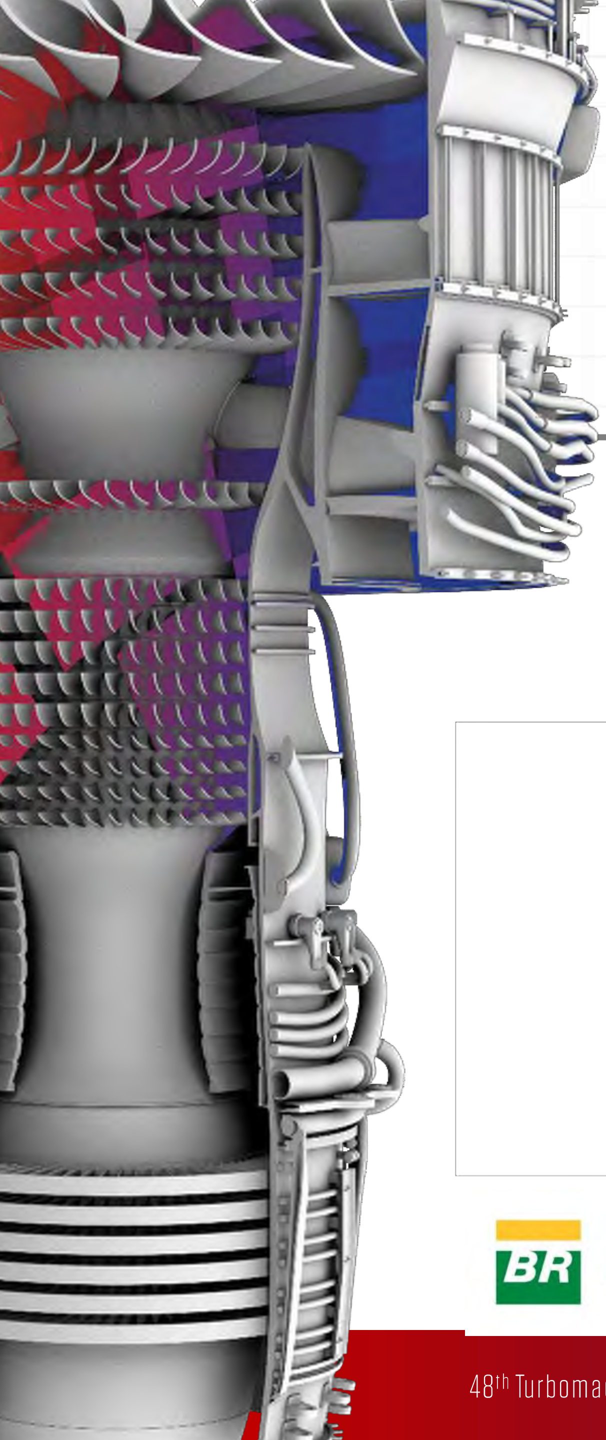
TURBOMACHINERY & PUMP SYMPOSIA



# RADIAL SUBSYNCHRONOUS VIBRATION CAUSED BY AXIAL VIBRATION

PETROBRAS

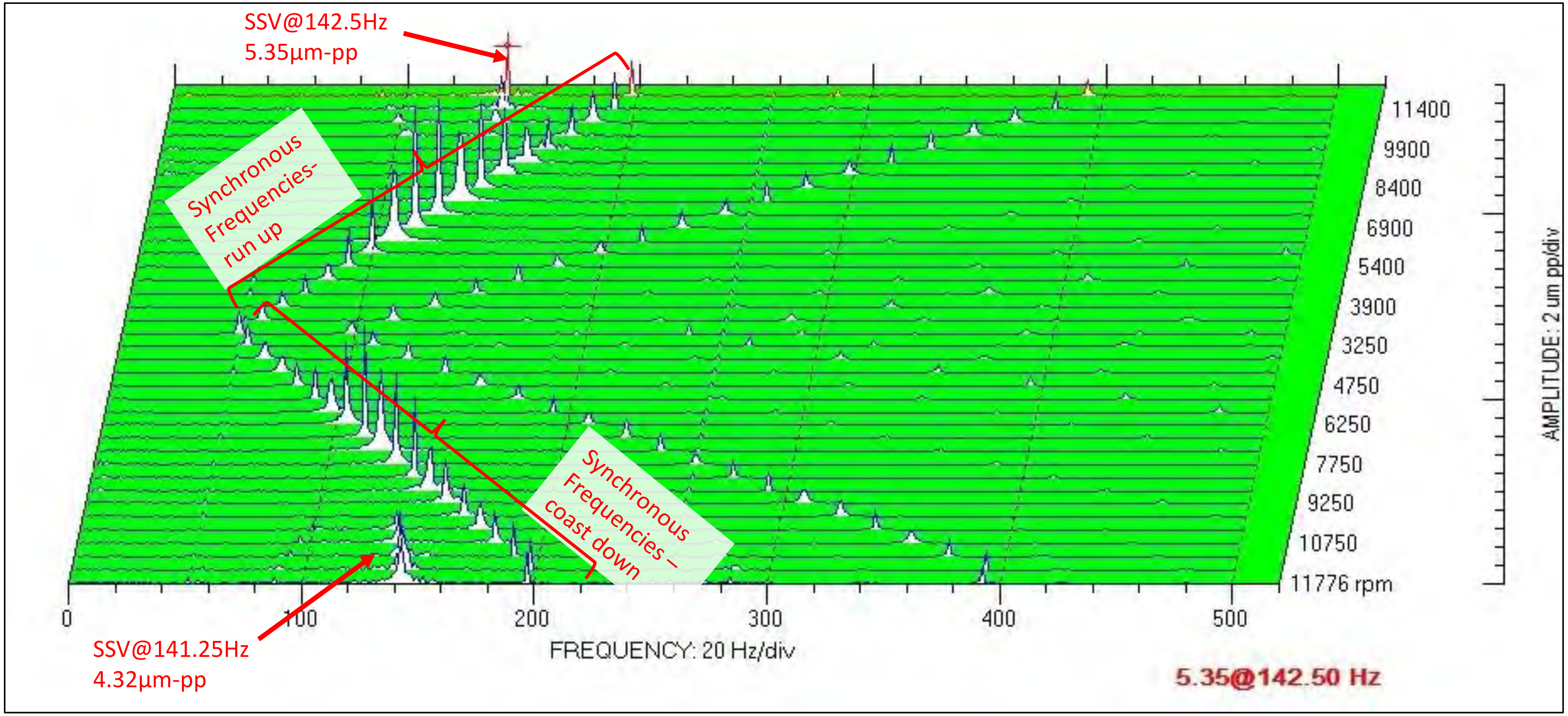
# ABSTRACT

*This case study depicts the cause of a radial subsynchronous vibration during mechanical running tests under vacuum of a High Pressure Compressor following API 617 requirement. During the tests it was investigated how the lateral vibration behaved while the rotor speed, oil pressure and flow to thrust bearing, load and torque were varied. After some tests, vibration analysis and literature revised, it was concluded that the main cause of radial subsynchronous vibration observed during mechanical running test (MRT) was due to axial vibration of the rotor.*

# PROBLEM OVERVIEW

- When a subsynchronous vibration is found in a spectrum of a rotating machine, it may become a concern because of its potential to induce instability.
