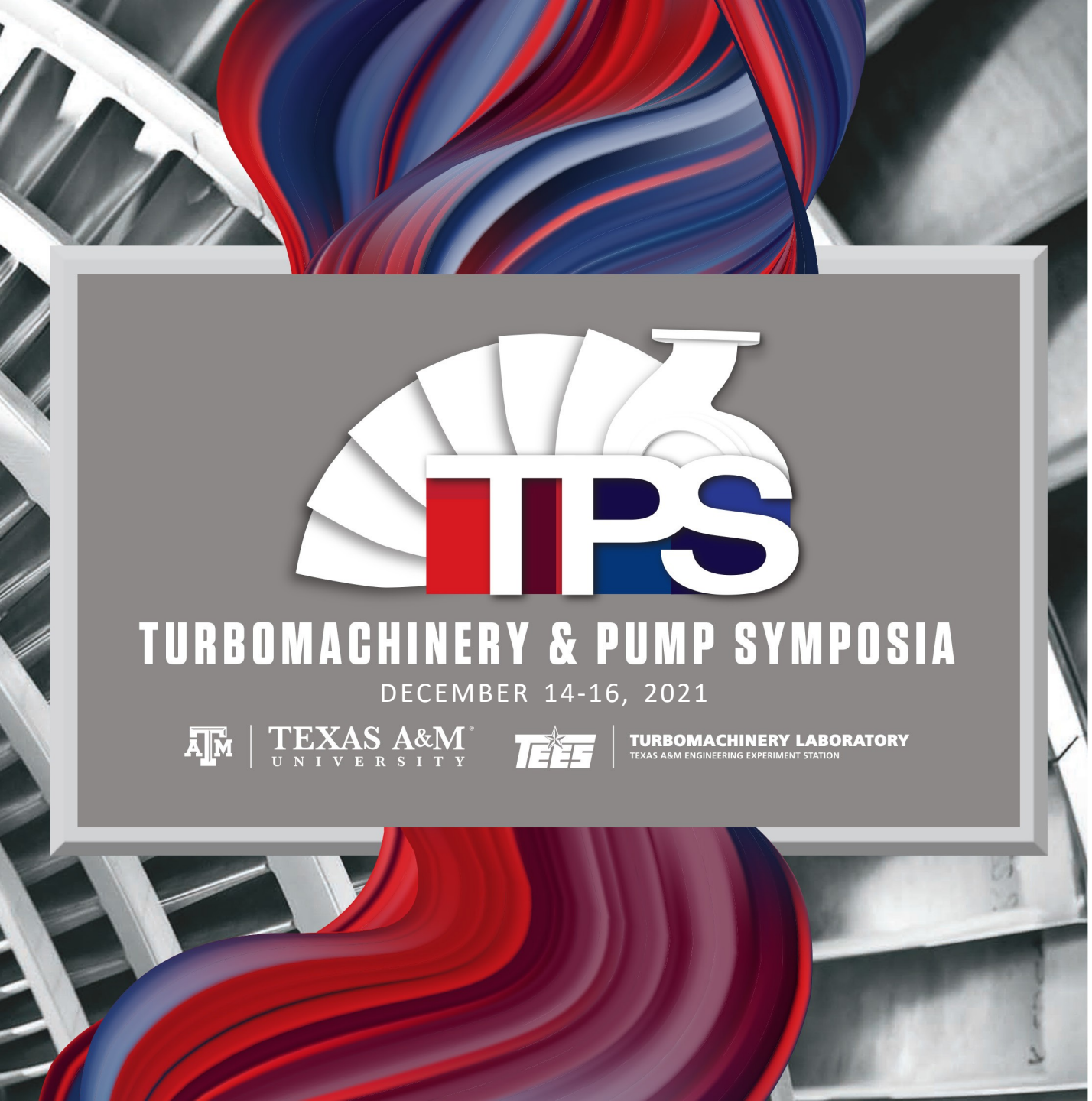

Effect of swirl canceller on impeller excitation

MITSUBISHI HEAVY INDUSTRIES COMPRESSOR

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Abstract

This case study is concerned with effect of the swirl canceller for impeller excitation force of integrally geared compressor.

The 5th stage shaft vibration of booster air compressor showed abnormal behavior as the discharge pressure was increased. The compressor load could not be increased due to high shaft vibration.

As a result of the frequency analysis of the shaft vibration, it was found that the vibration component around eigenvalue of the rotor was excited.

This study shows the details of root cause investigation and preventive measures for increase of shaft vibration.

