

Turbomachinery Symposium 2008

Case study

Evaluation and Successful Modification of Impeller Using Forced Response Analysis

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Background History

A compressor impeller failed in the field with multiple cracks and missing chunks of material from the blades were found at the inlet after 1,000~1,200 hours of service.

It appeared that a foreign object caused the damage (FOD).

The impeller was taken off the line for repair and a spare unit installed.

Background History (Continued)

The spare unit tripped off line following high compressor vibration after 1,700 hours of service.

Unit was disassembled and it was discovered that the impeller blades were damaged similar to the first event.

Inlet screen and upstream components were investigated to locate signs of FOD. No signs of FOD were found.

Pictures of failed blades with missing material are shown on Figure 1.

Pictures of Failed Blades



Figure 1: Pictures Showing Failed Blades with Missing Material

Evaluation of Original Design (1)

The unit has 12 Inlet Guide Vanes (IGV). Modal Analysis indicated possibility of resonance condition with 2x(IGV) forcing frequency and impeller natural frequencies at,

- 1) 1937 Hz, 5-ND (1C)
(5 Nodal Diameter, 1st Order Mode)**
- 2) 2006 Hz, 5-ND (2C)
(5 Nodal Diameter, 2nd Order Mode)**

The FEA Model and Modal Analysis results are shown in Figure 2 through Figure 9.

Evaluation of Original Design (2)

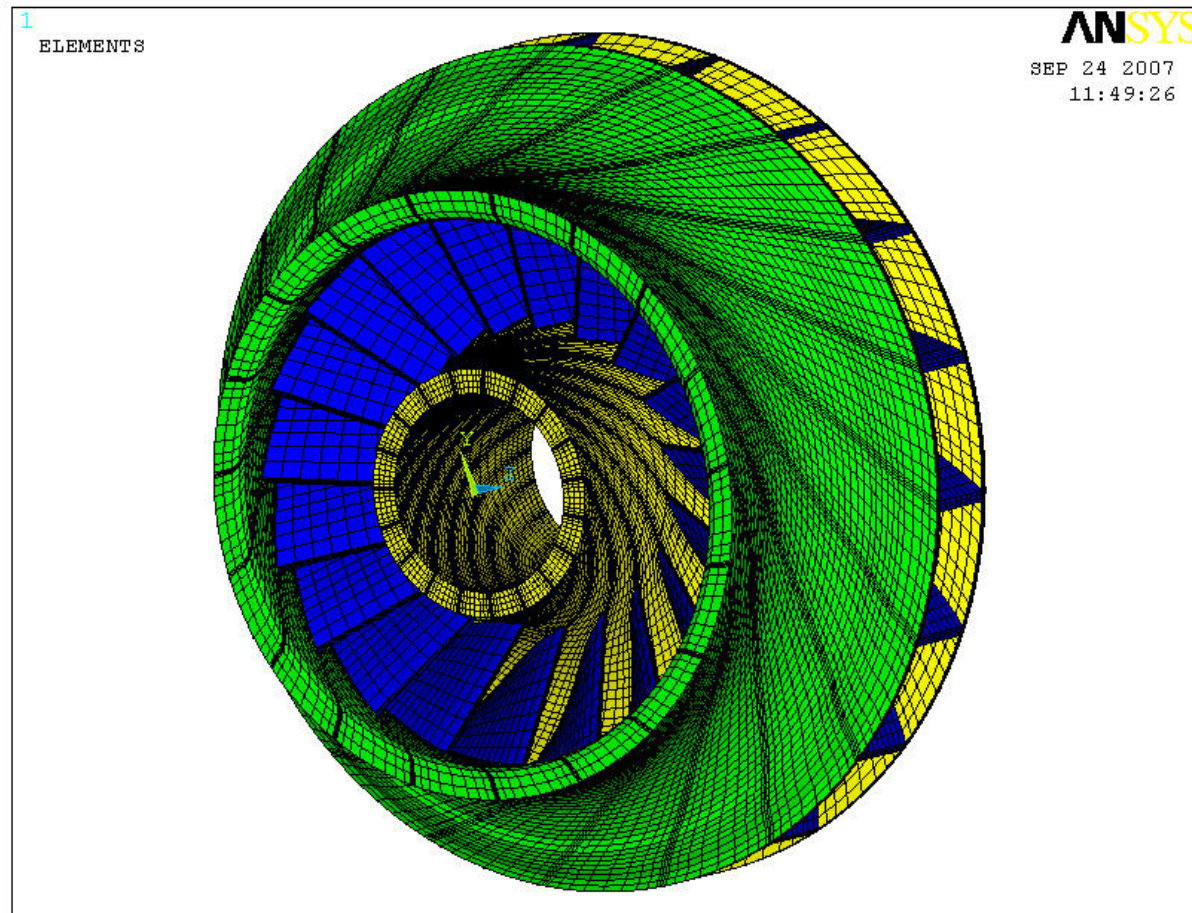


Figure 2: FEA Model of the Original Design

Evaluation of Original Design (3)

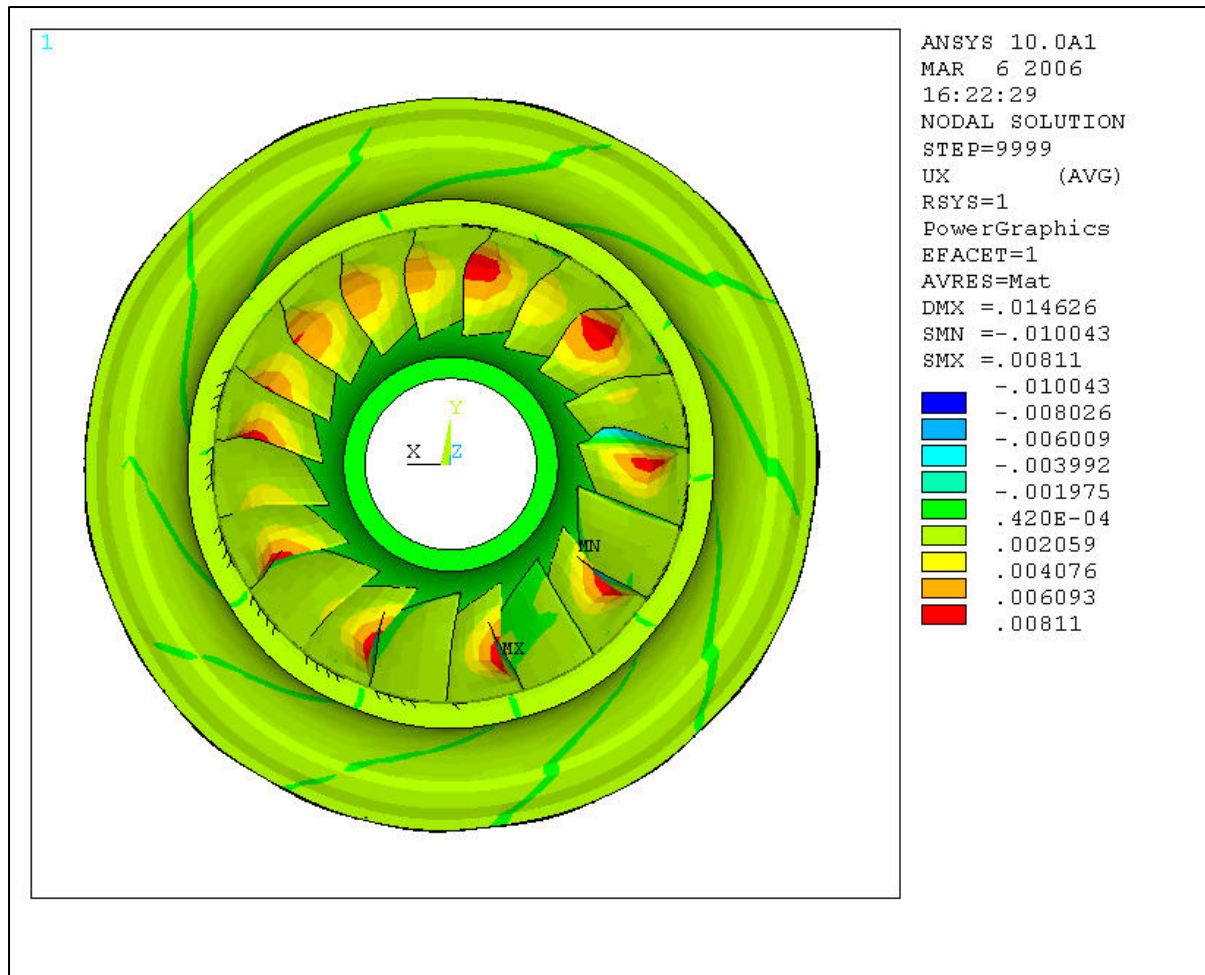


Figure 3: Radial Component, Mode Shape 1937 Hz, 5-ND (1C), Original Design

Evaluation of Original Design (4)