- During a mechanical running tests in vacuum of high pressure compressors, **subsynchronous vibrations (SSV**) were observed **in radial direction** using proximitor probes mounted in the non driven end as well as the driven end bearing. Therefore, the root cause of SSV was investigated in order to avoid future problem onsite.

# PROBLEM OVERVIEW




- The tests were carried out as specified by API617 and **the limit of the amplitude** of any discrete, **nonsynchronous vibrations (limited to 5 microns according to used procedure) were** sometimes **exceeded by this SSV.**

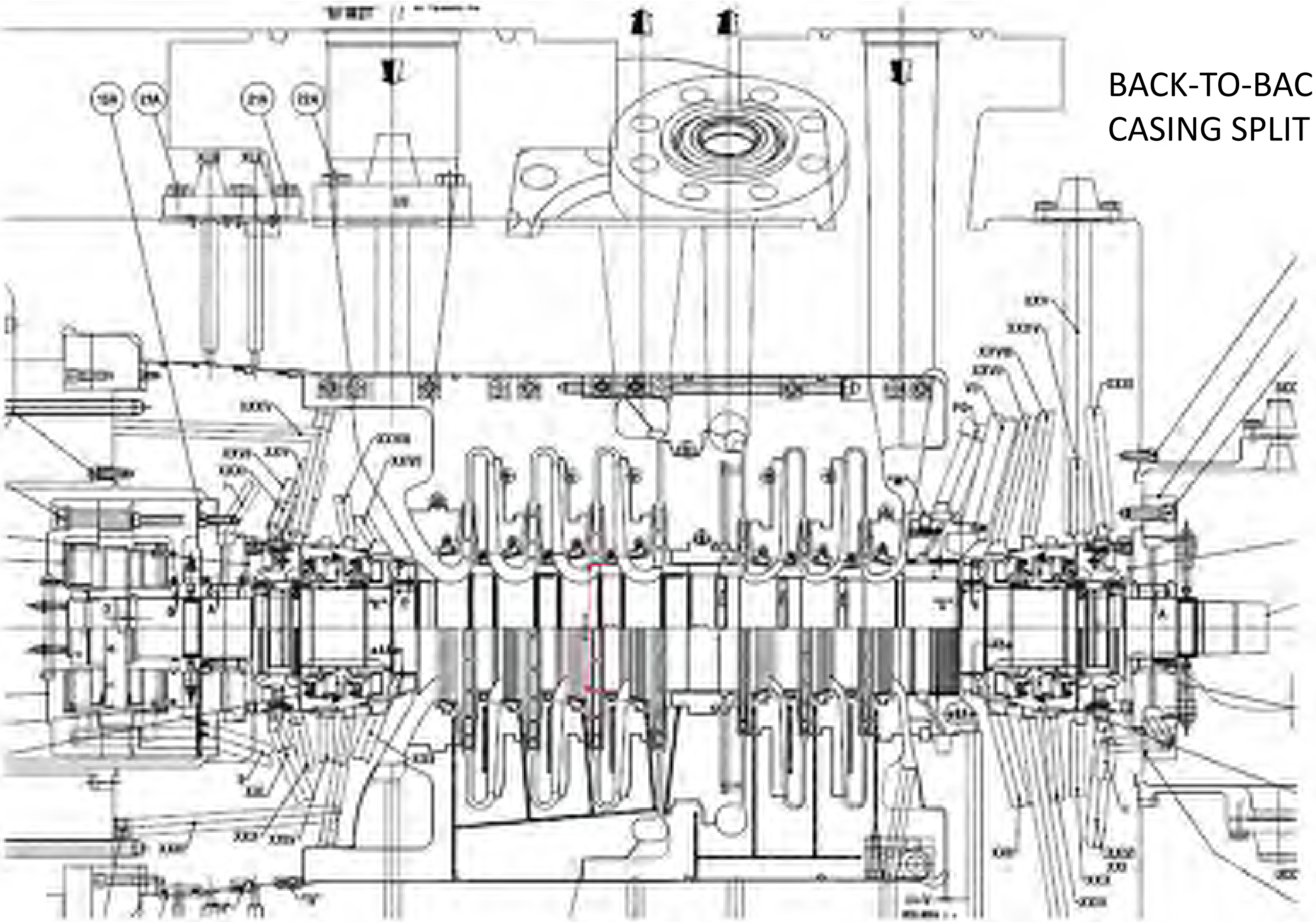
# COMPRESSOR DATA

- The compressor, which has two sections, was design to be submitted the following operation conditions:

| 1st SECTION | 2nd SECTION |
|---|---|
| First suction pressure: 47.39bara | Second suction pressure:135bara |
| First suction temperature: 40°C | Second suction temperature: 40°C |
| First discharge pressure:136bara | Second discharge pressure: 250bara |
| First discharge temperature:123.7°C | Second discharge temperature: 86°C |