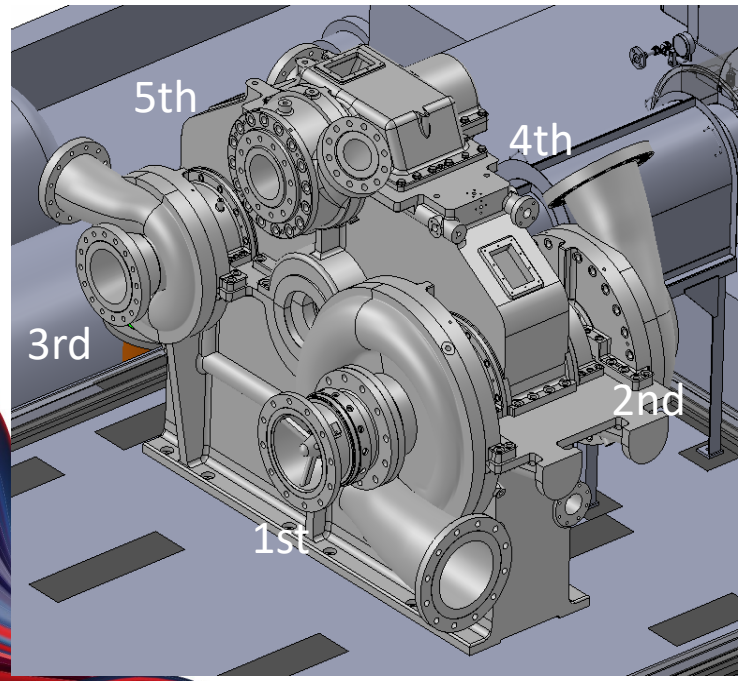
Contents

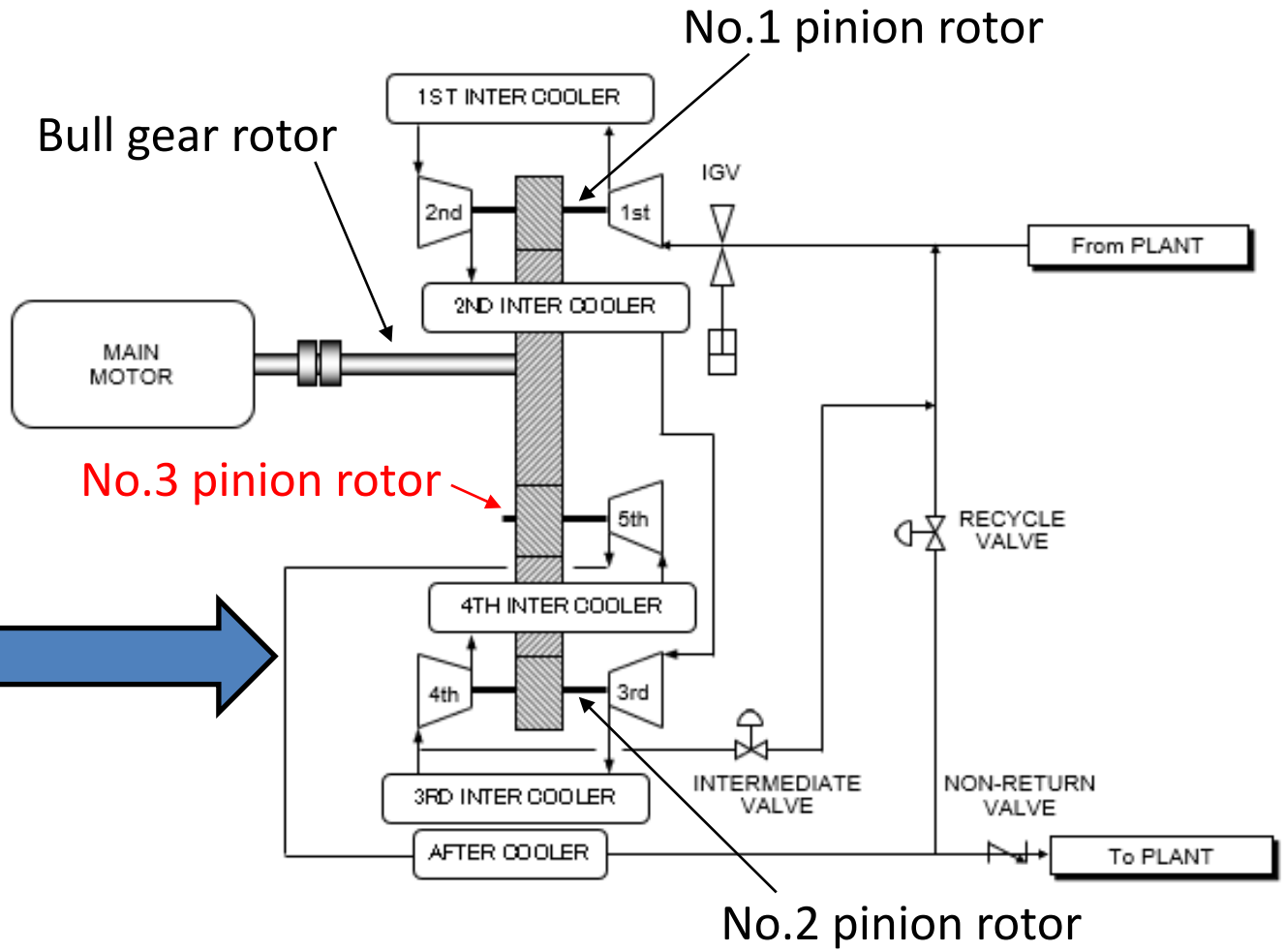
1. Machine configuration
2. Phenomenon
3. Root cause analysis
4. Detail investigation of impeller excitation force
5. Countermeasure
6. Future study
7. Conclusion
8. Lessons learned

1. Machine configuration

- This case study mainly deals with the 5th stage of this integrally geared compressor.

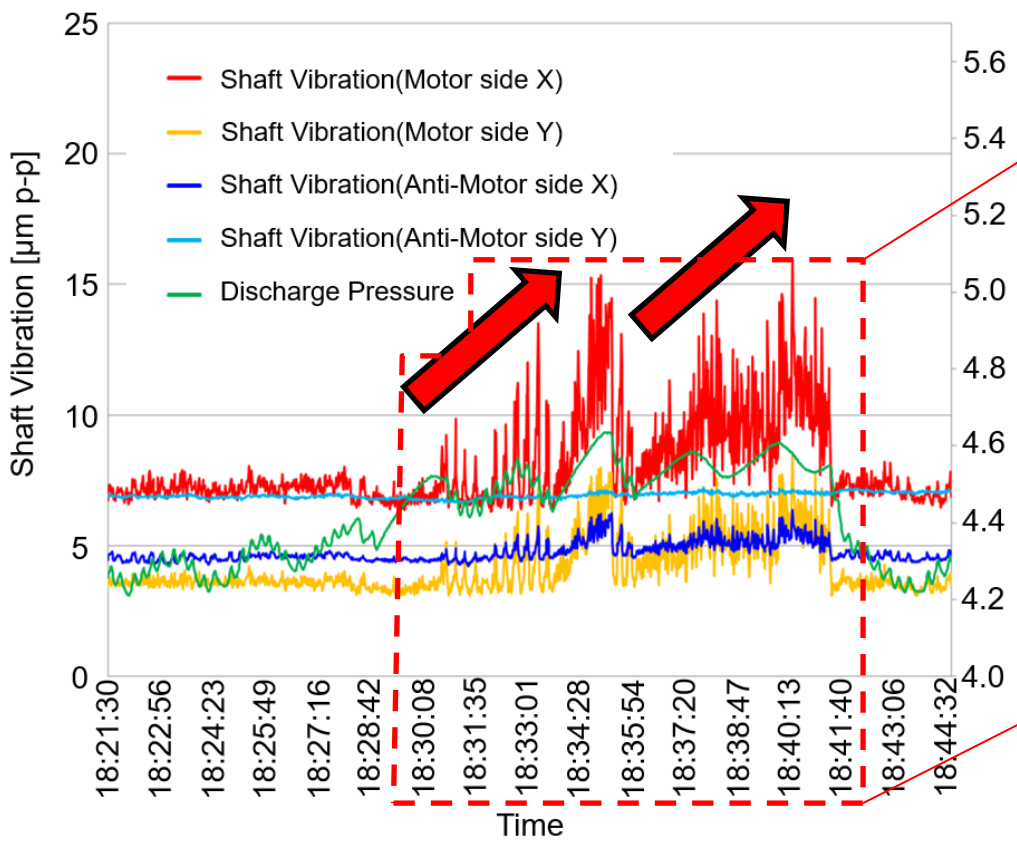
Service	Booster Air Compressor
Speed	No.1 & 2 pinion: Approx. 16k rpm No.3 pinion: 29,000 rpm Bull gear:1,800rpm
Shaft power	8.0 MW
Process Gas	Air
Suction gas press.	448 kPaG (64.9psiG)
Discharge gas press.	5700 kPaG (826.7psiG)