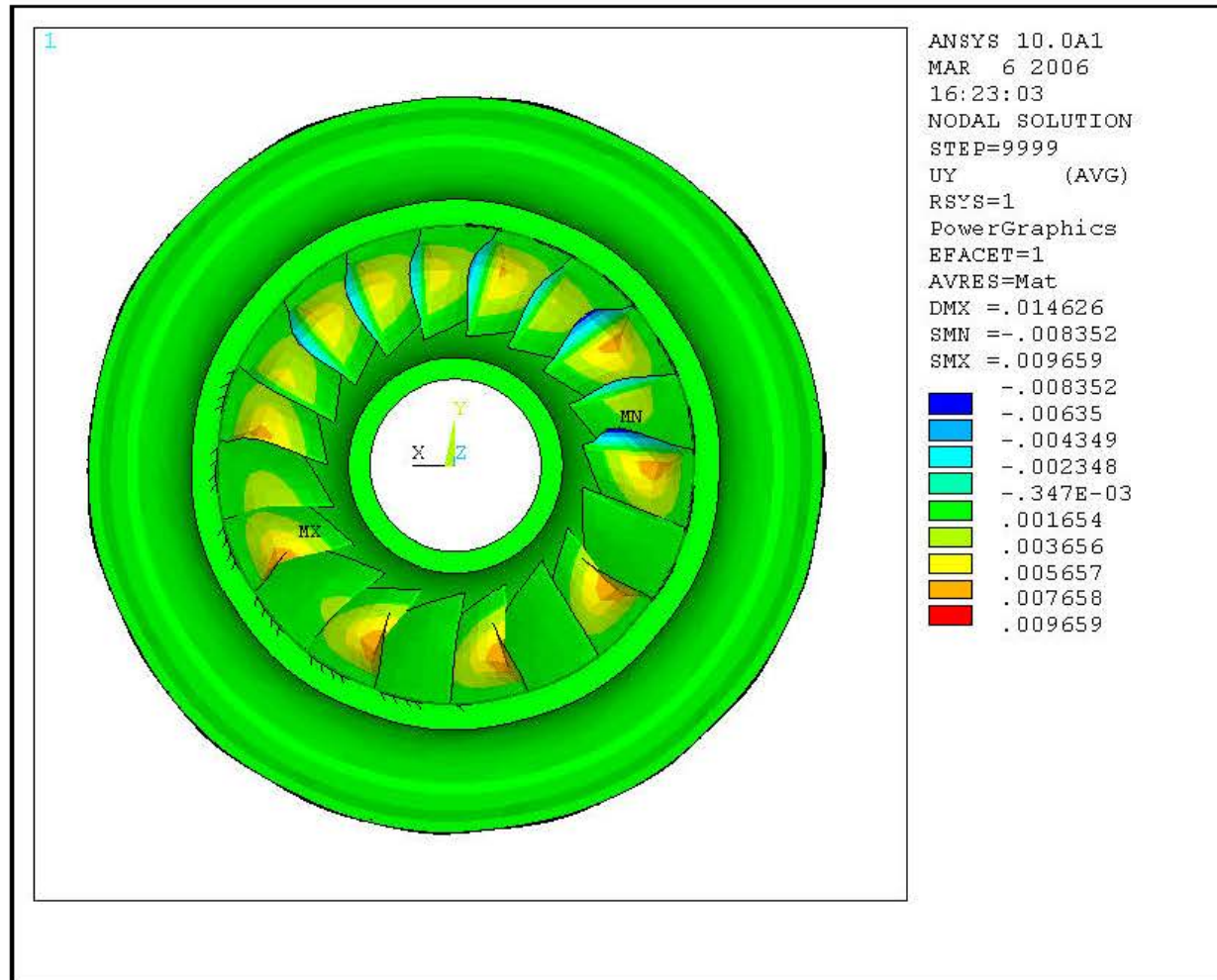
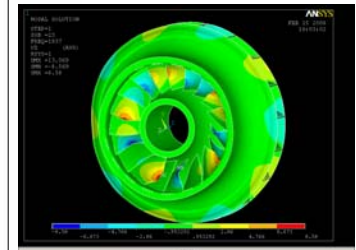
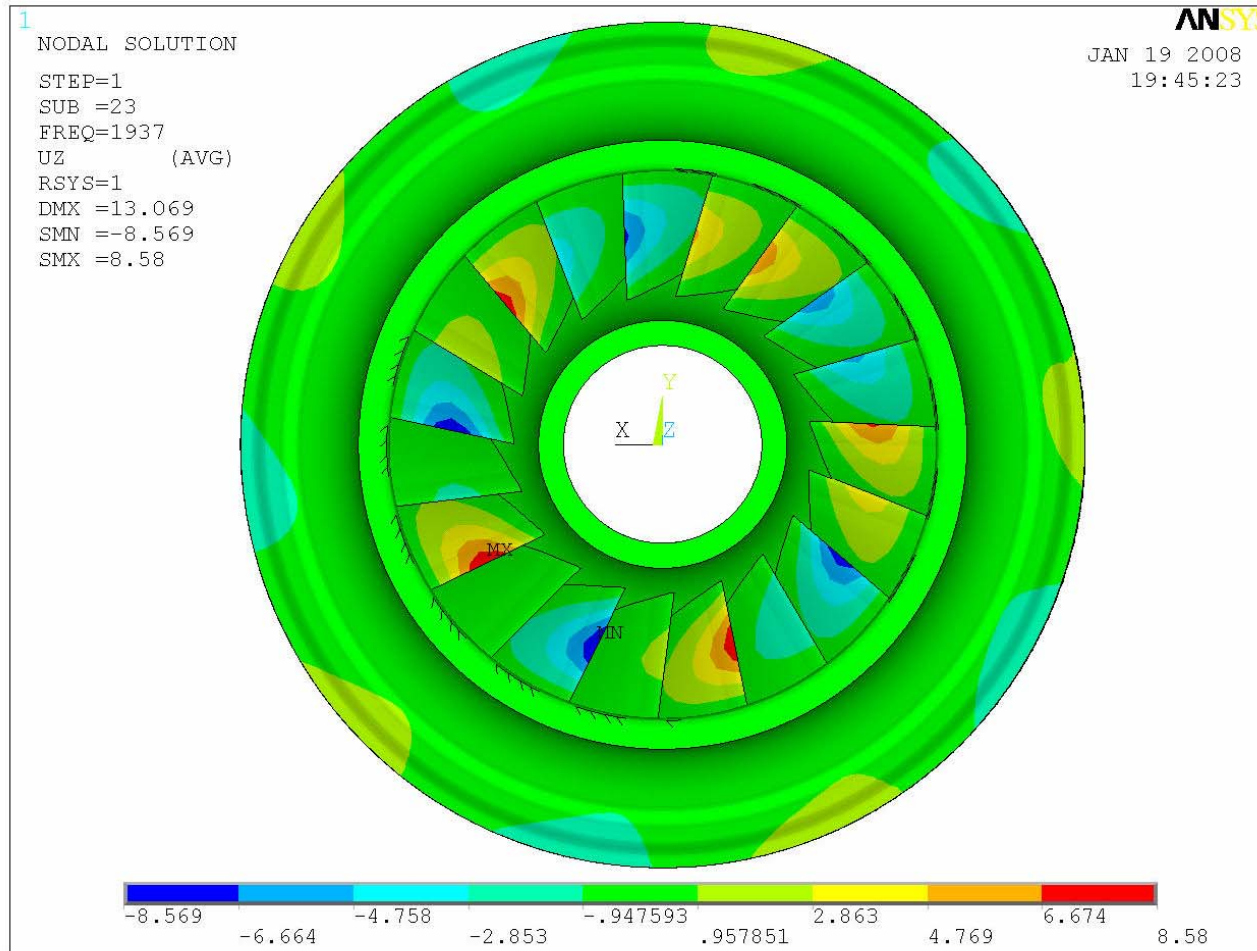