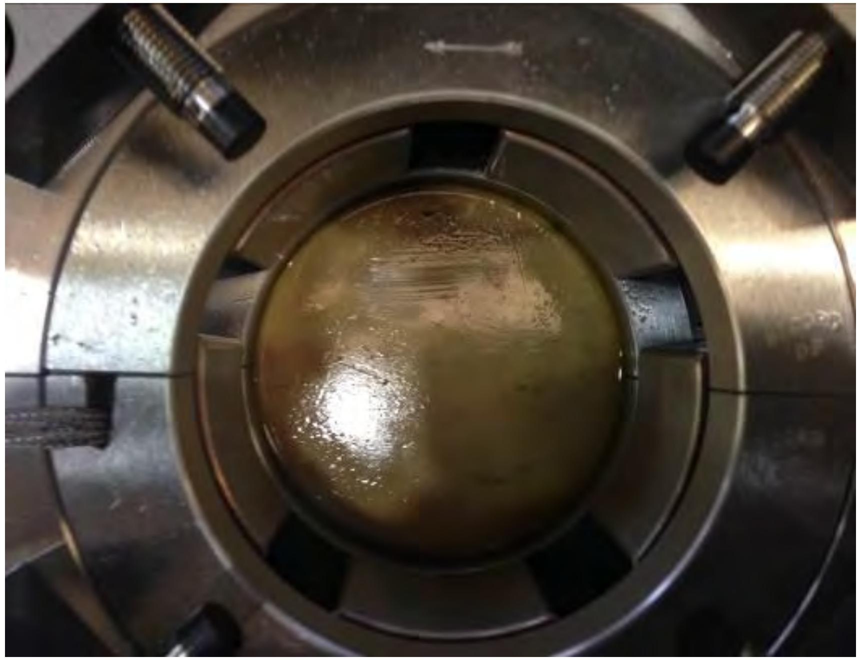
| |
|---|
| Range of first critical speed: 5.250-5.550rpm |
| Maximum continuous speed (MCS): 12.978rpm |
| Weight flow: 107.400kg/h |
| Overspeed: 13.367rpm |
| Rotor weight: 350kg |