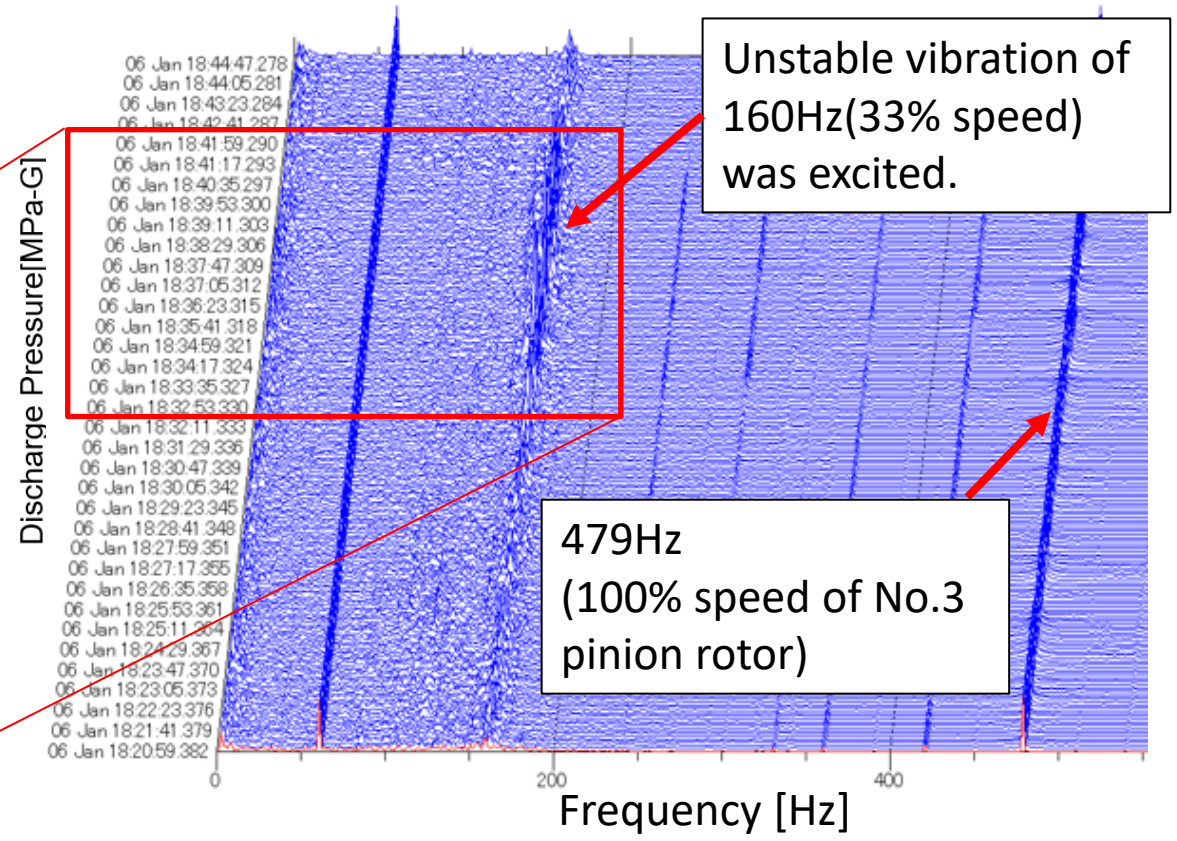




2. Phenomenon

- Abnormal vibration phenomenon was observed during operation of No. 3 pinion rotor around MCS (29,000 rpm)
- The main frequency of the unstable vibration was 160 Hz, which was different from the frequency of the shaft rotation (1X)
- The unstable vibration increased with the compressor load





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3. Root cause analysis

Phenomenon	Possible Cause	Possibility
Unstable vibration phenomenon caused by the excitation of 160 Hz which is close to the eigenvalue of the No.3 pinion rotor as increasing the compressor load.	Rotor Unbalance	Low
	Coupling Unbalance	Low
	Excitation force for gear mesh	Low
	Rubbing (rotor/stator)	Low
	Rotating Stall	Low
	Surging	Low
	Bearing Oil Whirl	Low
	Impeller & Labyrinth Excitation Force	**High**
	Failure of vibration sensor	Low

- The unstable vibration increased with the compressor load
- The unstable vibration at 160 Hz was close to the first eigenvalue of the rotor.
  (Calculated 1st critical speed
  : 9800rpm (163 Hz))

- Excessive impeller and labyrinth excitation forces were determined to be the main cause.

4. Detail investigation of impeller excitation force

Log decrement of No. 3 pinion rotor was calculated under actual operating conditions based on API 617 Level - II Analysis.

The Level-II calculation is used to evaluate the aerodynamic excitation forces of the labyrinth seal and impeller.

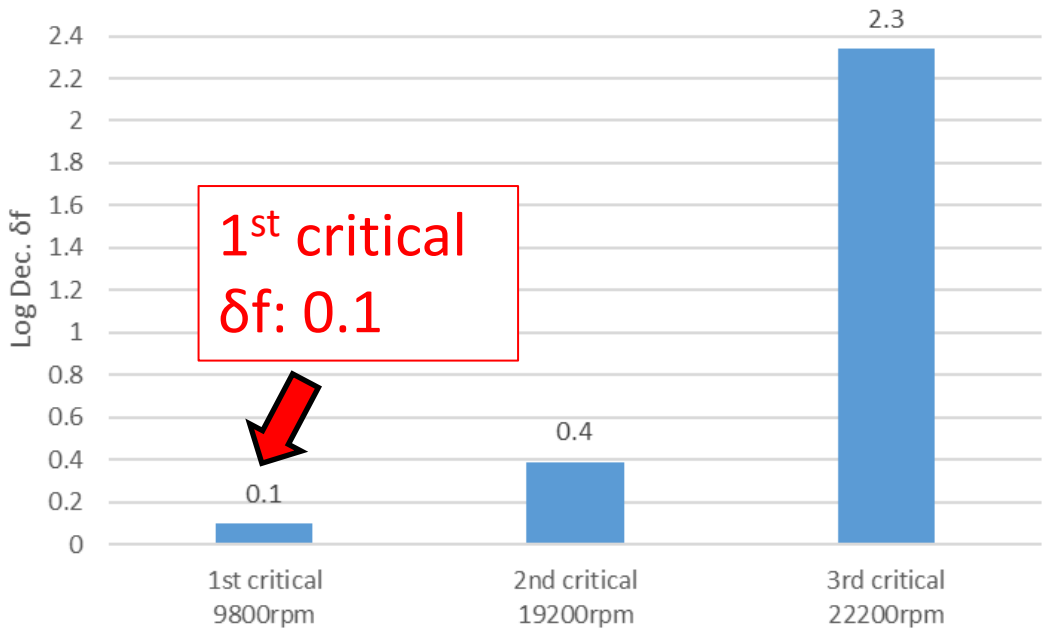
The cross coupling of the impeller excitation force was calculated by the modified alford's equation.