Figure 4: Tangential Component, Mode Shape 1937 Hz, 5-ND (1C), Original Design

Evaluation of Original Design (5)



Mode Animation

Figure 5: Axial Component, Mode Shape 1937 Hz, 5-ND (1C), Original Design

Evaluation of Original Design (6)

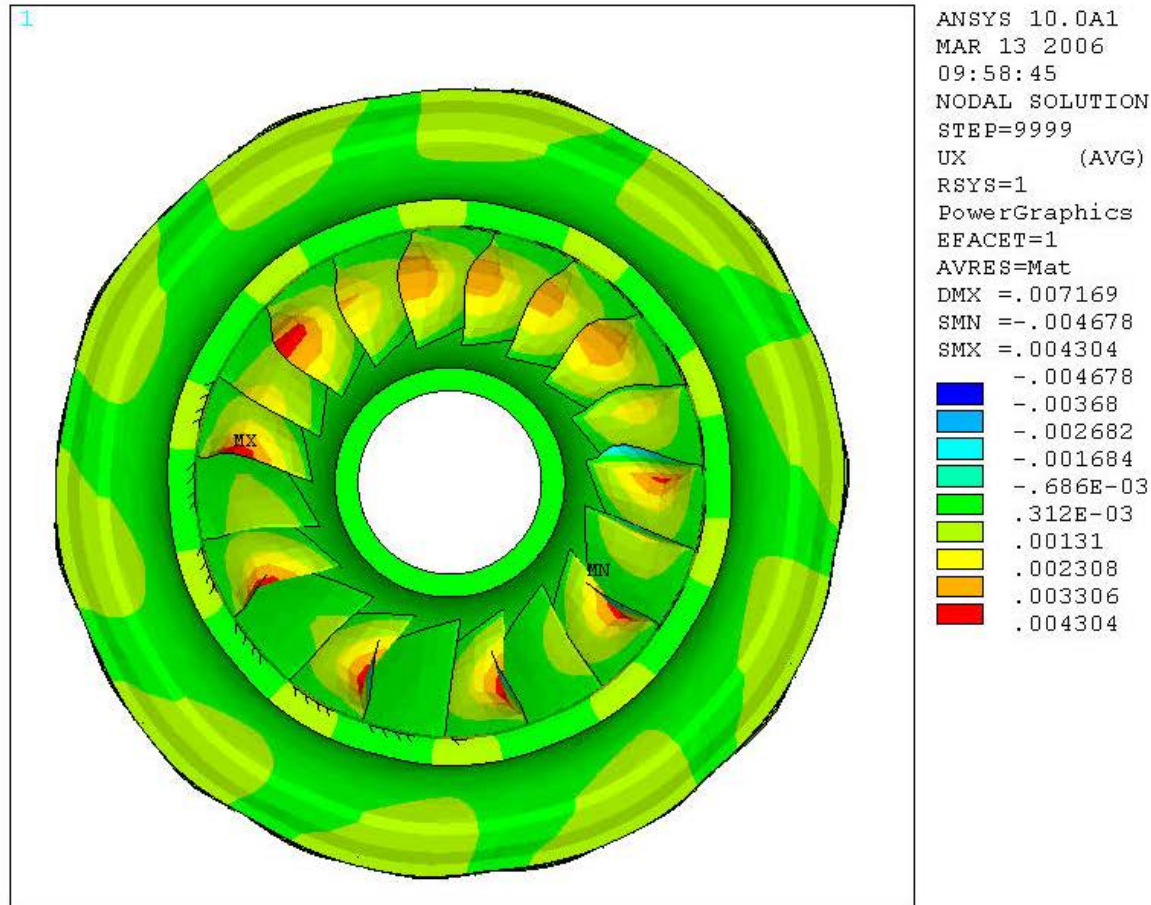


Figure 6: Radial Component, Mode Shape 2006 Hz, 5-ND (2C), Original Design

Evaluation of Original Design (7)

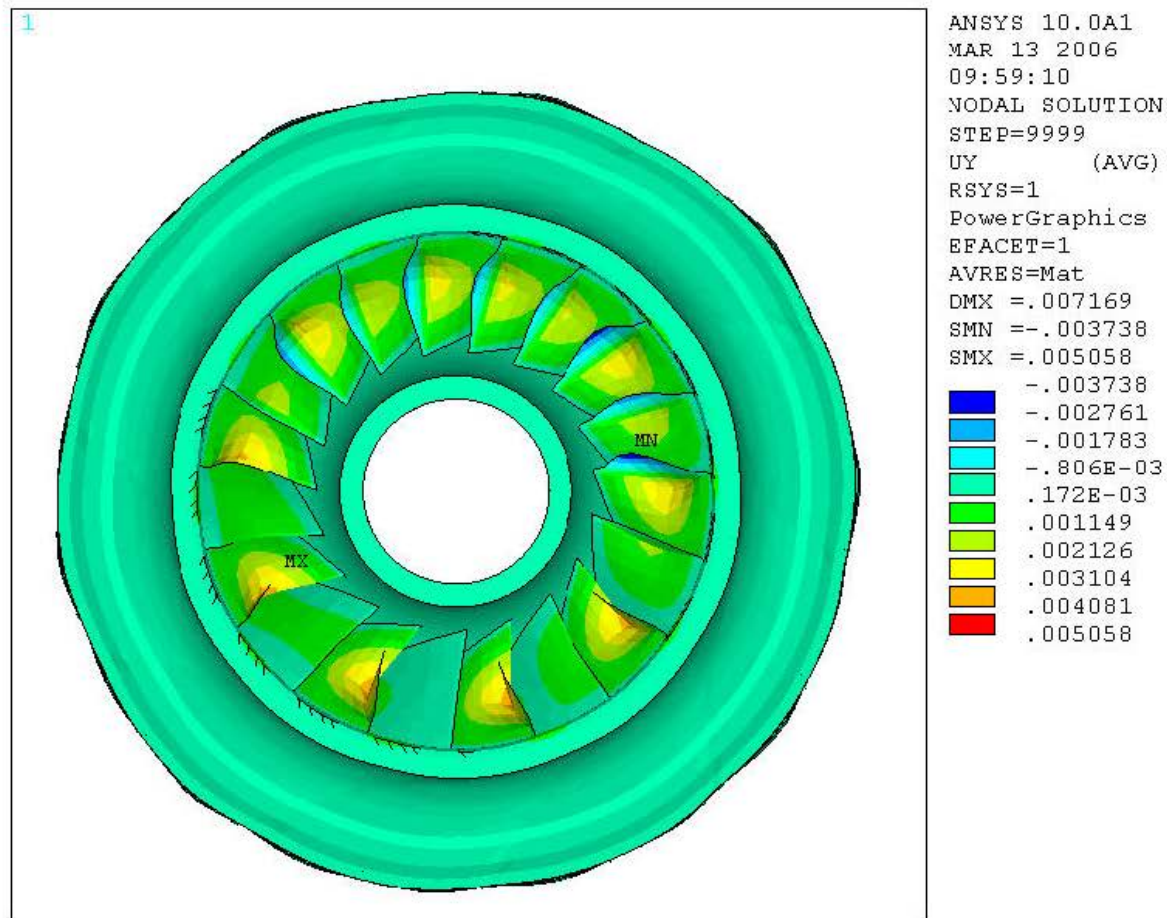


Figure 7: Tangential Component, Mode Shape 2006 Hz, 5-ND (2C), Original Design

Evaluation of Original Design (8)

