ASIA TURBOMACHINERY & PUMP SYMPOSIUM
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FLOW INDUCED VIBRATION PROBLEM DURING FULL LOAD TESTING OF A MULTI-STAGE CENTRIFUGAL COMPRESSOR

Mr. Yutaka Kurashiki
Kawasaki Heavy Industries, Ltd

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TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

TEXAS A&M UNIVERSITY

Author bios

- Mr. Yutaka Kurashiki — Manager
  Engineering and development section
  Aero-dynamic machinery department
  Machinery Division, Kawasaki Heavy Industries, Ltd

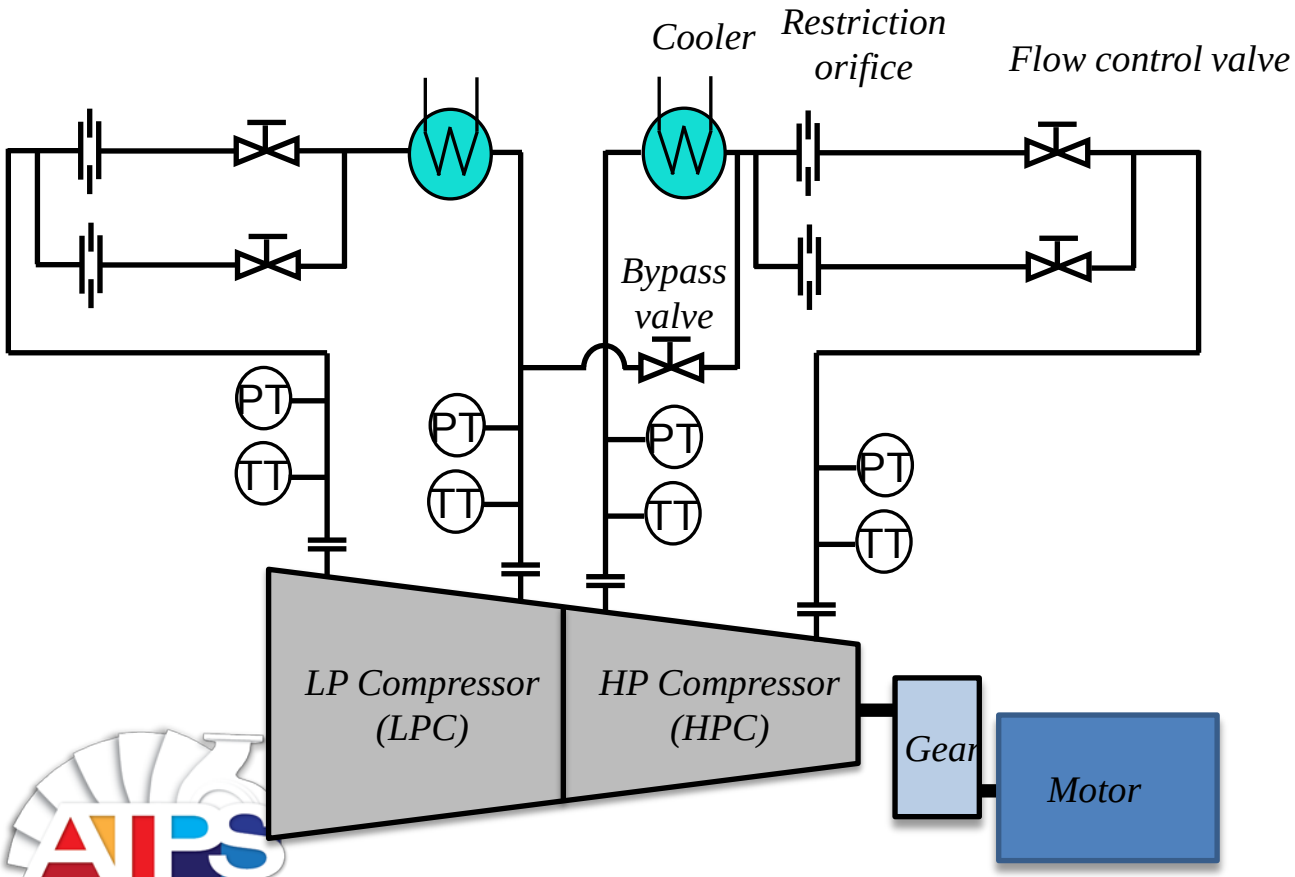
- Mr. Takahiro Hirao — Senior manager
  Aero-dynamic machinery department
  Machinery Division, Kawasaki Heavy Industries, Ltd

- Mr. Hidenori Yoshida — Senior researcher of aerodynamics
  Aero-dynamic machinery department
  Machinery Division, Kawasaki Heavy Industries, Ltd

Abstract

- During FAT of a centrifugal compressor, non-synchronous vibrations were observed. The dominant frequencies are different from both a) the rotor system natural frequency, and b) typical rotating stall frequency in parallel wall diffuser.
- Investigation is conducted and found that the downstream flow control valve generates pressure pulsation and it caused rotor vibration.
- As a practical solution, the flow control valve location is modified and this result in the lower pressure fluctuation and vibration amplitude.
- CFD analysis illustrates the actual phenomena qualitatively.