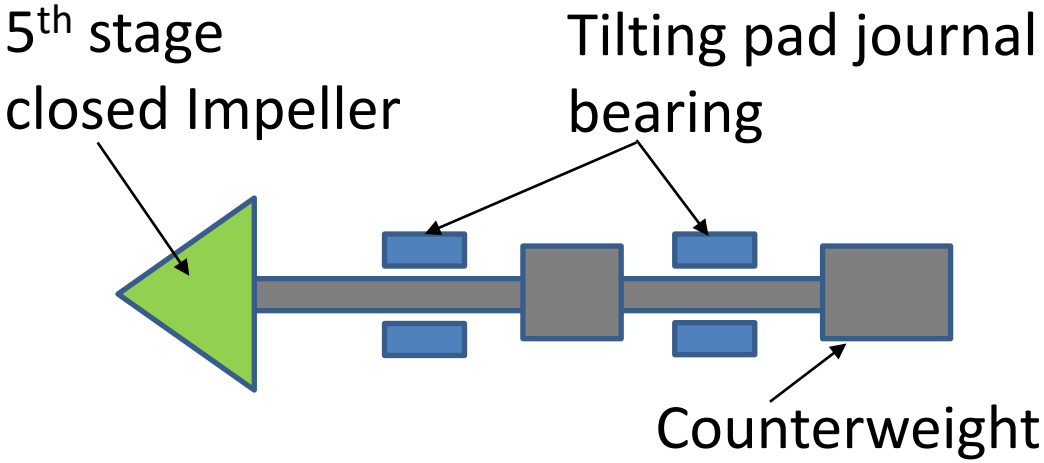
Labyrinth seals were calculated using OEM internal calculation tools which is based on the 1 control volume bulk flow code.

4. Detail investigation of impeller excitation force

- The value of Log decrement of the 1st critical speed was the smallest compared with other critical speeds.
- Log decrement at the 1st critical speed was 0.1.

➡ Further investigation was performed focused on gas excitation force



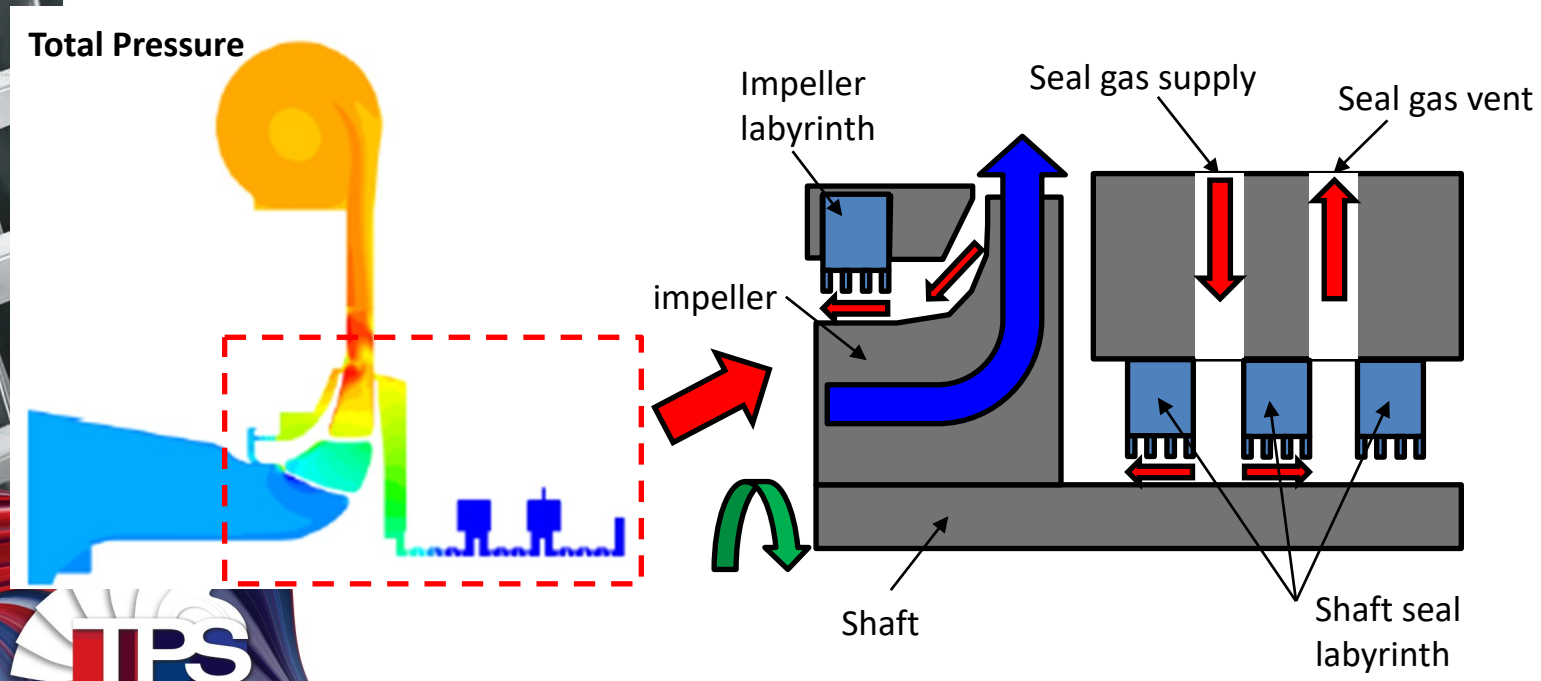


Rotor stability analysis for No.3 pinion rotor

4. Detail investigation of impeller excitation force

- CFD calculations by steady condition at 10% eccentricity of labyrinth seal clearance were performed to evaluate the detailed excitation force of the pinion rotor.

