

★ **HOT SPOTS IN TURBOEXPANDER BEARINGS:  
CASE HISTORY, STABILITY ANALYSIS,  
MEASUREMENTS AND OPERATIONAL  
EXPERIENCE**

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Joachim Schmied, DELTA JS

Josef Pozivil, Cryostar SAS

# HOT SPOTS IN TURBOEXPANDER BEARINGS

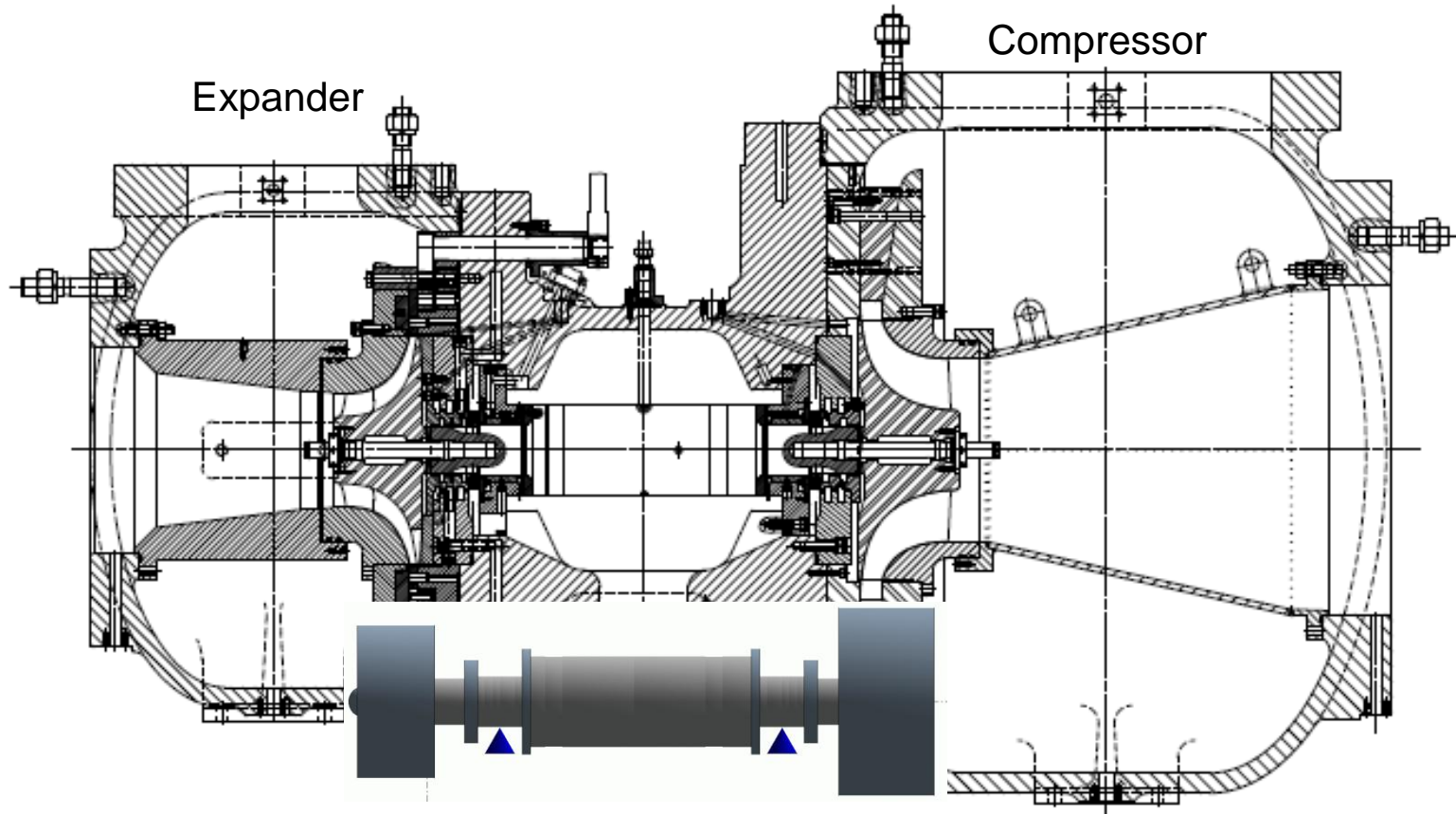
- ★ **DESCRIPTION OF THE MACHINE**
- ★ **ROTOR DYNAMIC BEHAVIOR (ANALYSIS AND TEST)**
- ★ **THE HOT SPOT PHENOMENON**
- ★ **ANALYSED AND TESTED MODIFICATIONS**
- ★ **CONCLUSIONS**