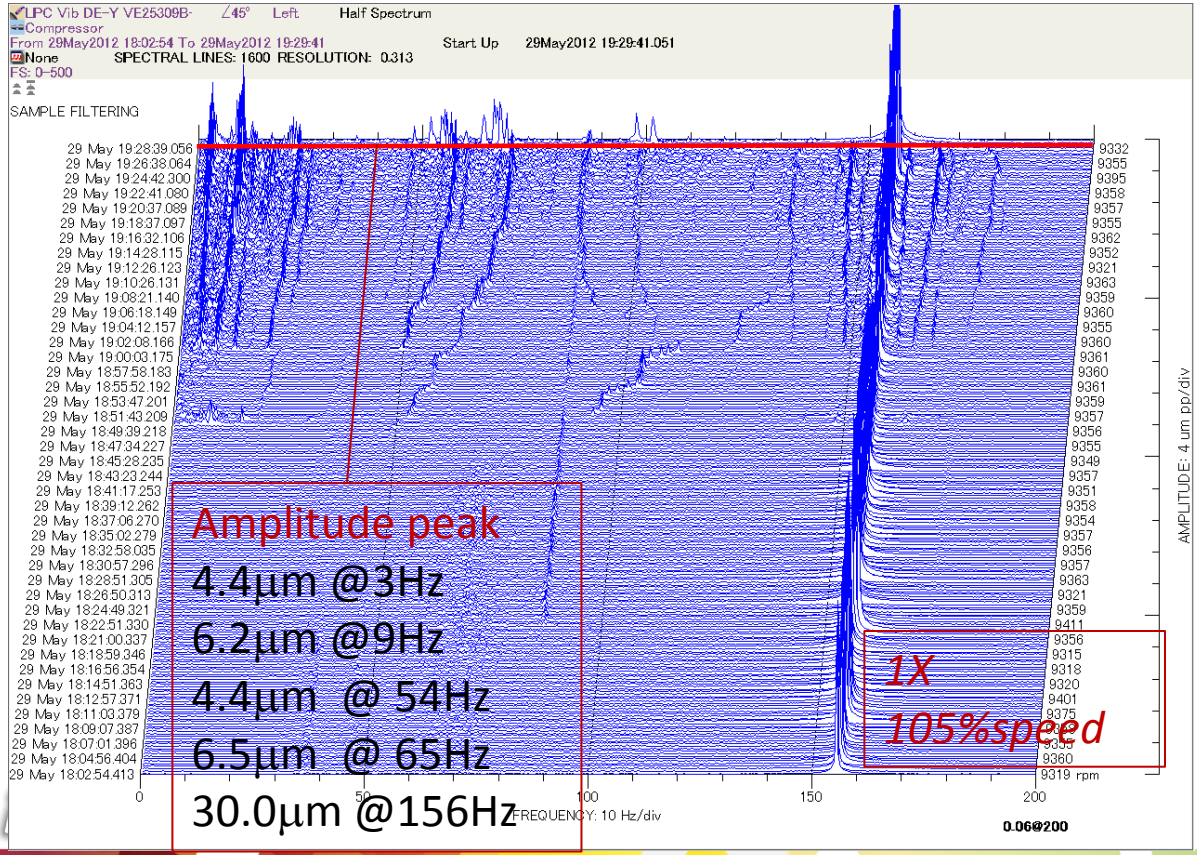
Factory test configuration



Compressor : 8 stages,
2 sections

Test condition
Gas = CO2(100%)
Ps=1 barG
Pd=63 barG
N= 8910rpm(100%)
9356rpm(105%)
Power = 6900kW(approx)

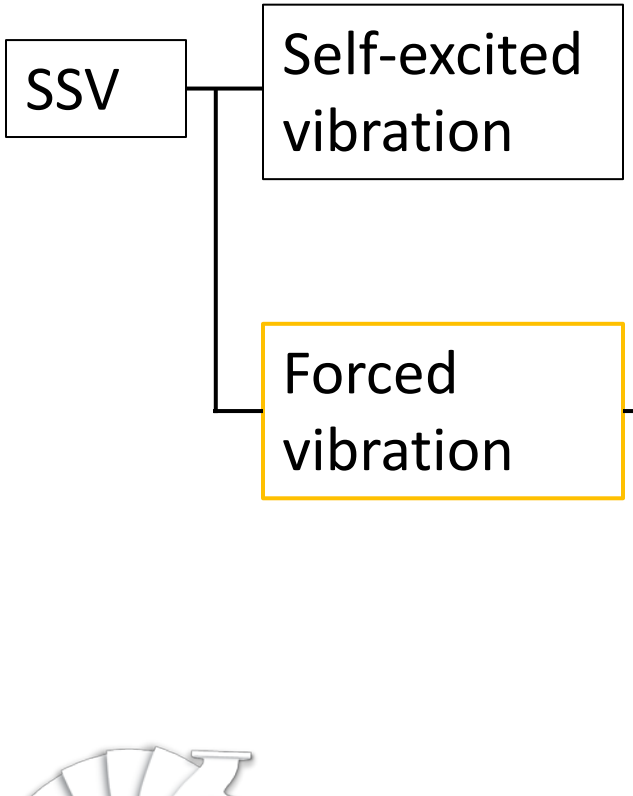
Sub synchronous vibration (SSV)



Features

- SSV observed as discharge pressure increased.
- Several frequencies are dominant.
- Some frequencies are changed as discharge pressure change.