# COMPRESSOR CROSS SECTIONAL DWG

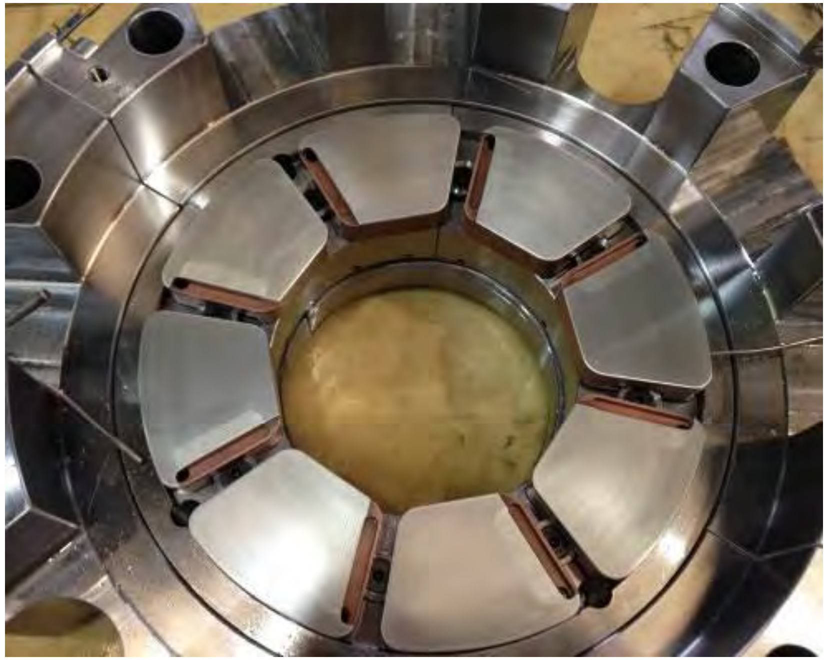


BACK-TO-BACK CENTRIFUGAL COMPRESSOR
CASING SPLIT VERTICALLY

# RADIAL AND AXIAL BEARINGS

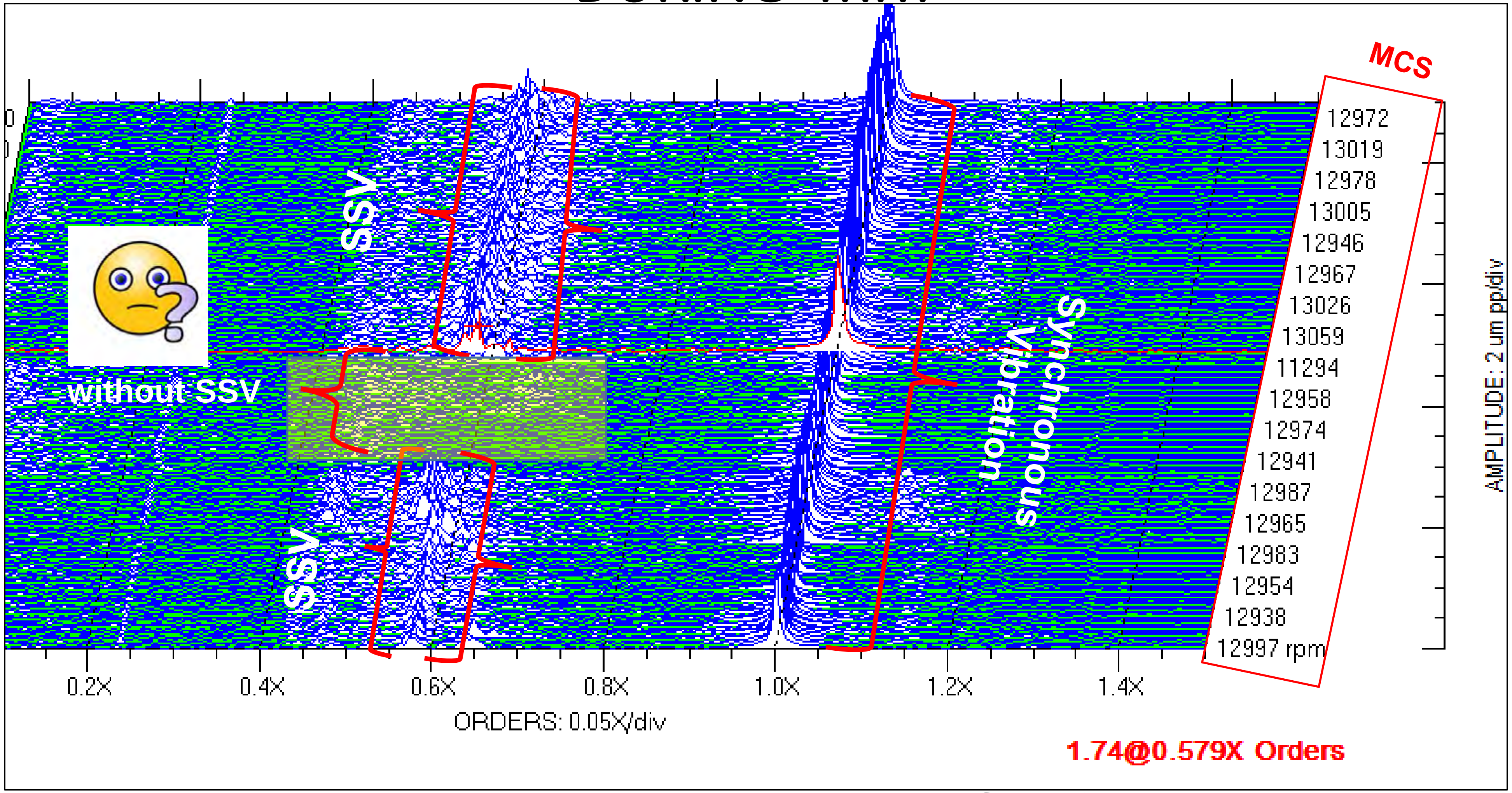


RADIAL TILTING PAD BEARING
Diametral Clearance (min/max):(012/0.138)µm
Load on pad
Offset 60%



AXIAL TILTING PAD BEARING
Axial Clearance (min/max):(0.30/0.40)µm
Manufacturer: Kingsbury
Offset: 60%

# RADIAL SUBSYNCRHRONOUS VIBRATION OBSERVED DURING MRT




Radial subsynchronous vibration amplitude ranged from 0.6 to around 6 μm-pp during the mechanical running test. In other words, higher than the limit defined.

# INVESTIGATION

- So as to unravel the root cause of radial subsynchronous vibration, it was carried out the following procedures:

i. Checking monitoring system configuration. Any relevant mistaken was found.

ii. It was verified if the source of SSV was from test bench or from drive machine. However, no possible cause of SSV was found.

iii. Measuring axial vibration. This idea came across as the compressor was running under vacuum condition. Hence, the rotor had no axial preferable position to work. Therefore, any axial and oscillatory force from axial bearing or drive machine could lead an axial vibration.

# INVESTIGATION

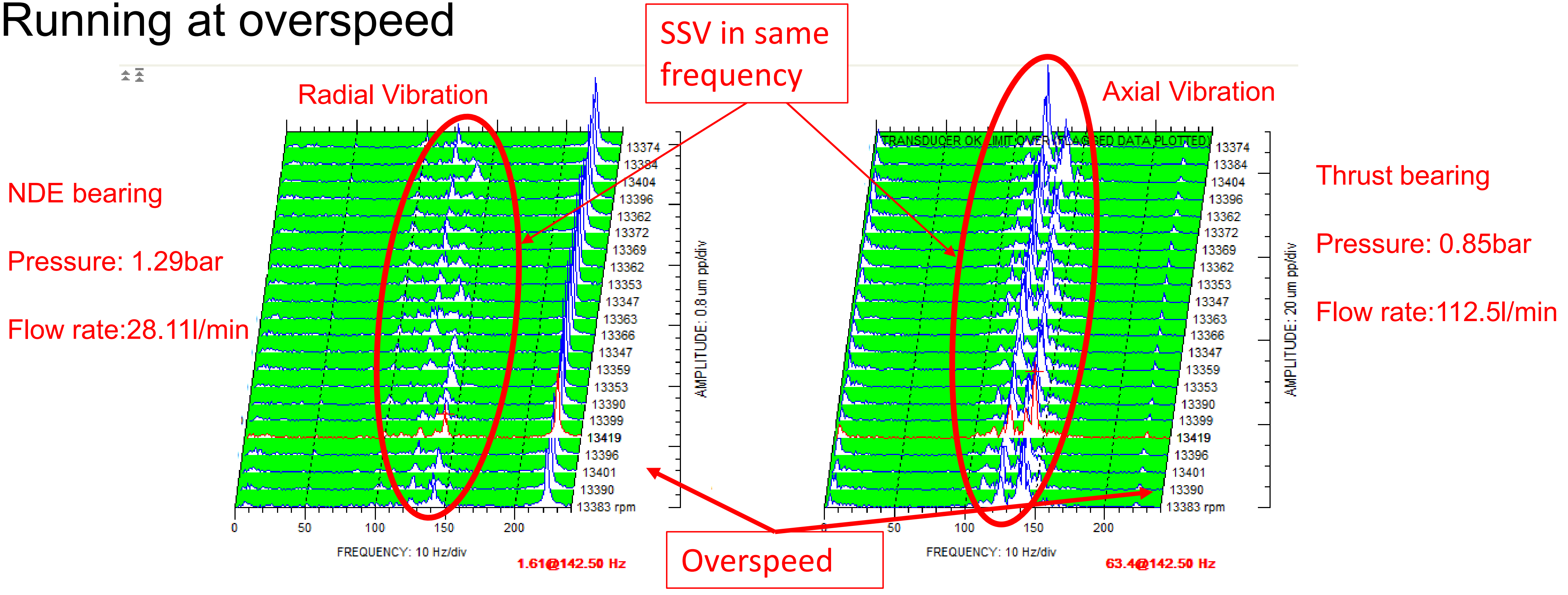
- While the axial vibration was being monitored, the following parameters were varied:

  a. Rotor Speed
  b. Torque
  c. Lube Oil Flow Rate and lube oil pressure
  d. Load on thrust bearing

- During the test, the compressor was kept under vacuum, except during variation of load on thrust bearing. At this condition, the compressor ran under differential pressure.