- Cross-coupled stiffness K was calculated by using by following formula.
  Fluid force F of each component was calculated by direct CFD analysis.



$$F/e = K\text{-}C \cdot \Omega$$

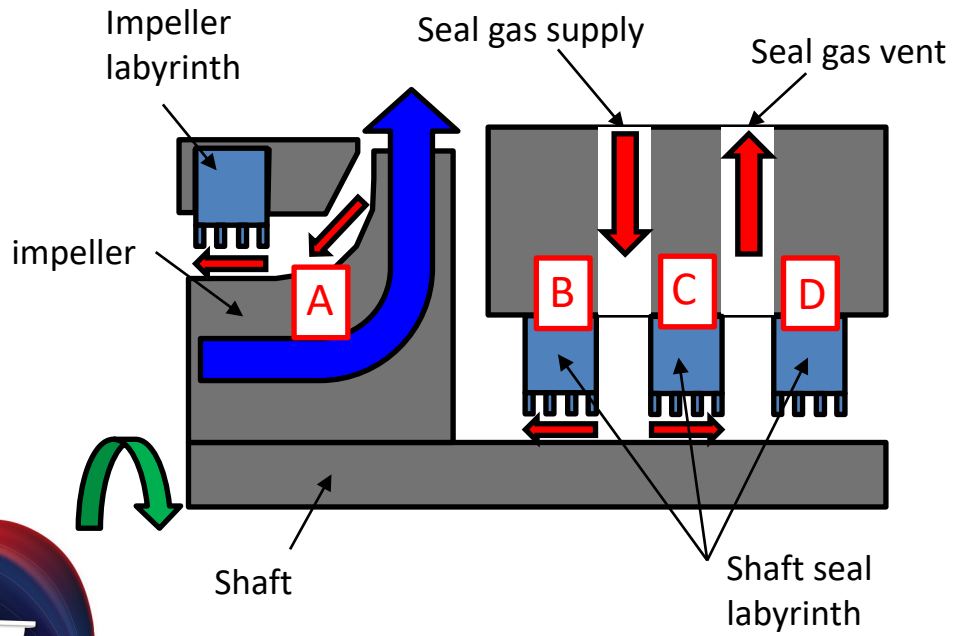
F: Fluid force
e: Static eccentricity
K: Cross-coupled stiffness
Ω: Whirl speed

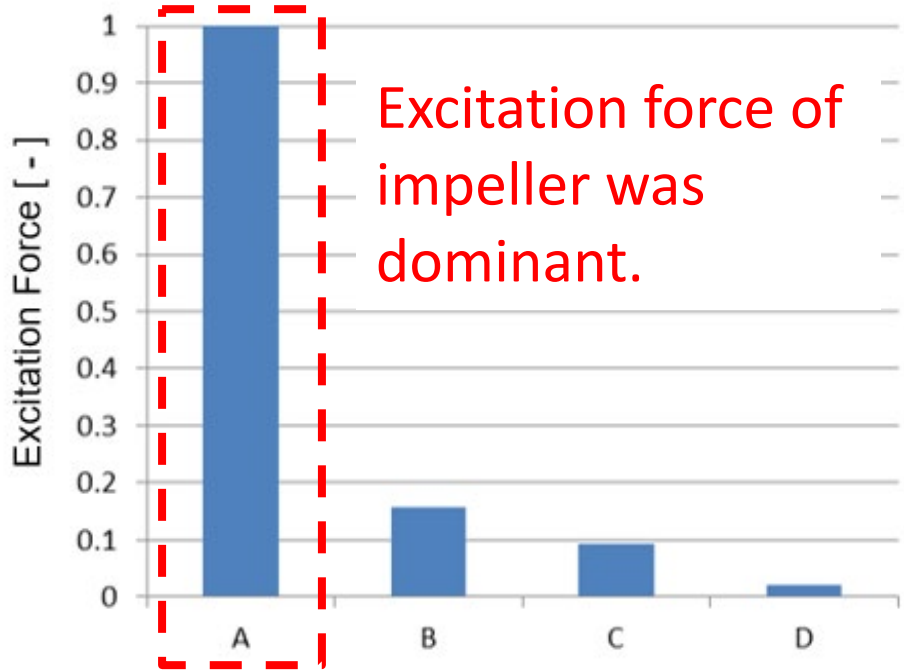
CFD analysis model for excitation force

4. Detail investigation of impeller excitation force

- The excitation force A was included in the impeller and impeller labyrinth seal.
- It was proven that the closed impeller was main source for the excitation force.

➡ It is important to reduce the excitation force of the impeller.





CFD analysis result for excitation force

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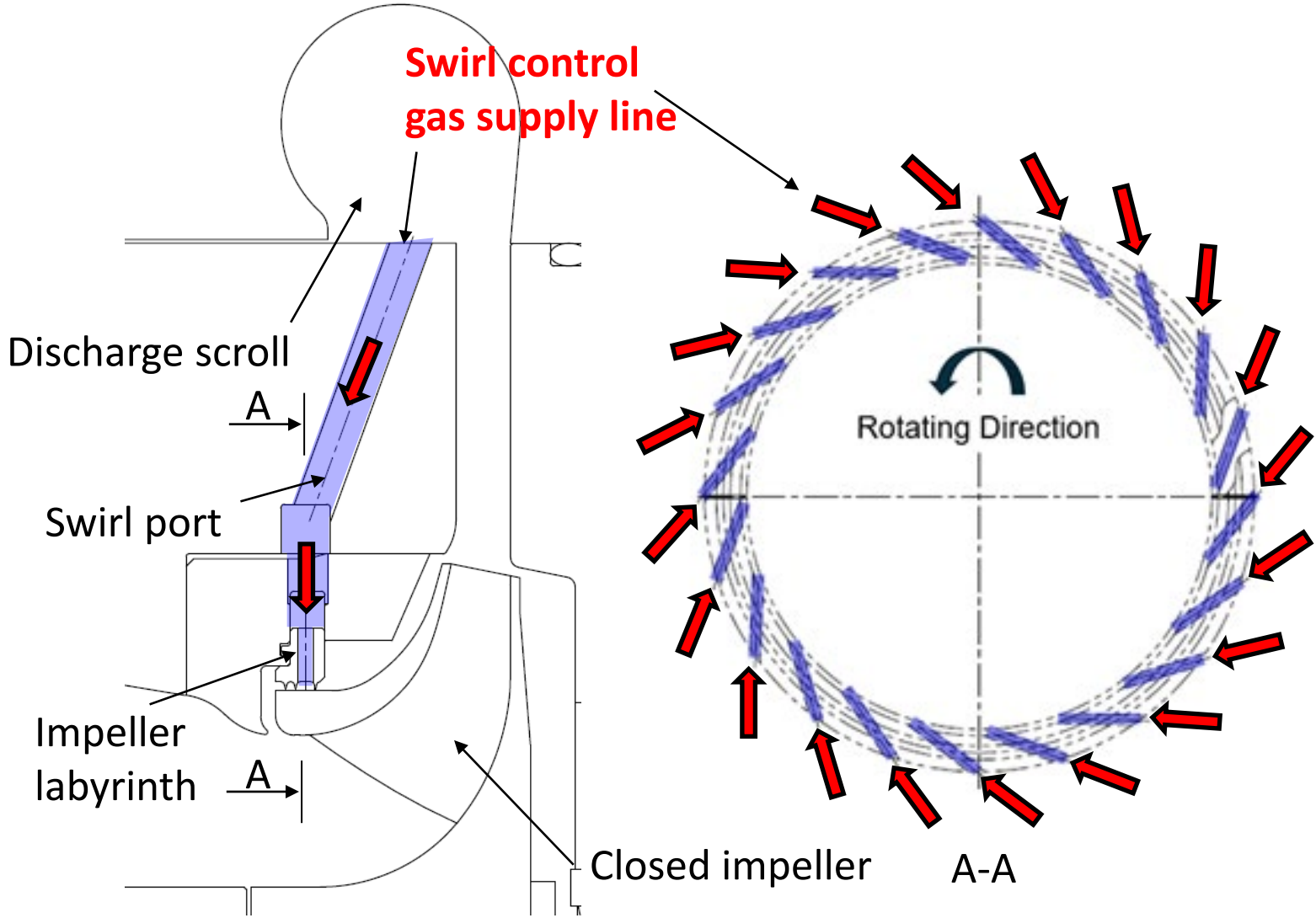
5. Countermeasure

What is a swirl canceller?