Root cause analysis –(1)



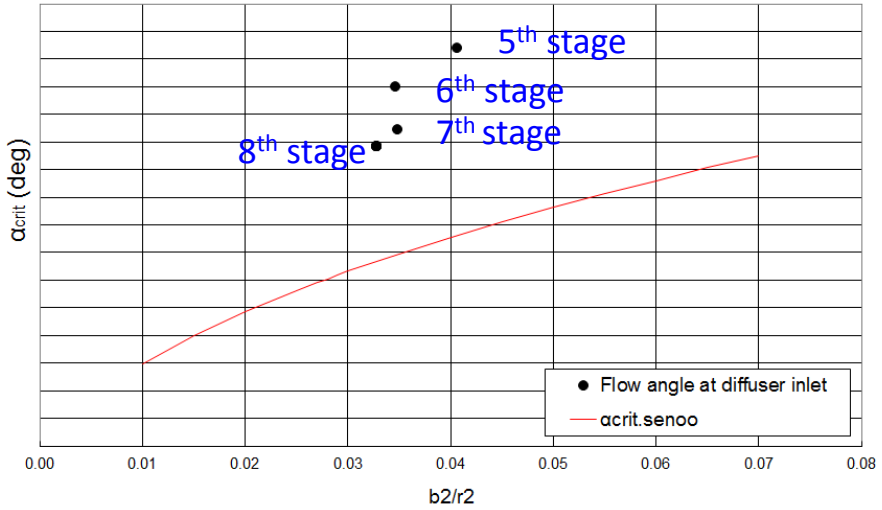
Typical frequency is NOT the system natural frequency(70Hz) and log dec is sufficiently large (= 0.7,approx.)

Flow angle meets the Senoo criteria.

Bend pipe and/or valves sometimes generate strong vortex, which may possibly excite the rotor.

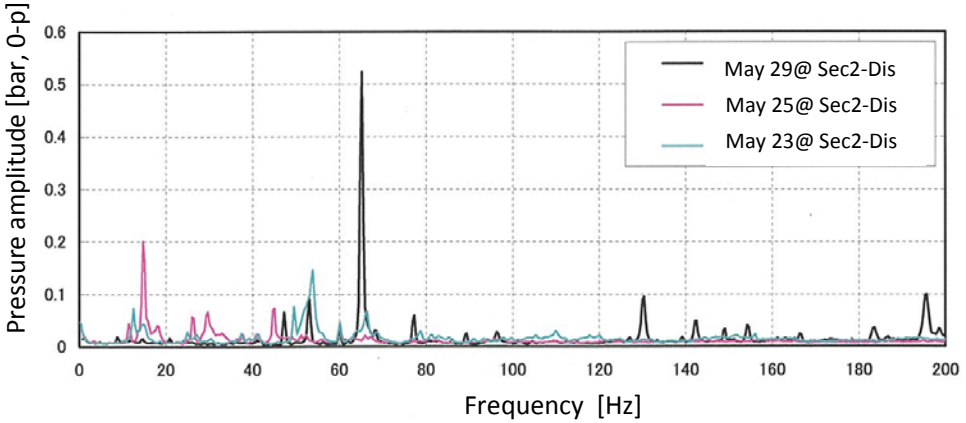
Root cause analysis –(2)

Rotating stall criteria check by Senoo criteria



Meet the Senoo criteria with reasonable margin

Pressure pulsation measurement

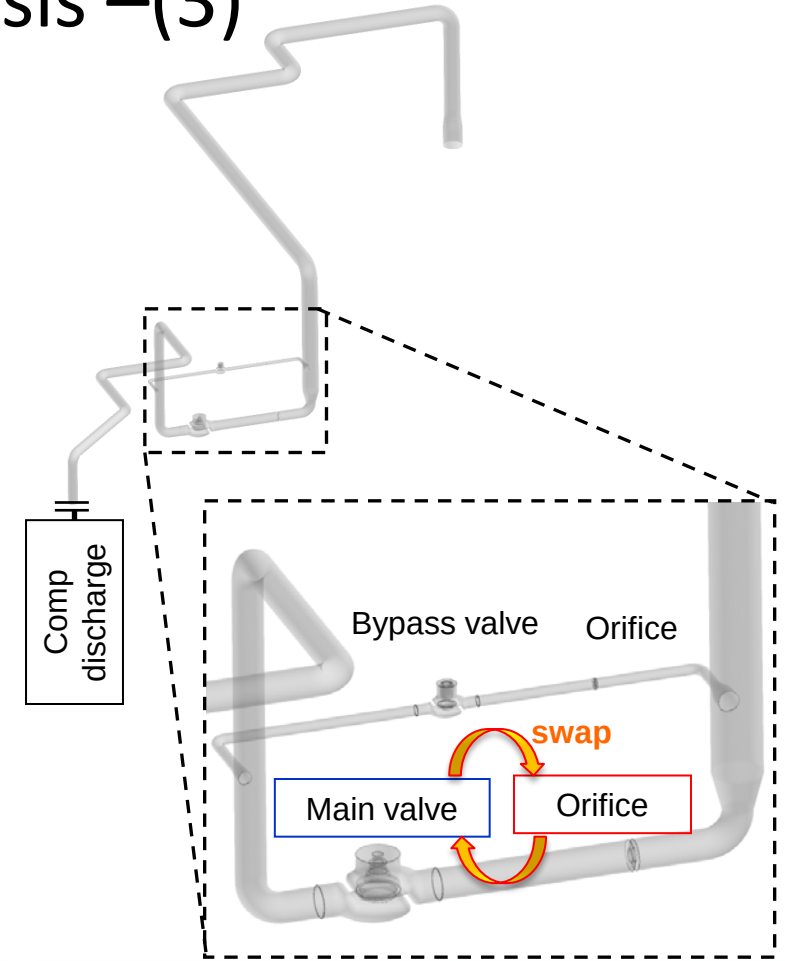


Pressure pulsation is observed, dominant is 0.052MPa, 65Hz.