# INVESTIGATION

- Running at overspeed




o It is clearly seen that the two frequencies, 125 and 142.5Hz, that excite the rotor in axial direction led lateral vibration, although in lower amplitudes. The average radial subsynchronous amplitude was near of 30% of radial synchronous amplitude, in other words, these SSV are important since they have high amplitude and they should be studied.

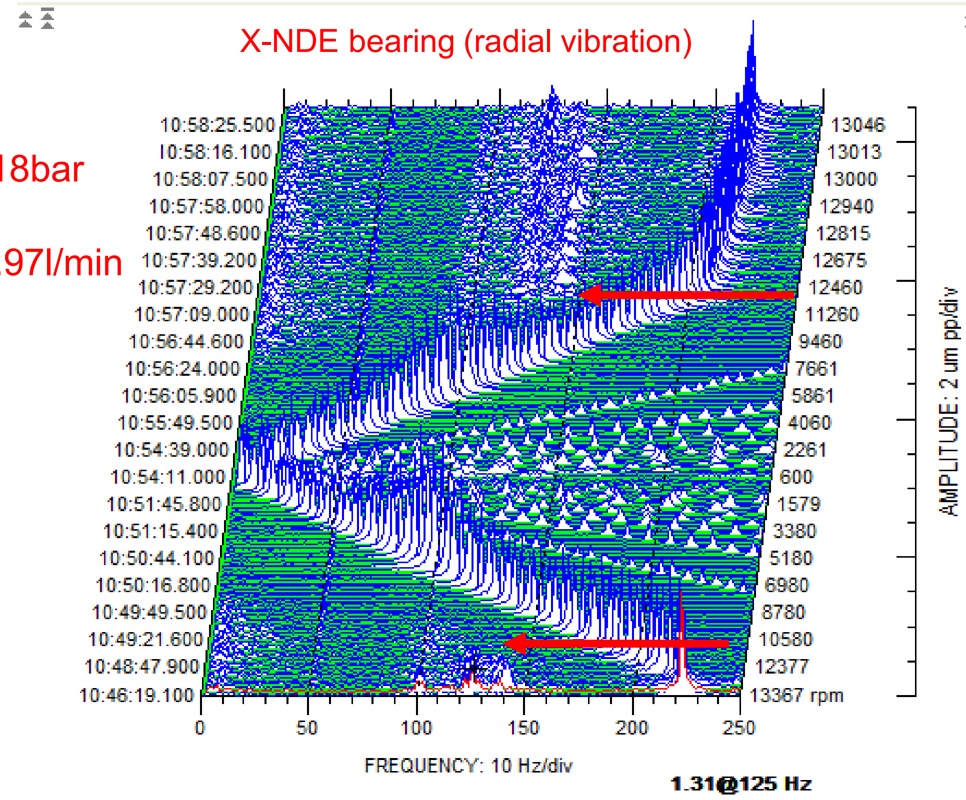
# INVESTIGATION

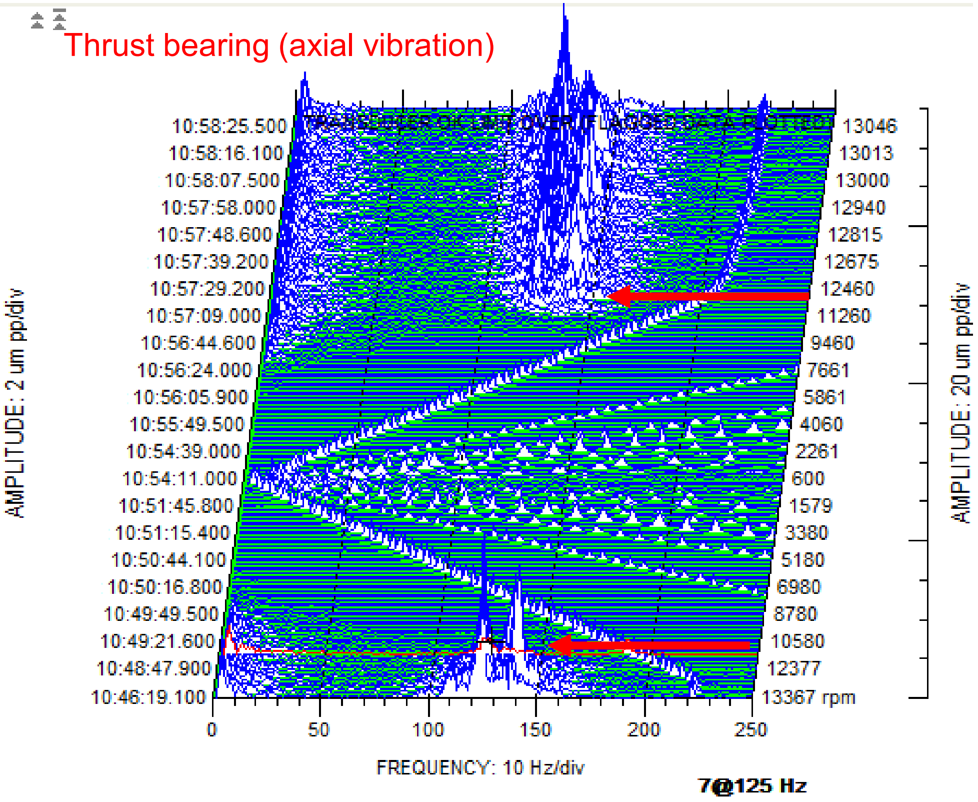