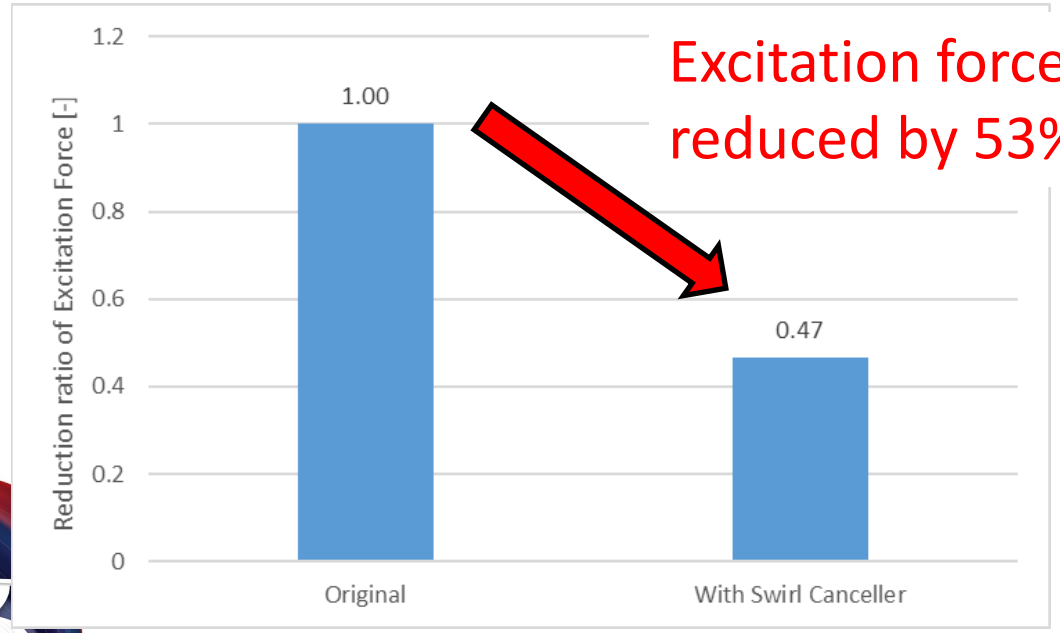
- Excitation force is generated in the labyrinth seal by swirling flow along the rotational direction.
- In order to reduce the swirl, process gas is injected to impeller labyrinth seal using the swirl port which is machined to the counter rotating direction.

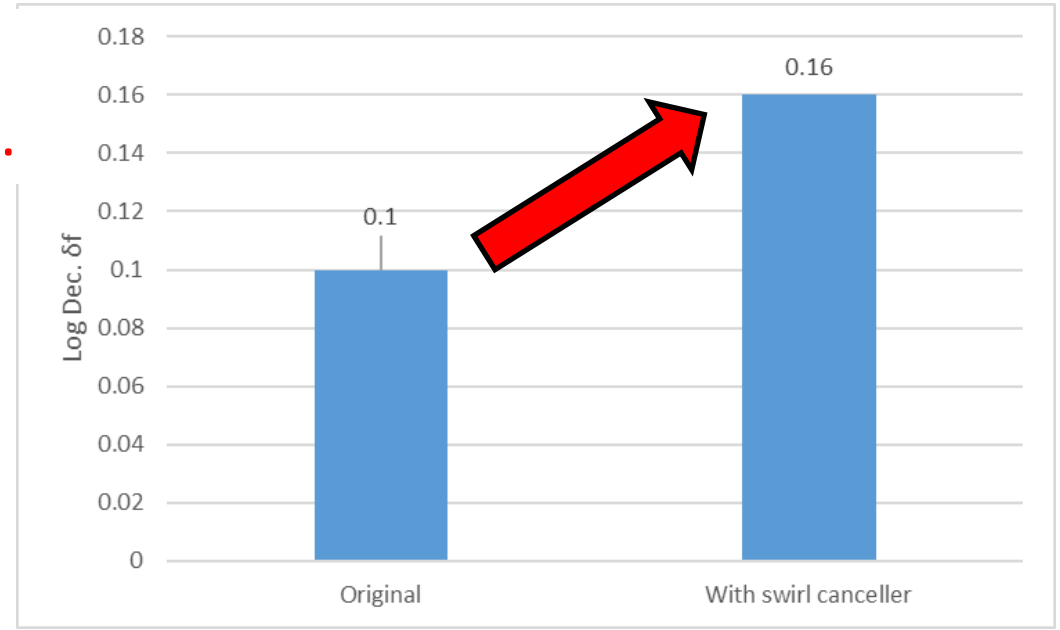


Detail of Swirl Canceller

5. Countermeasure

- By application of swirl canceller, the excitation force could be reduced by 53%
  (Polytropic efficiency was reduced by approx. 1% at 5th stage.)
- The log decrement of the 1st critical speed was improved from 0.10 to 0.16.
- Log dec. improvement comes from only the reduction of labyrinth seal excitation force by applying the swirl canceller.