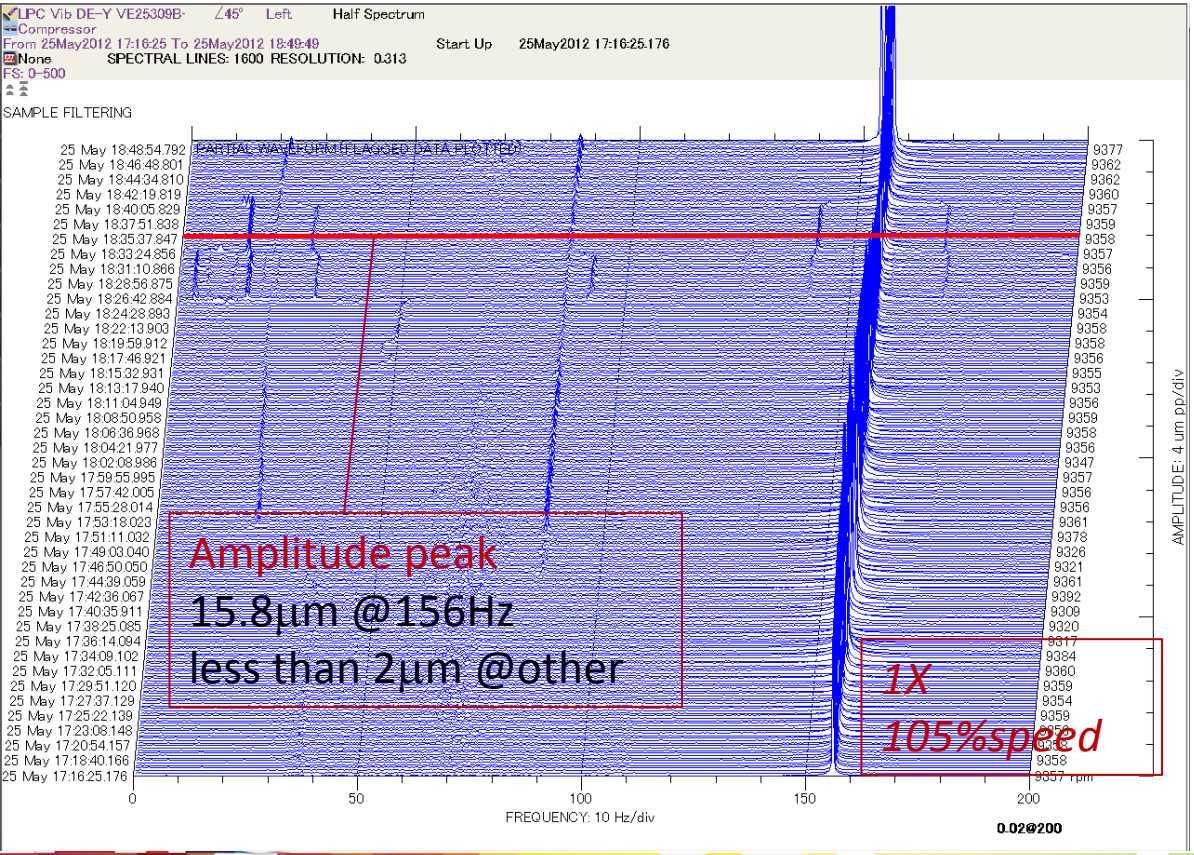
Root cause analysis –(3)

Shop piping arrangement is complicated, close distance between bends, valves, orifices, due to shop space limitation.

- Possible to generate excitation force at shop piping system.
- Main valve and orifice was to swap the position and tested.



SSV after swap



- Drastically reduced SSV vibration amplitude.
- Accordingly, excitation force is generated at shop piping system, NOT compressor.
- FAT is successfully completed.

Verification by unsteady CFD analysis

1. Presumed root cause

- ✓ Pressure fluctuation is generated at downstream of compressor.
- ✓ It propageted to compressor discharge and it result in rotor vibration.

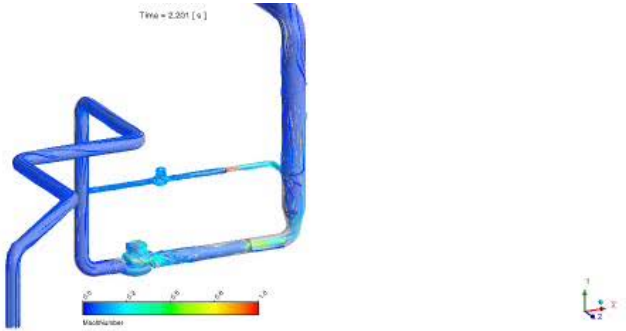
2. Verification procedure

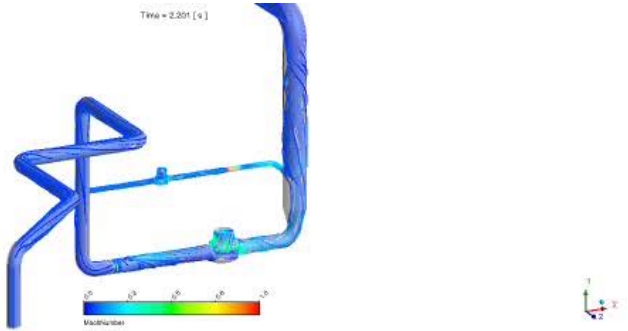
- ✓ Separate CFD to be conducted for 1)Piping and 2)Compressor.
- ✓ To confirm