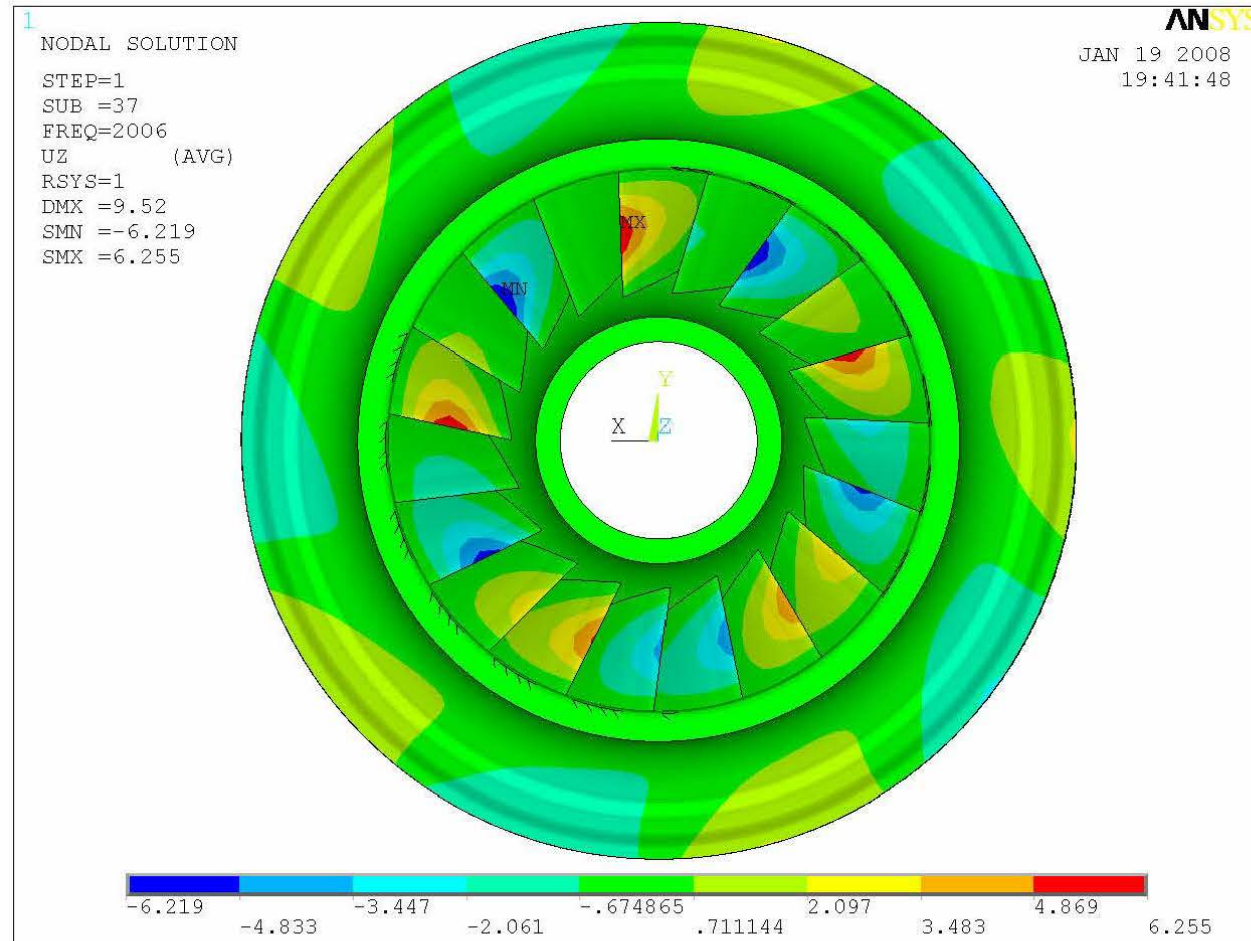


Figure 8: Axial Component, Mode Shape 2006 Hz, 5-ND (2C), Original Design

Evaluation of Original Design (9)

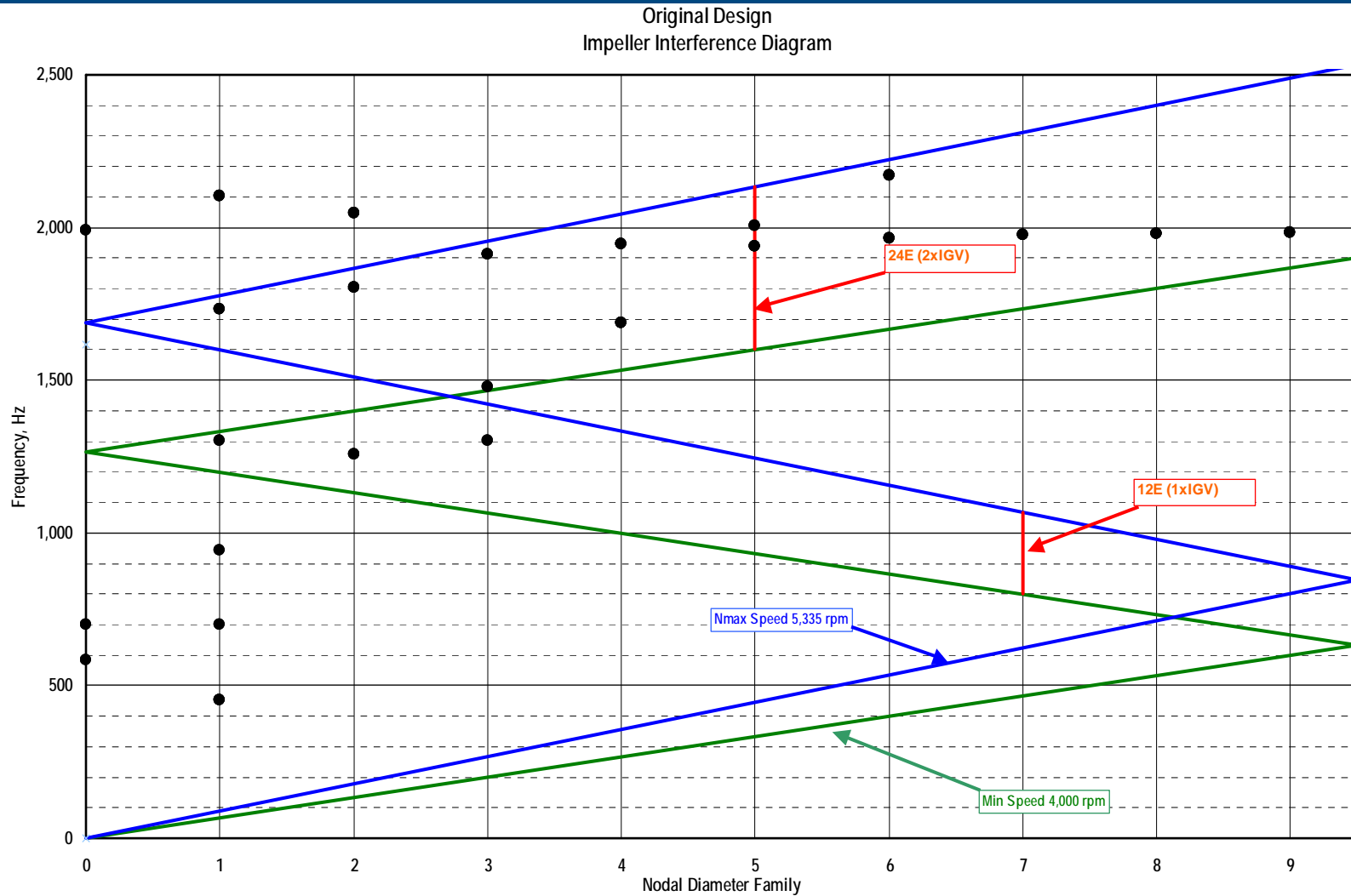


Figure 9: Interference Diagram, Original Design

Forced Response Analysis of Failed Impeller (1)

The Results of the Forced Response Analysis conducted at the possible resonance frequencies are as follows,

- 1) 1937 Hz, 5-ND (1C) – Goodman Factor of Safety 0.9 (Figure 10).**
- 2) 2006 Hz, 5-ND (2C) - Goodman Factor of Safety 1.3 (Figure 11).**
- 3) Goodman Factor of Safety 0.9 and 1.3 for the above cases are less than the acceptable Margin of Safety 1.5.**

Forced Response Analysis of Failed Impeller (2)