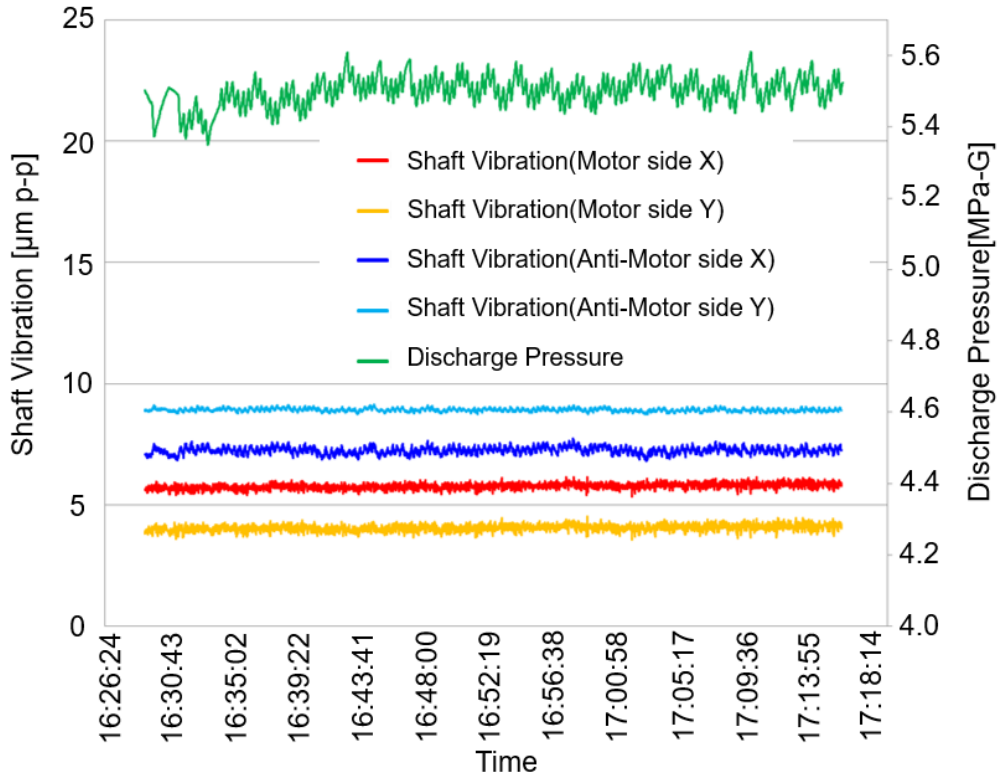
Excitation force

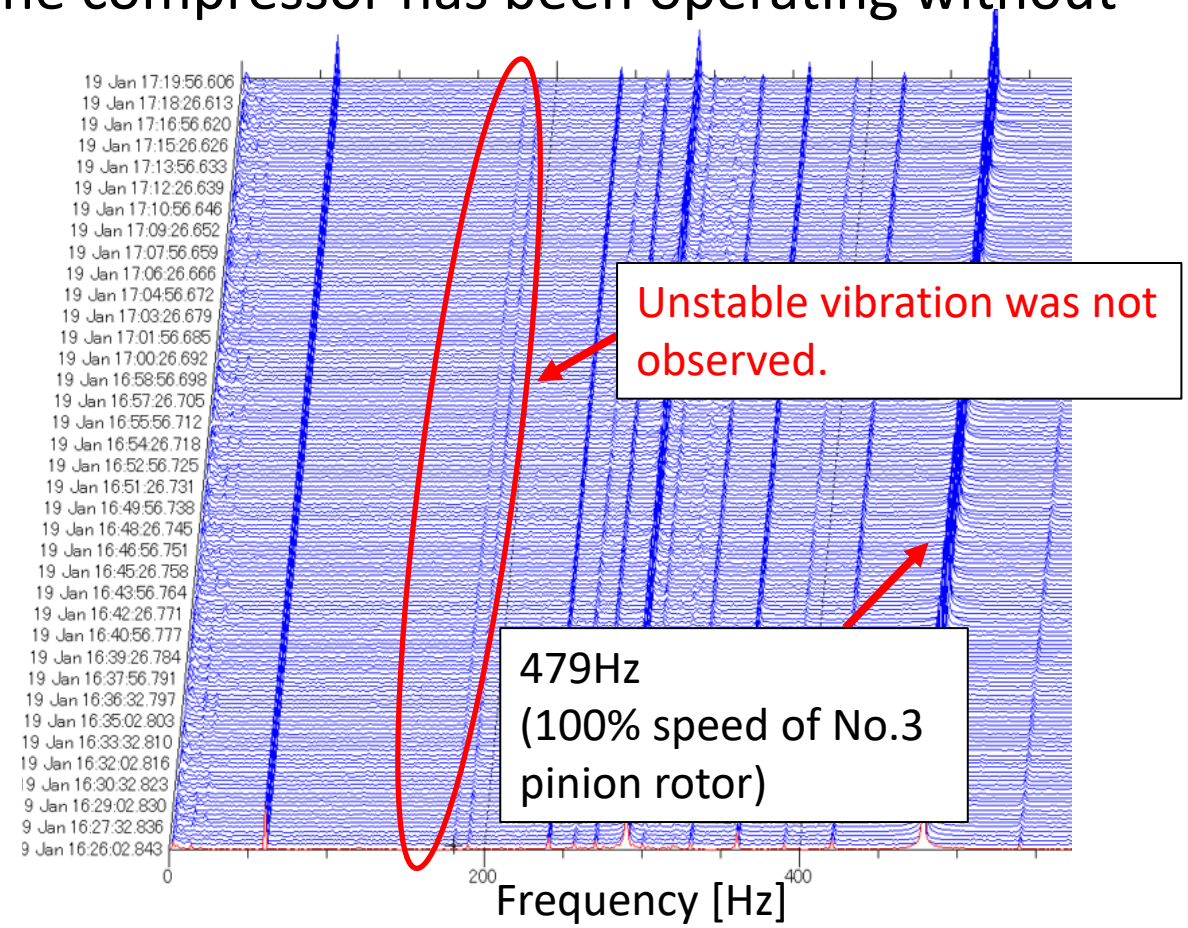
Log decrement of 1st critical speed

Effect of Swirl Canceller on Excitation force

5. Countermeasure

- Unstable vibration during site operation was not observed after application of swirl canceller at full load
- After the countermeasures were applied, the compressor has been operating without any trouble for past three years



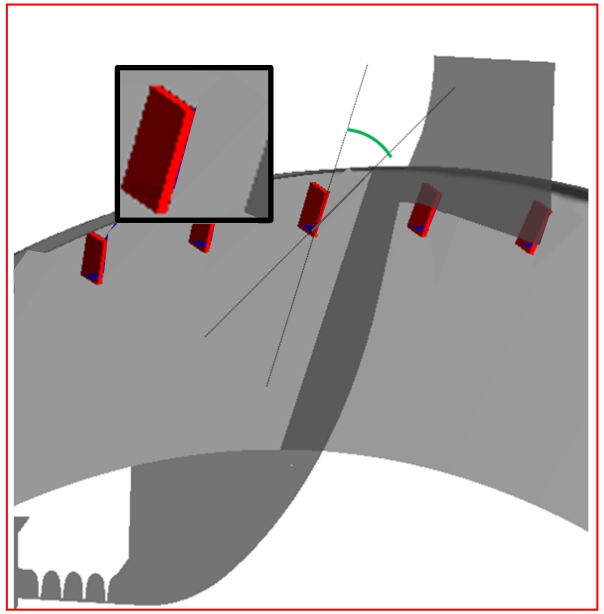


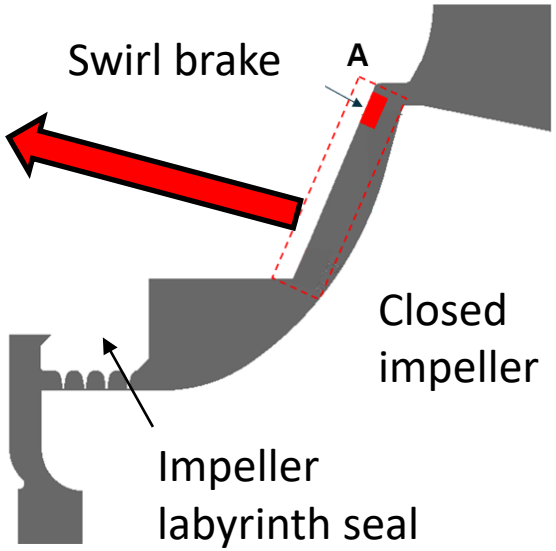
Operating Record after application of swirl canceller

6. Future study

In order to further reduce the impeller excitation force and improve the compressor performance, OEM is currently investigating a new swirl brake design instead of swirl canceller.