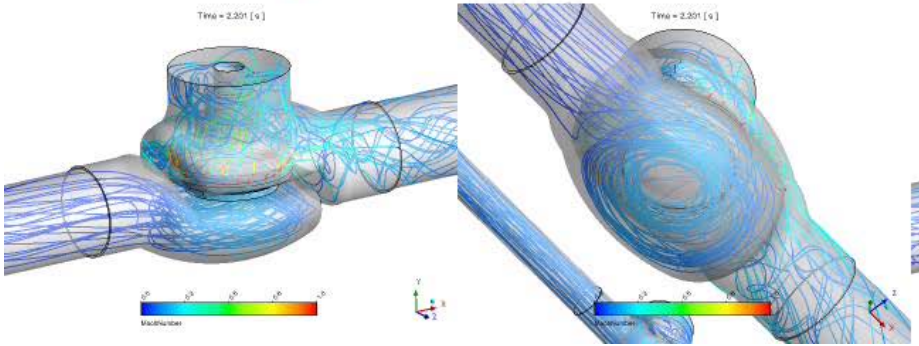
  1)Piping system to generate excitation force

  2)Compressor can be excited by the force generated by piping system.

CFD analysis result of piping –(1)

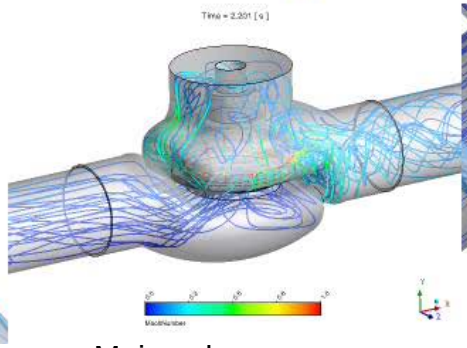




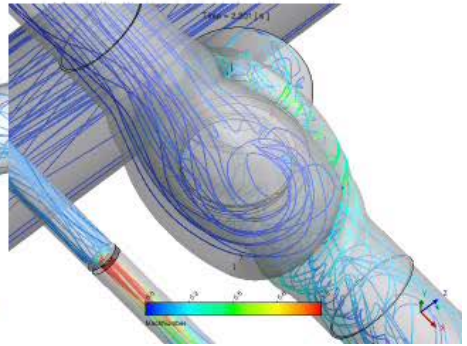


Main valve

View from bottom side of main valve



Main valve



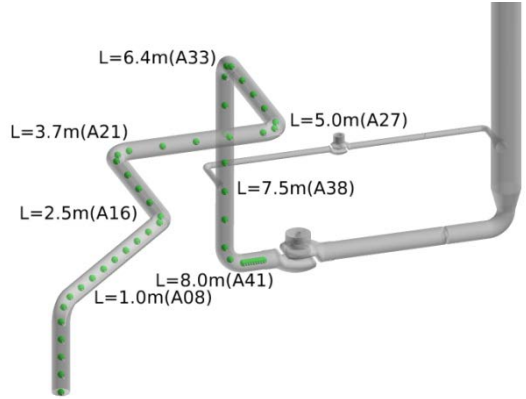
View from bottom side of main valve

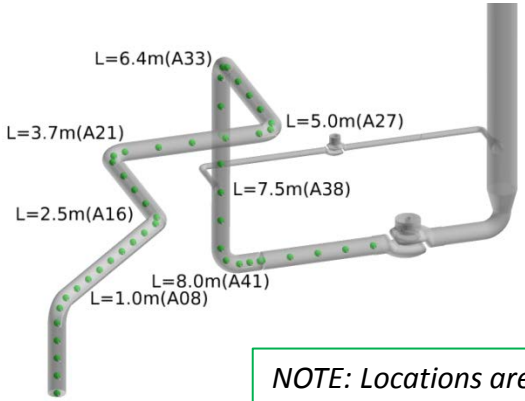
[1] Original configuration

[2] Swapped configuration

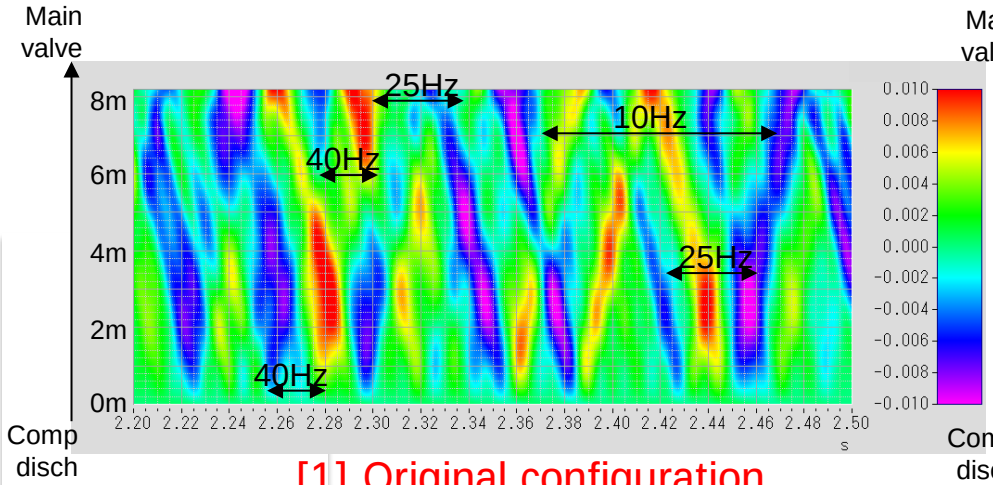
Streamline

CFD analysis result of piping –(2)