- Changing Torque and Speed

NDE bearing

Pressure: 1.18bar

Flow rate:26.97l/min




Thrust bearing

Pressure: 0.85bar

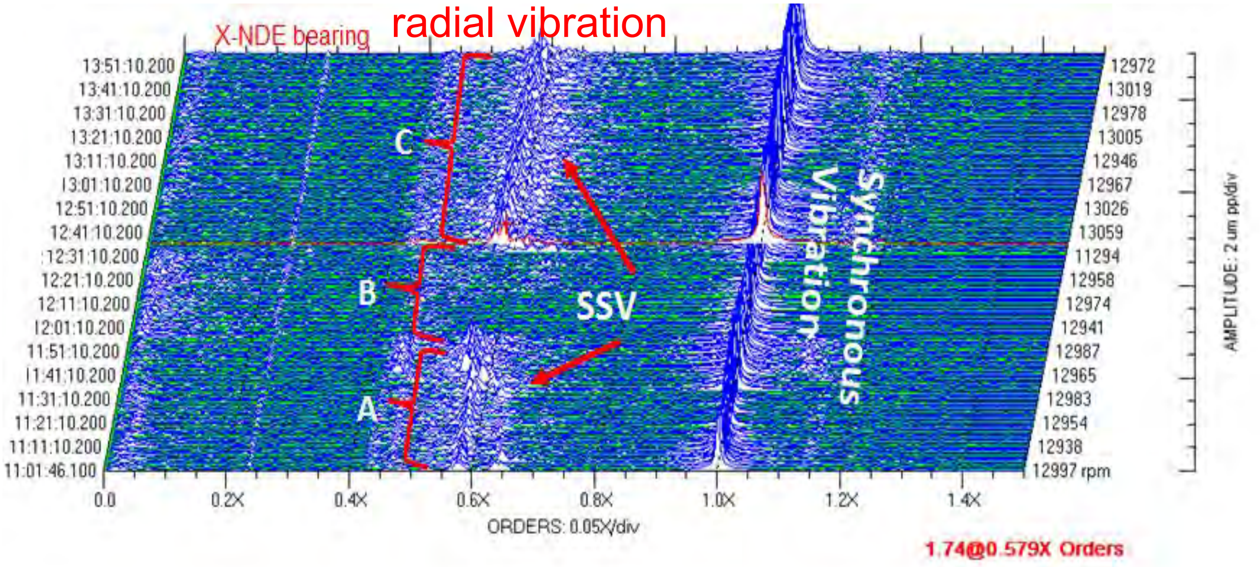
Flow rate:112.4l/min

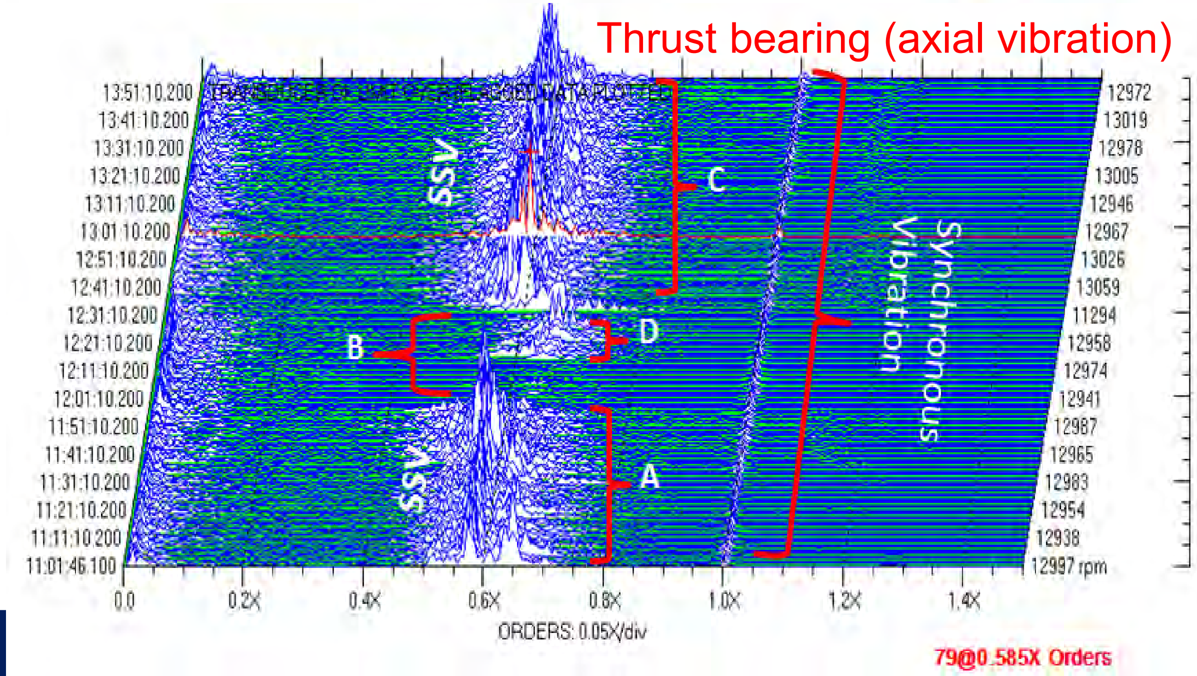
- The red arrows indicate when the SSV appear. It was noted that threshold of subsynchonous frequencies, 125 and 142.5Hz, is around 11.100rpm, without (run down) and with (run up) torque. Therefore, these SSV did not undergo influence from torque.