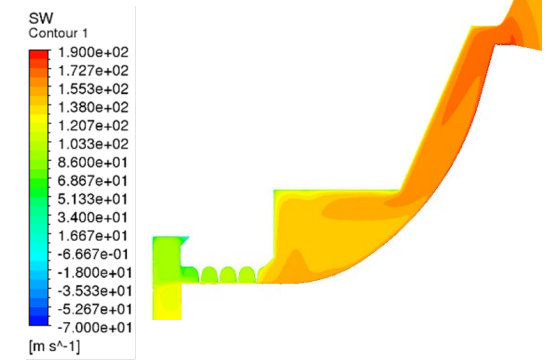
- The swirl brake is installed in the shroud part of the impeller to break the swirl flow
- The swirl brake does not require any injection of swirl control gas
- Optimization of the swirl brake is currently being investigated





Swirl contour

Detail A



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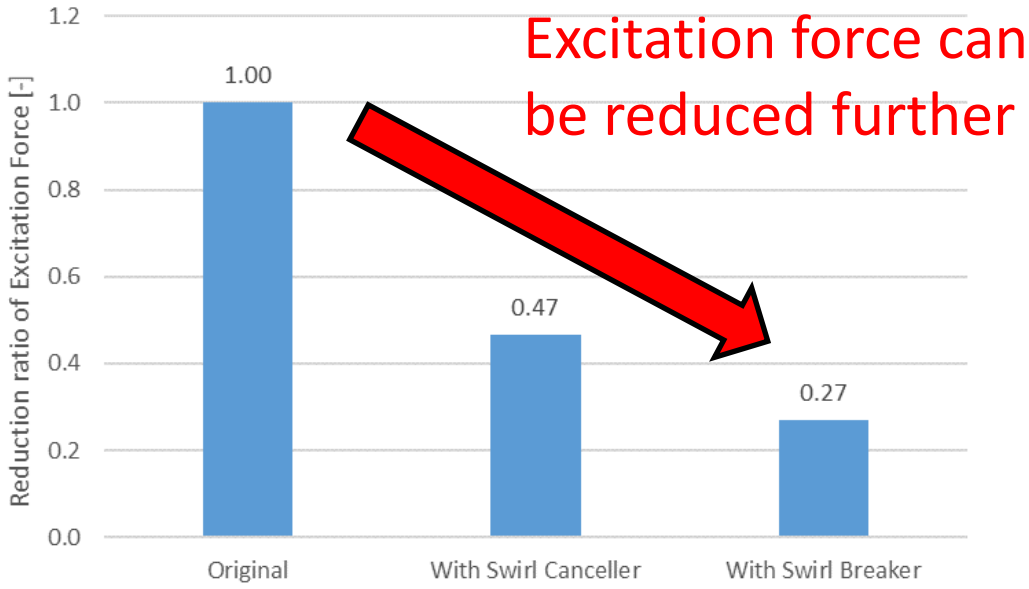
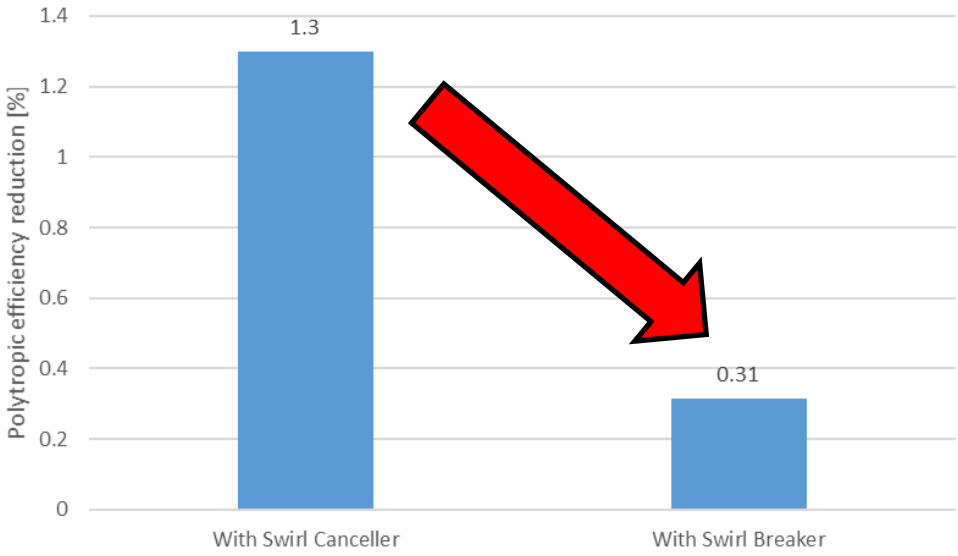
6. Future study

The impeller excitation force and compressor performance could be improved by the application of new swirl brake design



Performance loss can be improved because seal leakage are reduced.



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7. Conclusion

- The unstable vibration phenomenon of 160 Hz was caused by the excitation of the eigenvalue of the No. 3 pinion rotor and a subsequent increase in the shaft vibration was observed with the compressor load
- As a result of the CFD analysis, it was found out that impeller excitation force was the dominant factor
- As a countermeasure, application of swirl canceller to labyrinth seal was evaluated and it was confirmed that the impeller excitation force can be reduced thereby eliminating the unstable vibration phenomenon
- Further reduction of excitation force and improvement of compressor performance can be expected by applying a new swirl brake design to the impeller shroud instead of a swirl canceller. This is currently being investigated by the OEM

8. Lessons Learned

- There is a possibility that the excitation force of the impeller and impeller labyrinth is excessive when asynchronous vibration in which the eigenvalue of the rotor is excited is generated.
- In order to reduce the excitation force of the impeller and impeller labyrinth, it is effective to apply a swirl canceller to the impeller labyrinth.
- As another approach for stability improvement, there is a method improving the damping effect by modifying the journal bearing. In this case, it is necessary to confirm the rotor lateral analysis because bearing stiffness and damping is changed.

Thank you for your attention !

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