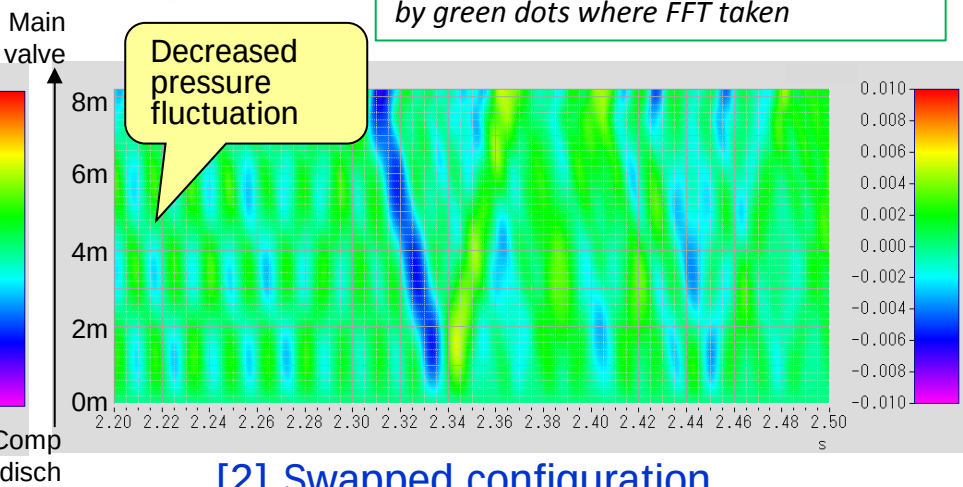




NOTE: Locations are shown in above fig by green dots where FFT taken

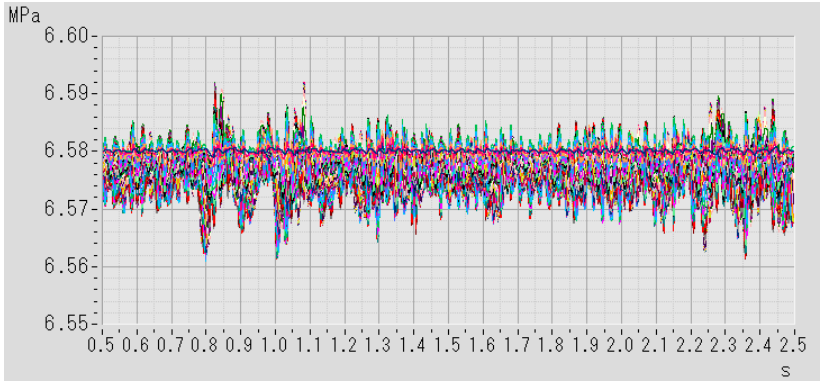


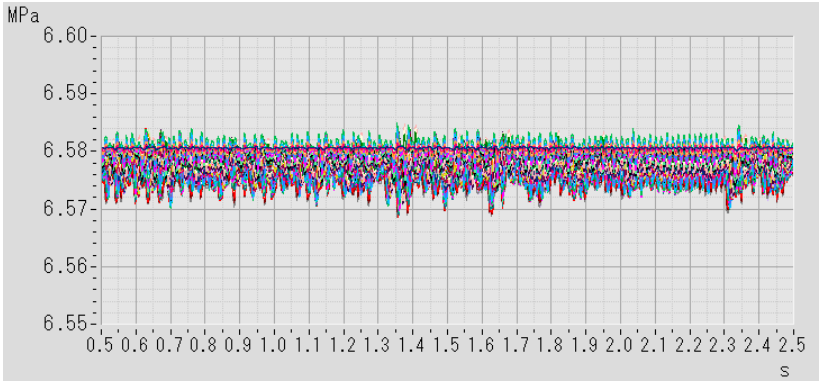
[1] Original configuration

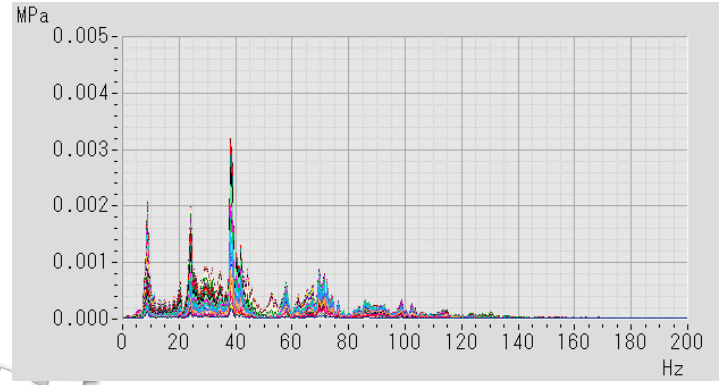


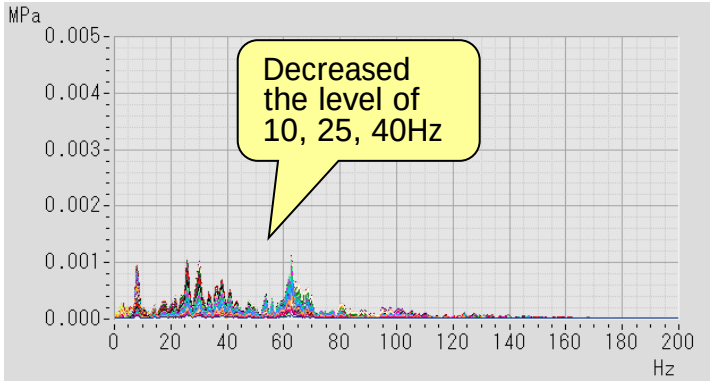
[2] Swapped configuration

CFD analysis result of piping –(3)









[1] Original configuration

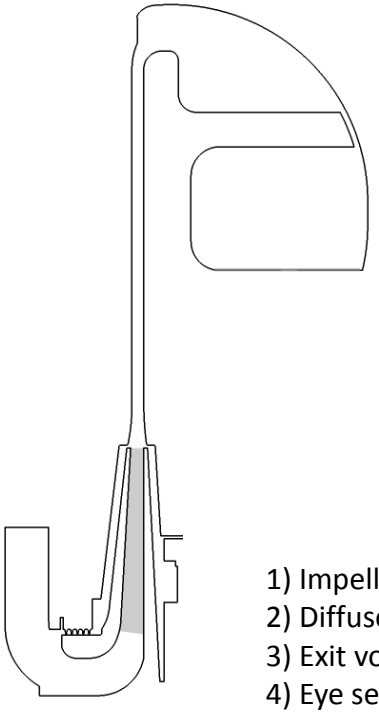
[2] Swapped configuration

Static pressure fluctuation upstream of main valve

Summary of piping system CFD

- According to the unsteady CFD analysis, static pressure fluctuation level is improved by swapping main valve and orifice.
- CFD result shows;
  10, 25, 40 Hz pressure fluctuation observed.
