less than 0.0002” inch.



# First Stage of Re-design

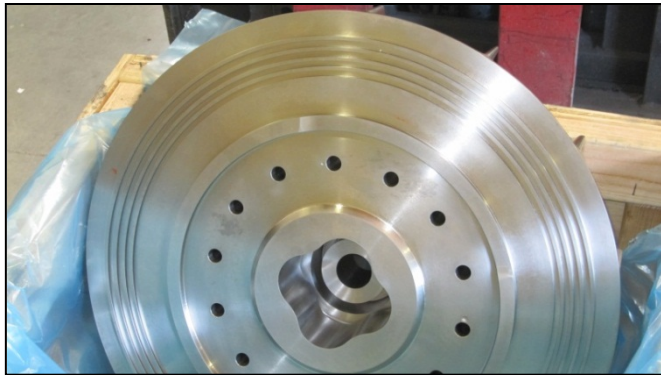
- To be able to repeat balancing procedure by keeping the wheel centric to the shaft, a tightly-machined locator was added to the end of the shaft design.



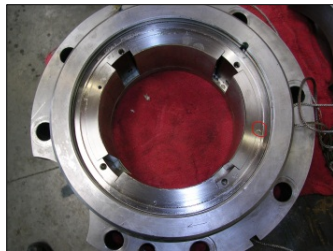


# First Stage of Re-design

- New machining design applied to the shaft and wheel.



- Increased bearing size by one inch to increase stiffness and increase the shoulder area between shaft and expander wheel.
- Changed the number of pads from four to five, and the pivot-pin to half-sphere pivot (4140 Rc52), for better strength and stability.

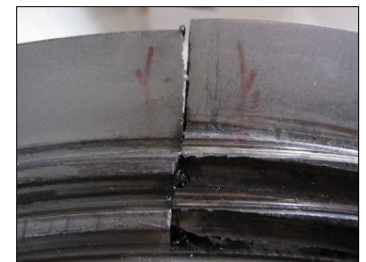


# First Stage of Re-design

- Installed new unit design, ran it continuously for three months.
- Balancing procedure was repeatable on this new design.
- Vibration was much lower this time, around two mils.
- After operation, damaged wheel was still firmly connected to the shaft and was not rubbing to the housing. (Minor rub between the wheel and the follower was detected.)
- Retaining bolt remained in place with no sign of elongation.
- No signs of high stress on the shaft and wheel hub.
- The expander wheel maintained its integrity so it could be sent to metallurgical lab for failure root cause analysis.

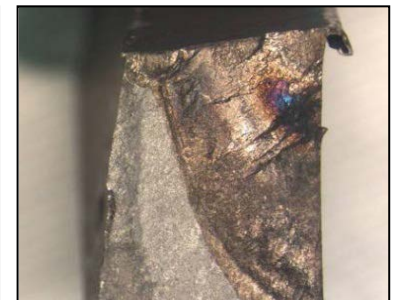
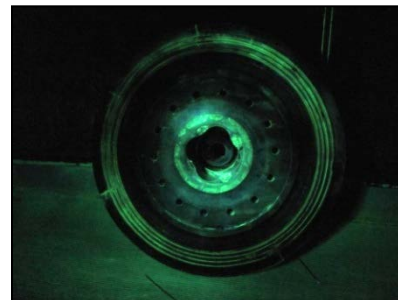
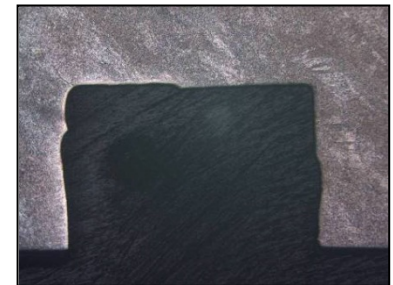
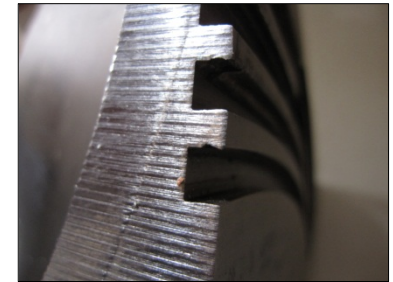
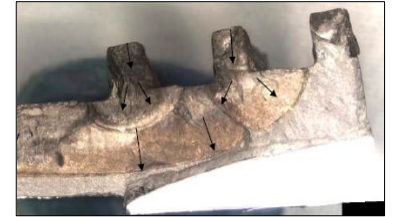
# Root Cause Analysis