Goodman Diagram
Harmonic Response Stresses, 1937 Hz, 5-ND (1C), Original Design

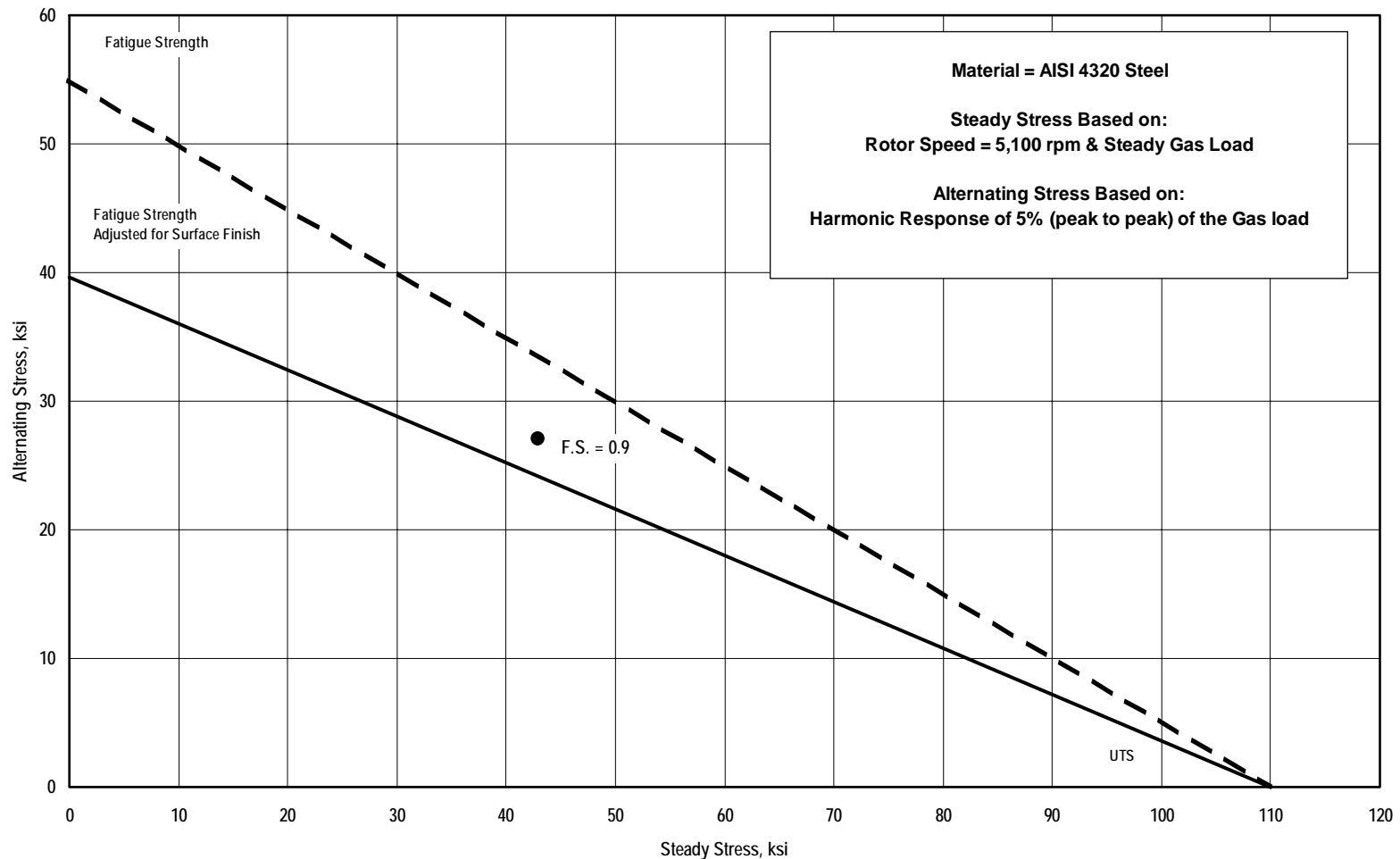


Figure 10: Goodman Diagram, Response Stress, 1937 Hz, 5-ND (1C)

Forced Response Analysis of Failed Impeller (3)

Goodman Diagram
Harmonic Response Stresses, 2006 Hz, 5-ND (2C), Original Design

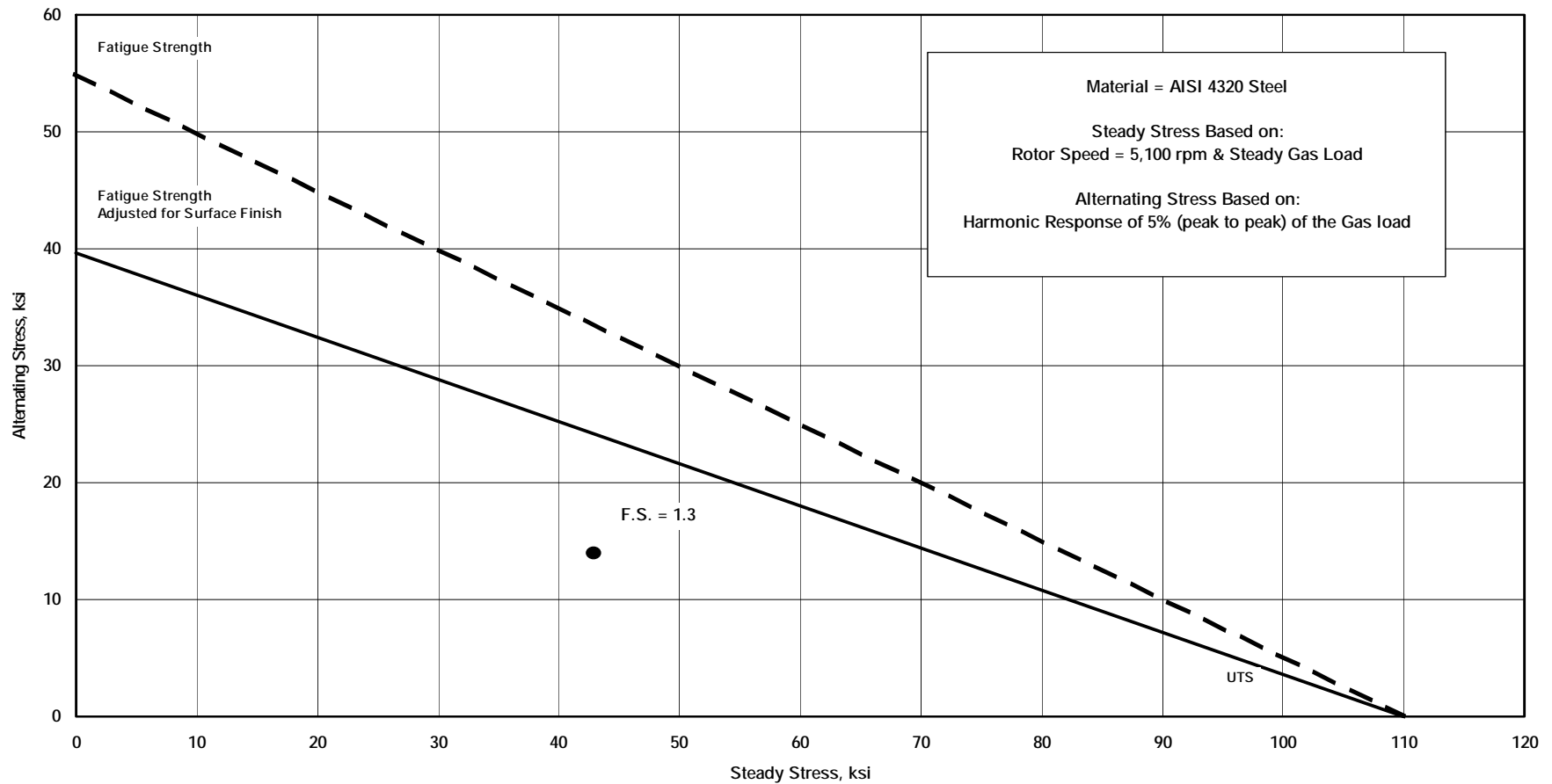


Figure 11: Goodman Diagram, Response Stress, 2006 Hz, 5-ND (2C)

Reason For Failure

- **Possible Resonance condition for 2x(IGV) Forcing frequency with Impeller natural frequencies at 1937 Hz, 5-ND (1C) and/or 2006 Hz, 5-ND (2C) may have caused failure.**
- **Considering Forced Response Stress, Goodman Factor of Safety 0.9 and 1.3 for the above cases are less than the acceptable Margin of Safety 1.5, which eventually may have resulted in the failure.**

Design Modifications

Design Modification:

- 1) Weld repair current damaged impeller.
- 2) Machine back blade Leading Edge 0.75 in. (Re-radius Leading Edge to maintain 0.17 in. normal thickness).
- 3) Perform Modal Analysis and Forced Response Analysis of new assembly.