# INVESTIGATION

- Changing lubricant oil pressure and flow

| | | Thrust Bearing | | | Radial Bearings | | |
|---|---|---|---|---|---|---|---|
| | Period | Lube Oil Flow (l/min) | Lube Oil Pressure (bar) | Axial Disp. (µm) | Lube Oil Flow (l/min) | Lube Oil Pressure (bar) | |
| A | 11h01min46s - 12h01min10s | 135 | 0.96 | 82 | 27.8 | 1.24 | with SSV |
| B | 12h01min10s - 12h41min10s | 170 | 1.51 | 75.9 | 33.4 | 1.59 | without SSV |
| C | 12h41min46s - 13h51min10s | 92.4 | 1.52 | 83 | 29.12 | 1.37 | with SSV |
| D | 12h21min10s - 12h31min10s | 124.5 | 0.8 | 85.3 | NA | NA | with SSV |



# INVESTIGATION

- Changing lubricant oil pressure and flow

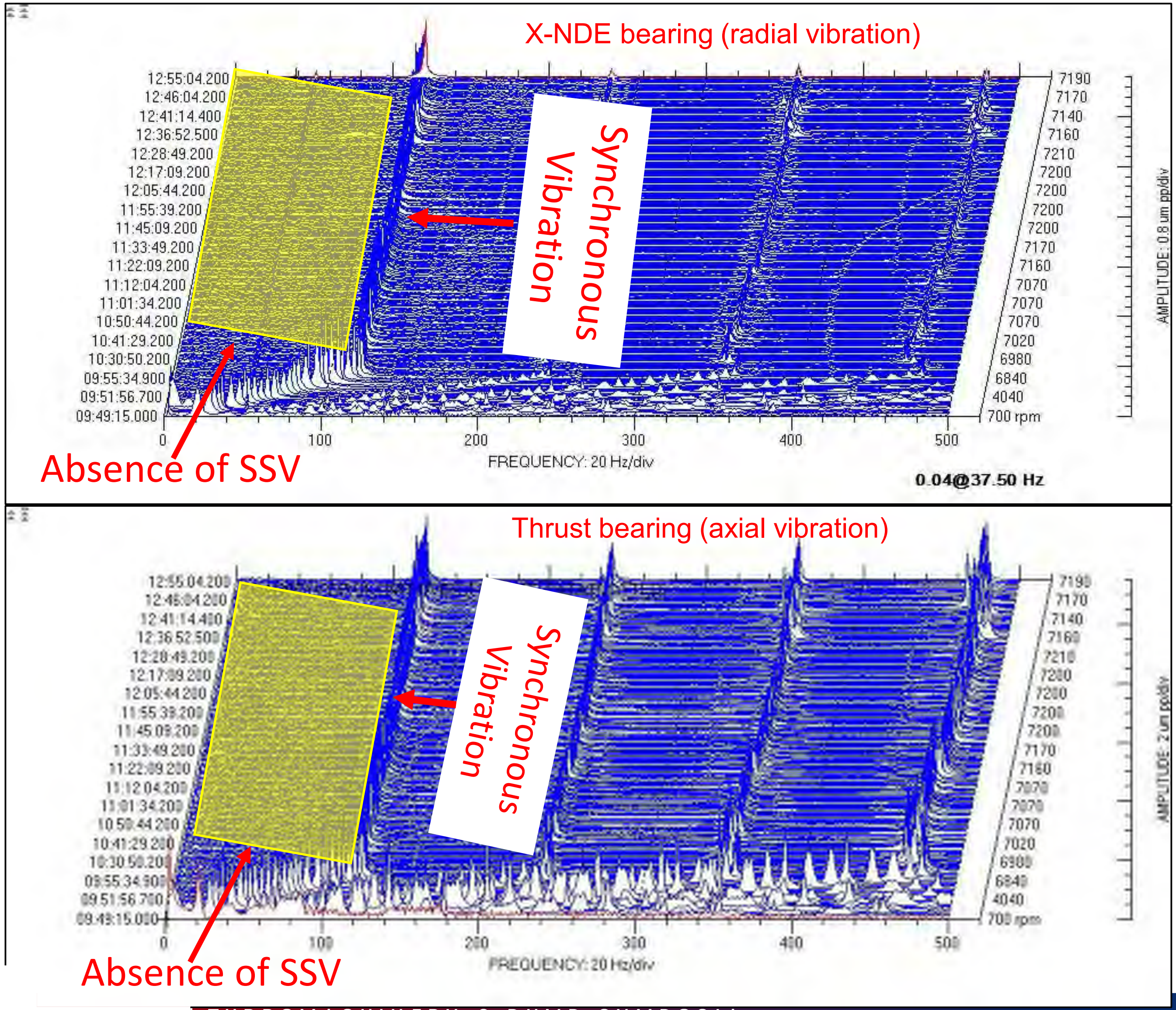
    - Analyzing the waterfall graphics on the previous slide, it can easily seen that an increase of thrust bearing stiffness by increasing lube oil flow and pressure, the radial subsynchronous as well as axial vibration (@125 and142.5Hz) disappeared. In other words, starved thrust bearing causes pad vibration that leads lateral SSV motions.

# INVESTIGATION

- Changing the load on thrust bearing
    - Running the compressor under axial load, varying the differential pressure in first stage between 6.3 and 9.5bar and the second stage from 2bar to 7.0bar at 7200 rpm, the subsynchronous (125/142.5Hz) did not appear. However, the rotor speed did not reached the 11,600rpm, threshold of 125/142.5Hz, because of the temperature limit of the casing.

# INVESTIGATION

- Changing the load on thrust bearing




- o Instead of running the compressor under vacuum (light loading on thrust bearing), the rotor ran under differential pressure so as to rise the axial load on thrust bearing, thereby increasing axial stiffness. In this way, the rotor would have a preferable axial position to stay and the SSV would have a chance of vanishing if the source of this vibration were the pad flutter as mentioned by DeCamilo [1].