1. Expander wheel was attached to the shaft and retaining bolt was intact.
2. Build-up from the operating steam was firmly attached to the blades OD and was causing friction between expander wheel blade and the follower.
3. Expander wheel blades were cut off in several locations, signs of high cycle fatigue observed.
4. Expander wheel disc had cracks in three locations on the OD.



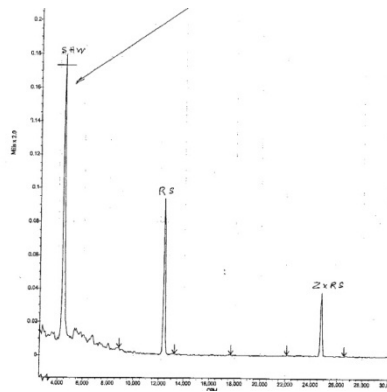
# Root Cause Analysis

5. Disc cracks were initiating from the third stage of the back wheel seal on all three locations.
6. Signs of severe rubbing were observed between the wheel and back wheel seal inside all four stages of the back wheel seal. Material property changed locally and became brittle.
7. Discovered electrical current was passing through the unit. Signs observed on blades between each crack and between shaft and wheel shoulder surface.



# Root Cause Analysis

8. Serious instability observed during operation after the start-up but the vibration limit was steady and less than two mils.



9. On both bearings, journal pads and thrust faces were showing signs of high temperature exposure.



# Second Stage of Re-design

- No change made to shaft-wheel attachment.
- Increased the clearance between the expander wheel and the follower to avoid rubbing on blade's outer edges.
- Wheel resonance reevaluated on complete rotor assembly and with the maximum stretch on the retaining stud. Few blade frequencies observed to be close to the operating speed. By cutting blades in front and on the OD, safety margin increased on these frequencies.
- Back wheel seal design changed to increase the clearances and consider the wheel expansion by centrifugal forces and temperature.

# Second Stage of Re-design

- New grounding system implemented on all casings on four different locations, and on two places on the shaft with higher capacity brushes to eliminate current migration through the unit.
- Moved sphere pivot to 55% position under each pad to improve the bearing stability.
- Used new Cr-Cu material for bearing casings to transfer heat faster to the bearing housing.
- Repaired both oil pumps to ensure the maximum capacity of oil flow is reachable.
- Cleaned up oil piping and filters.

# Results

- Implemented/commissioned the new machine design in November 2010.
- Machine started smoothly and the vibration was less than 0.6 mils.
- Machine ran continuously for 14 months providing up to 12 MW (an average of 11.5 MW) power with no alarm until customer decided to inspect condition of internal parts.
- Vibration remained controlled in the range of 1.0 mils during operation.



# Results

- Unit removed in February 2012 to be evaluated. Spare MCS with same design enhancements installed and started with same low vibration.
- Main unit disassembled, wheel was intact and complete X-ray and florescent dye check showed no signs of cracking.
- No sign of overheating observed on bearings.
- No sign of rubbing on back wheel seal.
- Main unit was cleaned, reassembled and is ready to be back in service.
- Spare MCS has been running continuously for more than 12 months. It is running with low vibration and it is providing up to 12 MW power which is at minimum 20% above any previous operating points.

# Conclusion

- Innovative re-design meets and exceeds performance requirements:
  - Wheel's C.G. is located on the shaft and the attachment is transferring an average of 12 MW power.
  - Wheel is located tightly on the shaft, balancing procedure is repeatable which results in low vibration during operation.
  - Bearings are running cool and stable.
  - Wheel's operating life has exceeded customer's expectation and is ready to be back in operation after minor clean up.

# Discussion

Thank You

Any Questions?



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