Affect on Impeller Performance:

- 1) Decreases head approximately 0.65%
- 2) Decreases flow approximately 0.12%

Modified Design (1)

- The FEA Model with modified design, blade trimmed at leading edge by 0.75 inch, was created.**
- The Frequency variation of the Tested Blades with the FEA model was 3.32- 6.38 % (lower).**
- The FEA Model and Modal Analysis results are shown in Figure 12 to Figure 16.**
- The Goodman Diagram Based on the Results of Forced Response Analysis is shown in Figure 17.**

Modified Design (2)

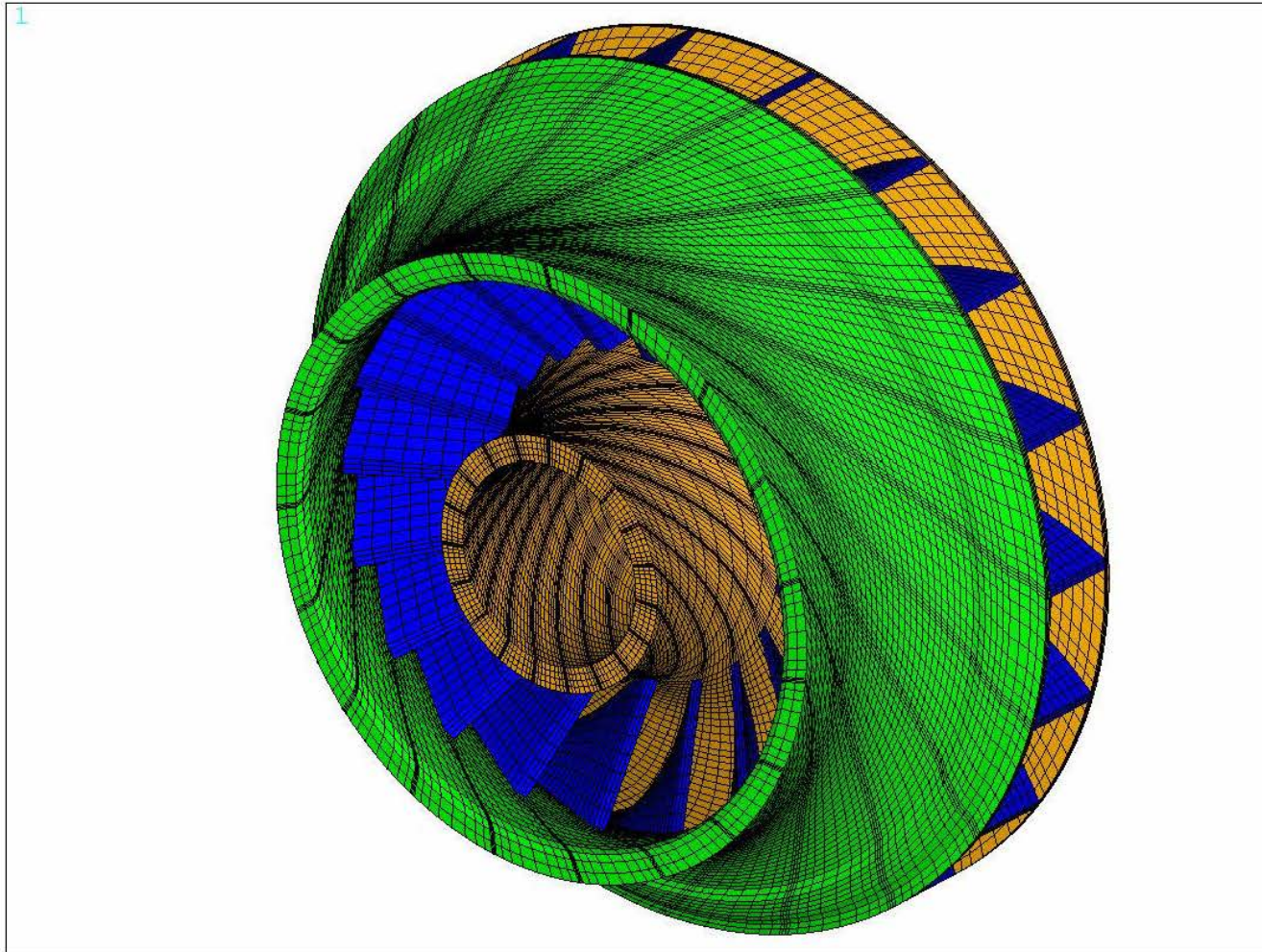


Figure 12: FEA Model Modified Design, Blade Trimmed at Inlet 0.75 in.

Modified Design (3)

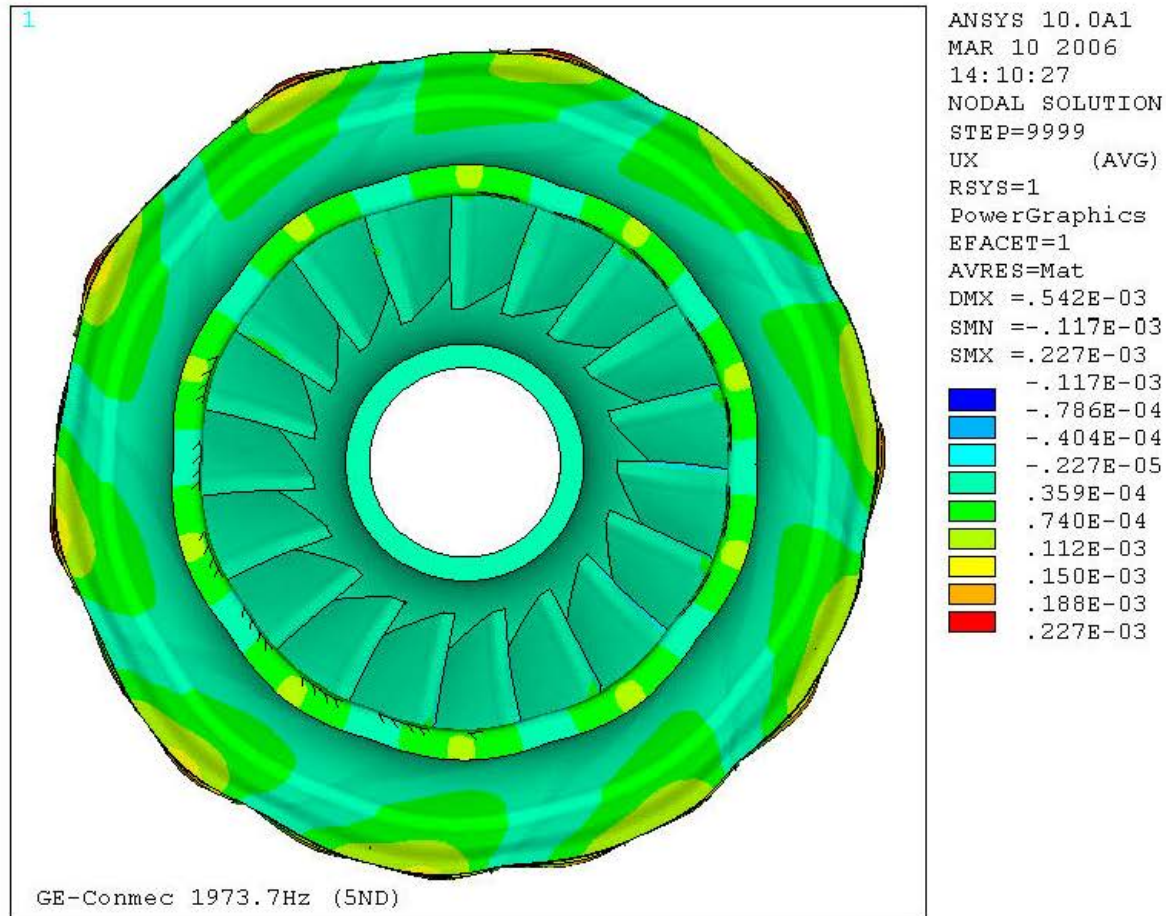


Figure 13: Radial Component, Mode Shape 1974 Hz, 5-ND (1C), Modified Design

Modified Design (4)