# INVESTIGATION

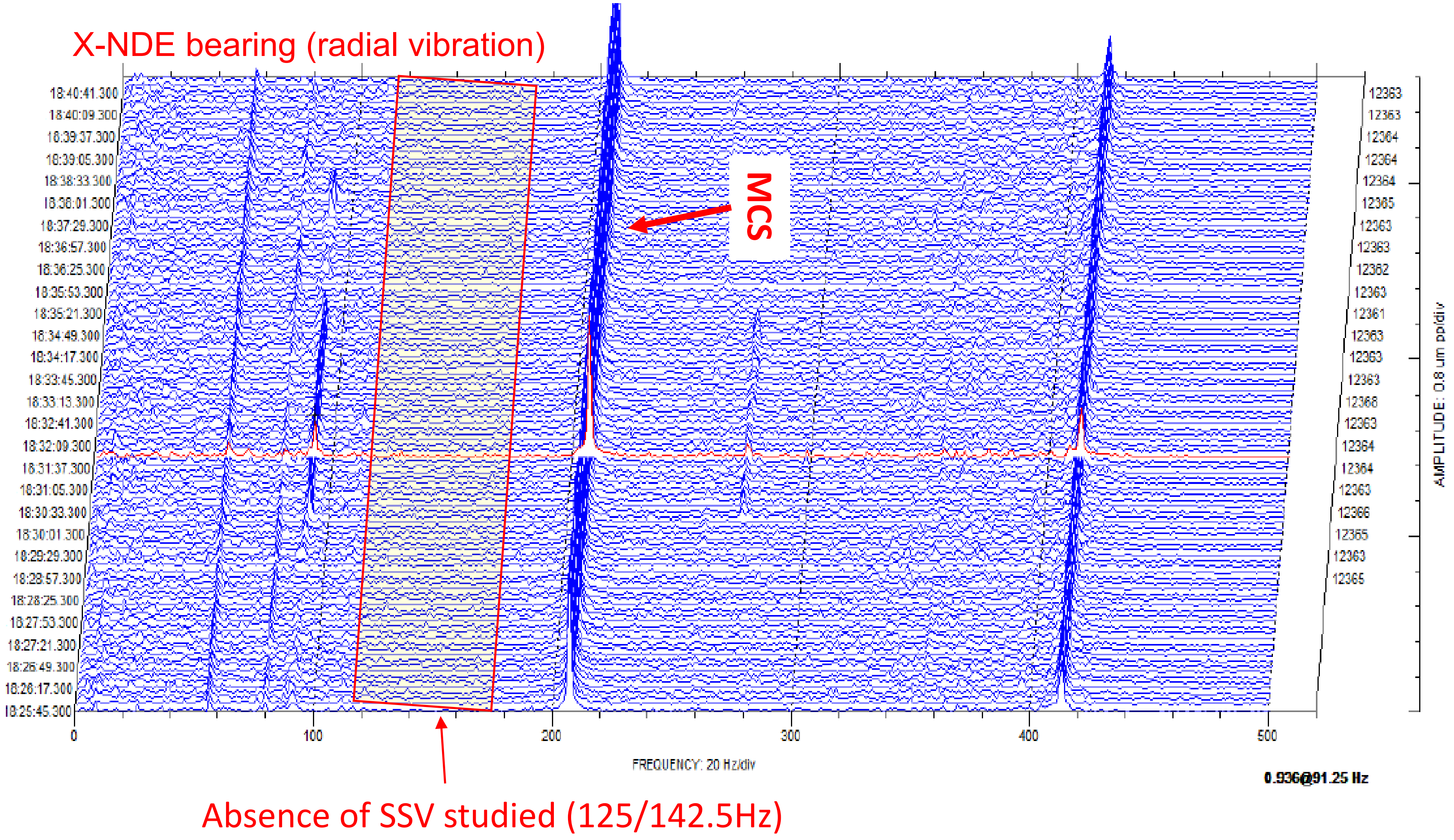
- Running in Full Load/Full Speed/Full Pressure (FLFSFP) and close to Surge

Running the compressor in FLFSFP and under harsh condition (close to surge), the subsynchronous (125/142.5Hz) did not appear, as seen on next slide. Therefore, these SSV will not be a problem when the compressor is working onsite. Moreover, it might be concluded the main cause of these SSV mentioned is due to light load and starved thrust bearing.

The subsynchronous frequencies lower than 100Hz showed on the next slide were caused by surge condition, that is not the relevant for this present study.

# INVESTIGATION

- Running in Full Load/Full Speed/Full Pressure (FLFSFP) and close to Surge



# CONCLUSION

- The main cause of radial subsynchronous vibration in these analysis is probably due to axial SSV, since the SSV amplitude in axial direction was much higher than in radial direction. This confirm the theory that the dynamic of thrust bearing are coupled with the rotor-journal bearing system. A model which could explain this behavior is described by Lie, at  al[3].
- The cause of axial SSV (125/142.5Hz) is due to light load and/or starved thrust bearing since these vibration frequencies disappear when the thrust bearing is working under normal operation condition and the compressor is running in FLFSFP.

# CONCLUSION

- Oil flow rate and pressure variables on thrust bearing play the key role on lateral subsynchronous vibration induced by axial vibration. One possible cause of SSV is that the insufficient oil on the pad film thickness may trigger pad flutter behavior on thrust bearing.
- In spite of not being a API 617 requirement and not usual monitored in industrial application, these tests showed the importance of set the axial probe to measure vibration instead of just checking rotor displacement during mechanical running test and operation onsite.

# REFERENCES


[1] DeCamilo, S., 2014. *Axial Subsynchronous Vibration.* 43rd Tubomachinery & 30th Pump Users Symposia (Pump & Turbo 2014). Houston, TX

[2] Gardner, W. W., 1996. *An Experimental Study of Thrust Pad Flutter*. Journal of Tribology. [doi:10.1115/1.2834590]

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[5] Wilkes, J., DeCamilo, S., Kuzdzal, M. and Mordell, J., 2000, Evaluation of a High Speed, Light Load Phenomena in Tilting Pad Thrust Bearing. Proceedings of the 29th Turbomachinery Symposium, Turbomachinery Laboratory, Texas A&M University, College Station, Texas, pp. 177-185. [doi:10.21423/R1C95P]