  These fluctuation can be reduced by approx. 30% - 50% from original to swapped configuration.
- CFD qualitatively illustrates the actual phenomena.
  Pressure fluctuation amplitude is different between CFD and measurement. This is because constant pressure is given at compressor discharge as a boundary condition.

CFD analysis model for compressor discharge



1) Impeller
2) Diffuser
3) Exit volute
4) Eye seal

[Case-1]

Compressor Pd = 6.7 Mpa (constant)

[Case-2]

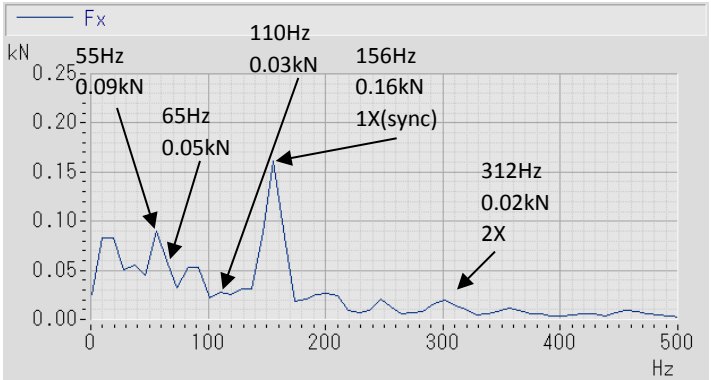
Compressor Pd is fluctuated as blow based on the pressure pulsation measurement.

$$Pd[MPa] = 6.7 + 0.052 \times \sin(\omega t)$$

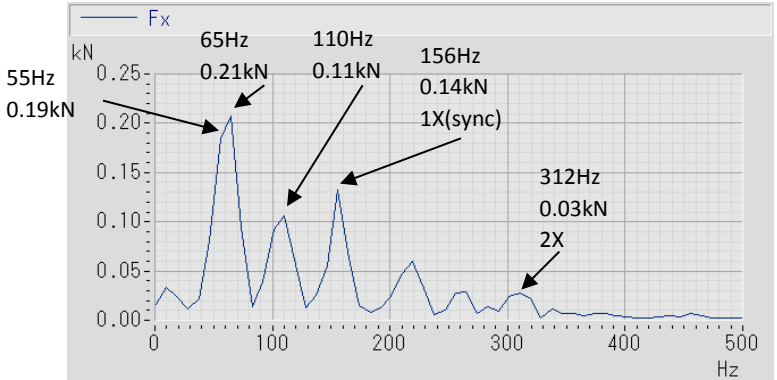
$$\omega = 65[Hz] \times 2\pi = 408.4\,[rad/\sec]$$