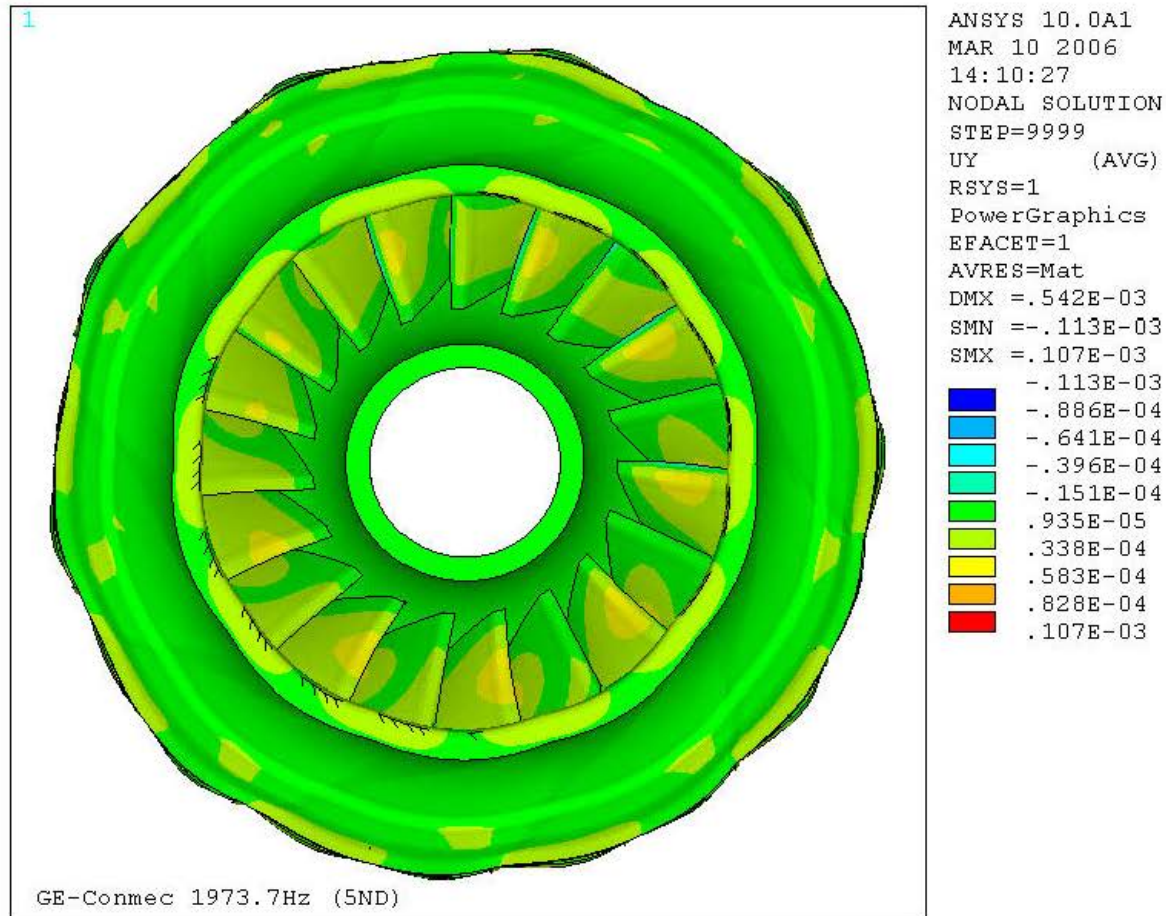


Figure 14: Tangential Component, Mode Shape 1974 Hz, 5-ND (1C), Modified Design

Modified Design (5)

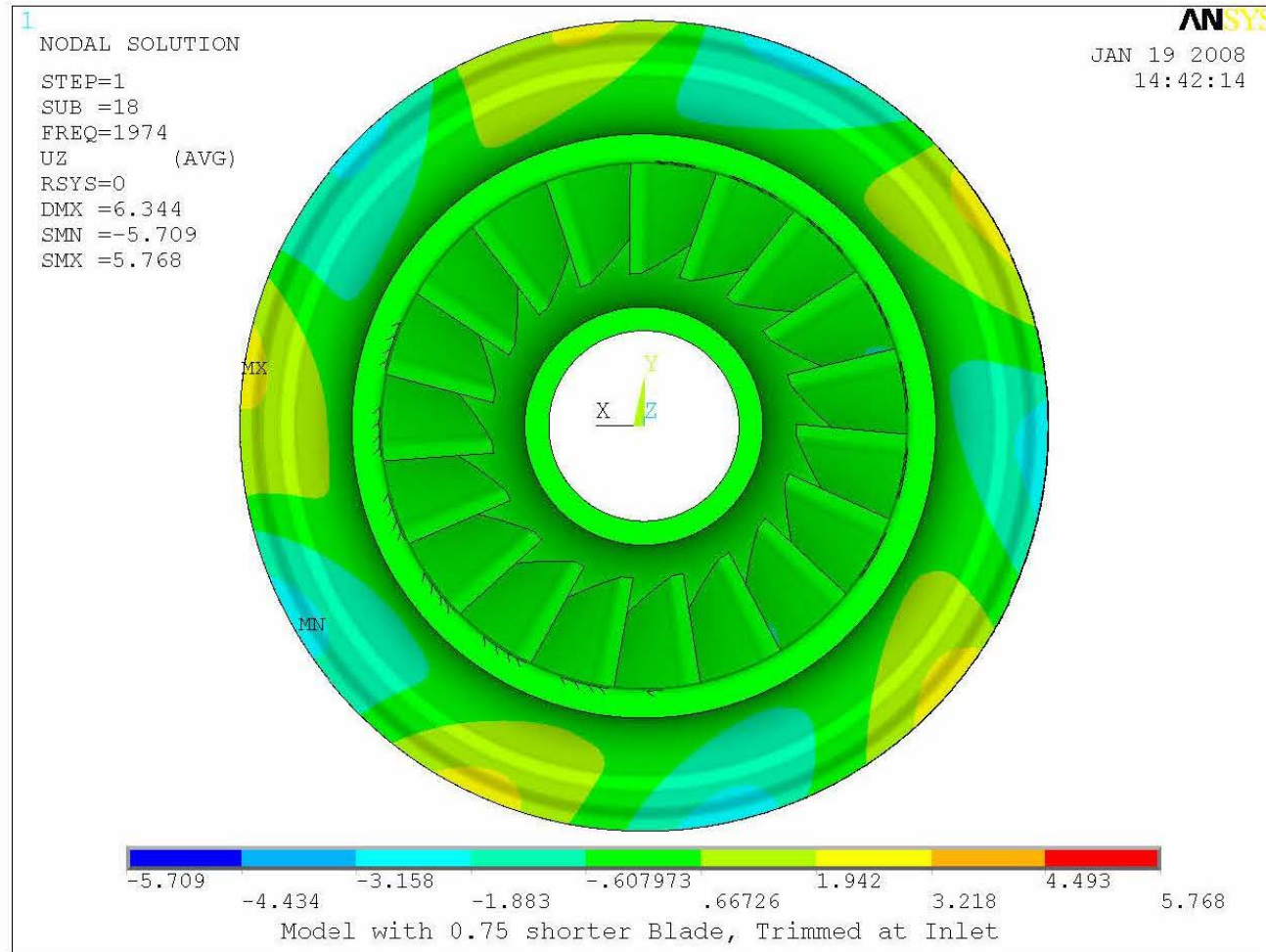


Figure 15: Axial Component, Mode Shape 1974 Hz, 5-ND (1C), Modified Design

Modified Design (6)

Modified Design
Impeller, Blade leading Edge Cut (0.75 inch)

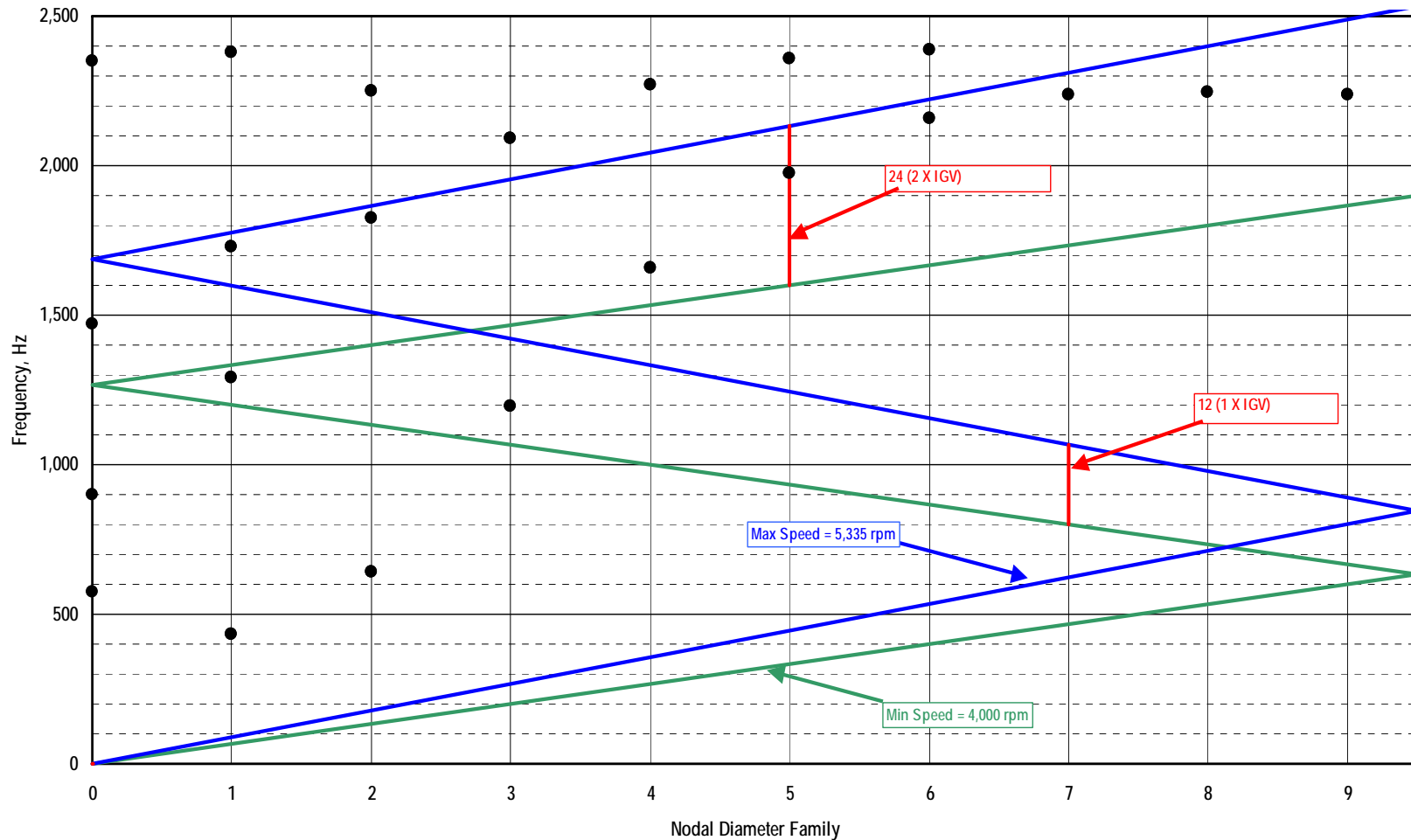


Figure 16: Interference Diagram, Modified Design

Forced Response Analysis – Modified Design (1)

The Results of the Forced Response Analysis conducted at the possible resonance frequency are as follows,

- 1) 1974 Hz, 5-ND (1C) – Goodman Factor of Safety 2.4 (Figure 17).**
- 2) Goodman Factor of Safety 2.4 for the above case is greater than the acceptable Margin of Safety 1.5.**

Forced Response Analysis – Modified Design (2)

Goodman Diagram
Harmonic Response Stresses, 1974 Hz, 5-ND (1C), Modified Design

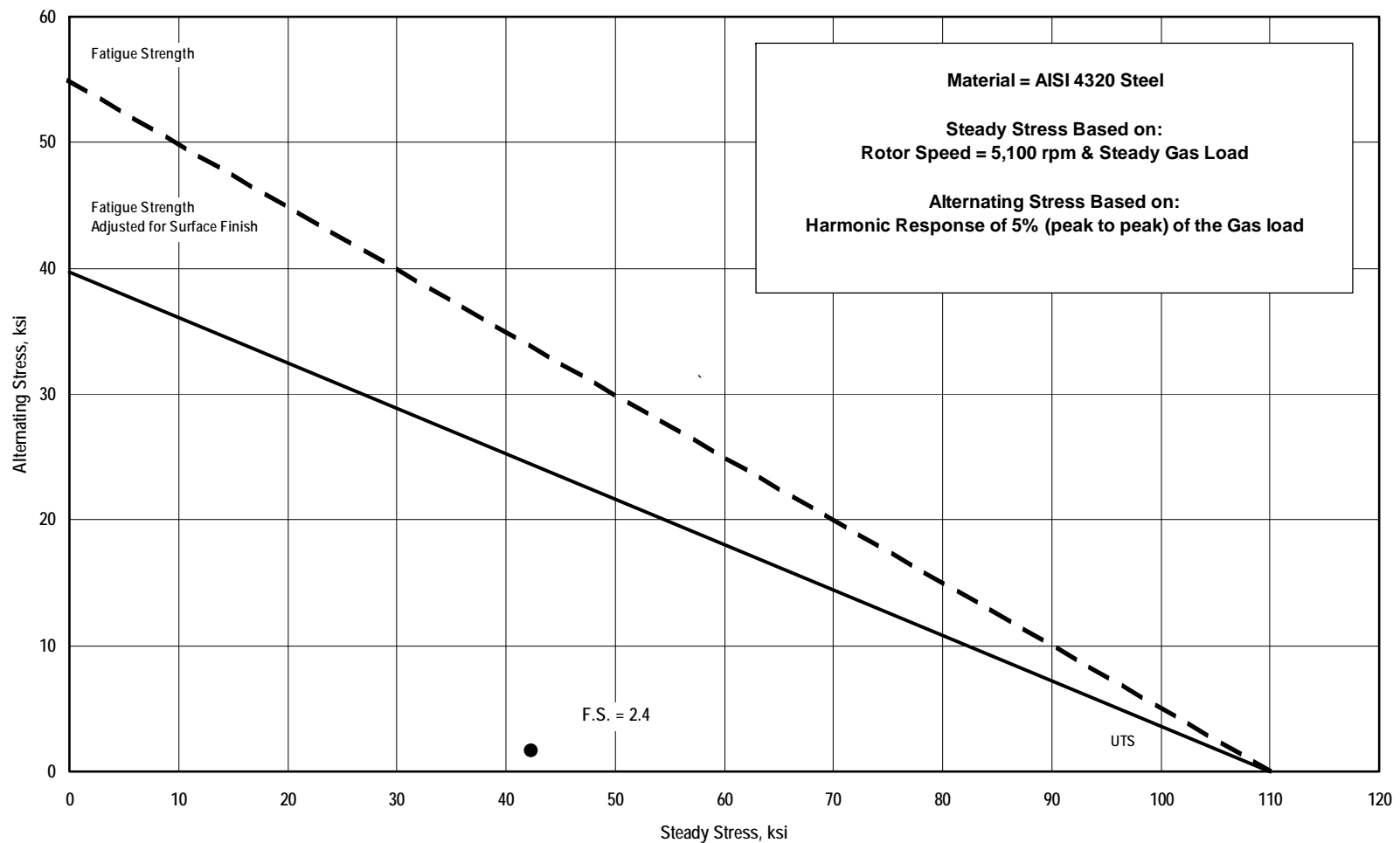


Figure 17: Goodman Diagram, Response Stress, 1974 Hz, 5-ND (1C)

Conclusion

❖ **Original design was modified:**

- 1) **Blade trimmed at leading edge by 0.75 inch.**
- 2) **Damaged blades repaired.**

❖ **The above modifications resulted in increased Impeller frequencies and acceptable Goodman Factor of Safety:**

- 1) **1937 Hz, 5-ND (1C) increased to 1974 Hz, 5-ND (1C) and Goodman Factor of Safety increased from 0.9 to 2.4**
- 2) **2006 Hz, 5-ND (2C) increased to 2357 Hz, 5-ND (2C) Out side range of the Forcing Frequency.**

❖ **The unit with the modified design has been in service during the past last 3 years without a failure.**