$$t\,[\sec]$$

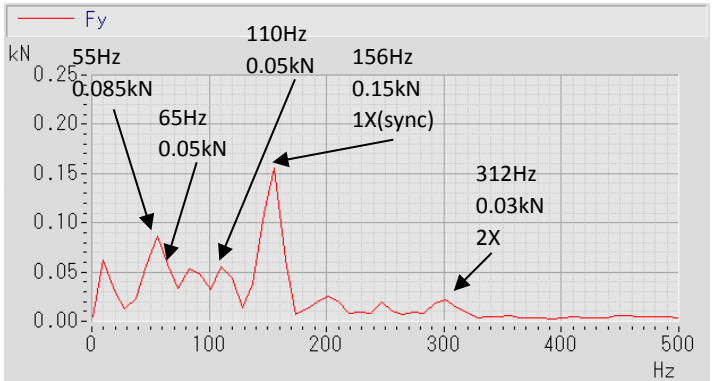
CFD analysis result of compressor



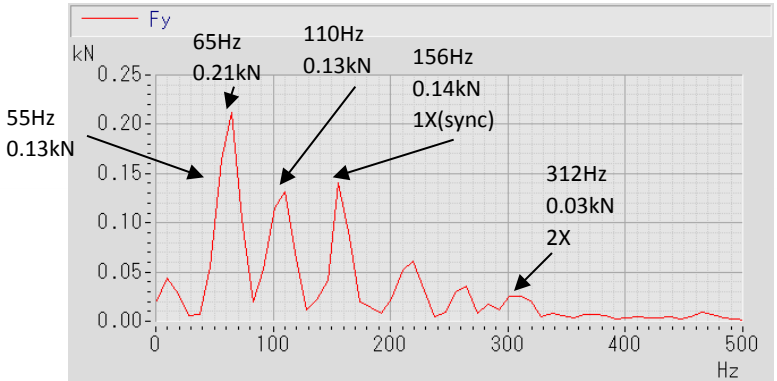
FFT of fluctuating force X-direction



FFT of fluctuating force X-direction



FFT of fluctuating force Y-direction



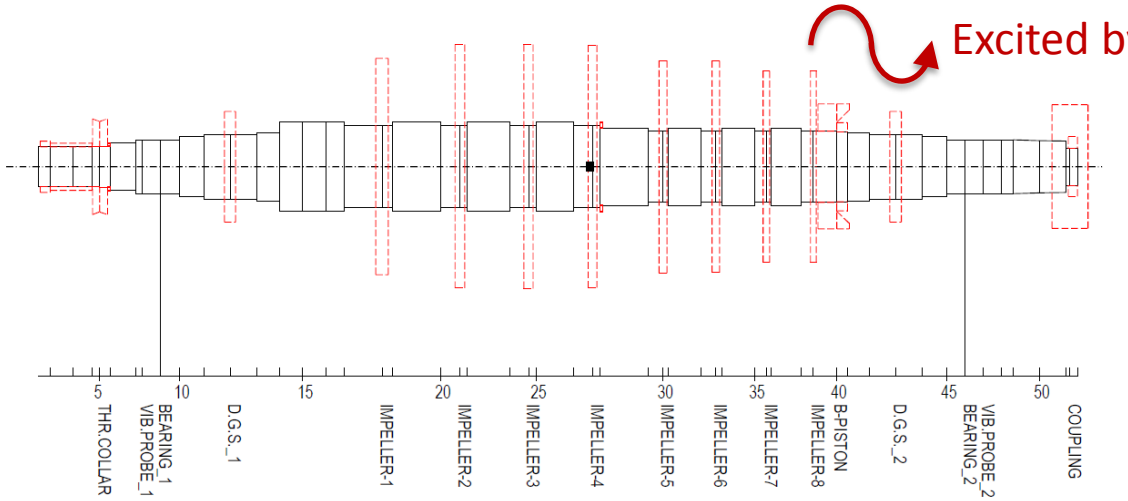
FFT of fluctuating force Y-direction

[Case-1] Pd constant

[Case-2] Pd fluctuated

Excitation force and resultant vibration amplitude

	[Case-01] Pd constant	[Case-02] Pd fluctuated
Fr (kN) around 60Hz	0.0686	0.147



Excitation is calculated and its resultant vibration amplitude is 7.3 micro m(p-p), which is similar level of the actual SSV amplitude.

Summary of comp discharge CFD

- ✓ According to the CFD, in case the compressor discharge pressure is fluctuated by external force by shop piping, force acting on the rotor is increased.
- ✓ Case-2 analysis indicate different frequency such as 110Hz is observed, even the compressor discharge is fluctuated at 65Hz only.
- ✓ Vibration amplitude is calculated by the excitation force of 65Hz on 8^{th} stage impeller, it result in 7.3microm at the probe position and is very similar level of the actual (6.5microm) .

Conclusion

- Separate unsteady CFD was conducted for 1)piping system and 2) compressor discharge. It's result indicates the piping system was the root cause of the SSV.
- The excitation force can be reduced by swapping, and CFD shows qualitatively good agreement with actual phenomena.
- Shop piping system generate pressure fluctuation and it propagate toward compressor discharge.
  Compressor rotor is excited by the external force and vibrate at excited and different frequency.
- Due to the separate CFD, it seems that excitation force is calculated lower than the actual. In actual, piping excitation force and compressor discharge disturbance interact and result in higher excitation force, and vibration.

Lesson learnt

- When high pressure test condition, even a shop downstream piping system can possibly generate excitation force, which result in compressor rotor vibration.

- Sufficient consideration shall be taken to the shop piping system also.