# DESCRIPTION OF THE MACHINE



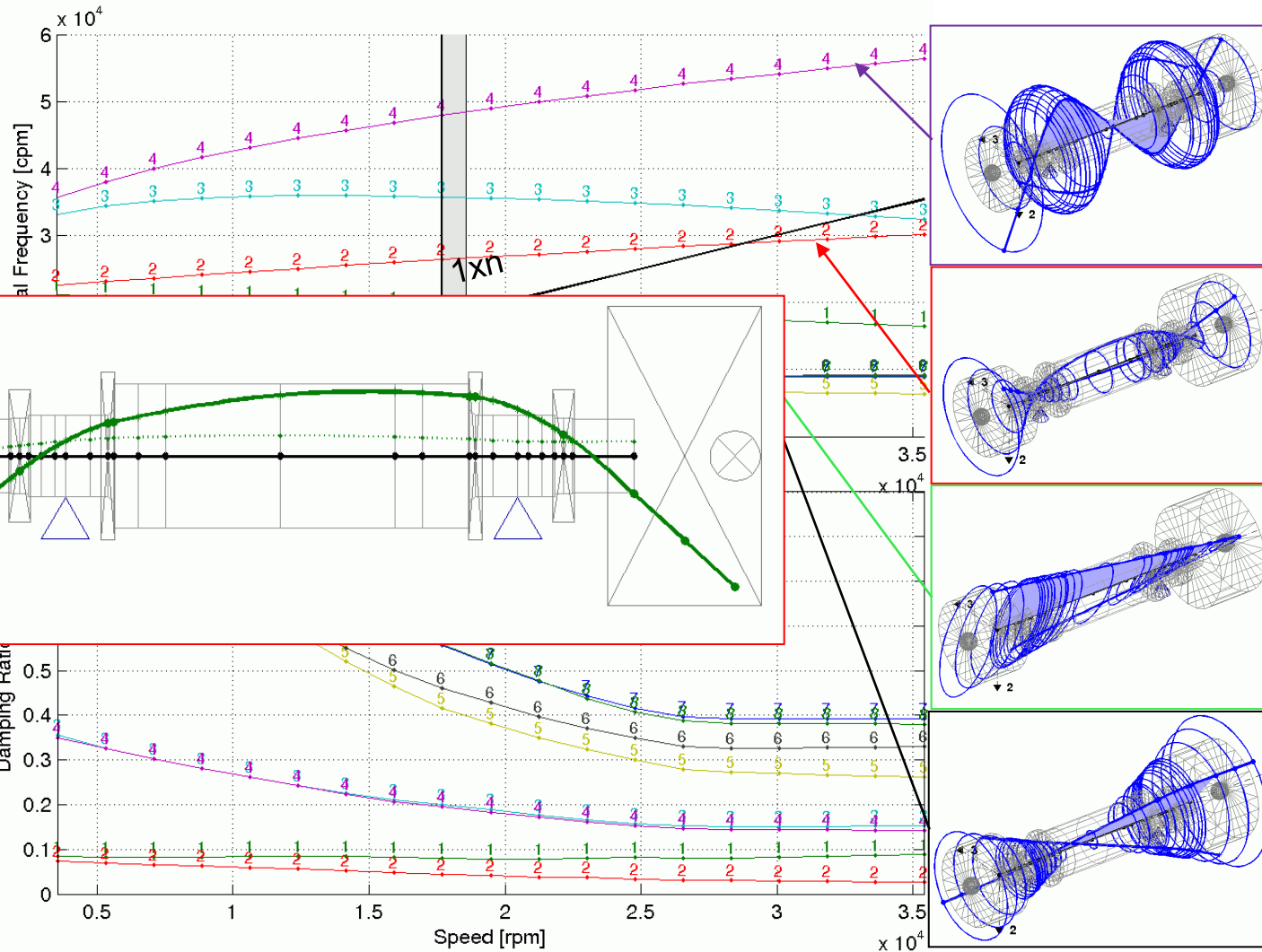
**Dual turboexpander 2-TC 400/90 with oil unit and control panel**

# DESCRIPTION OF THE MACHINE



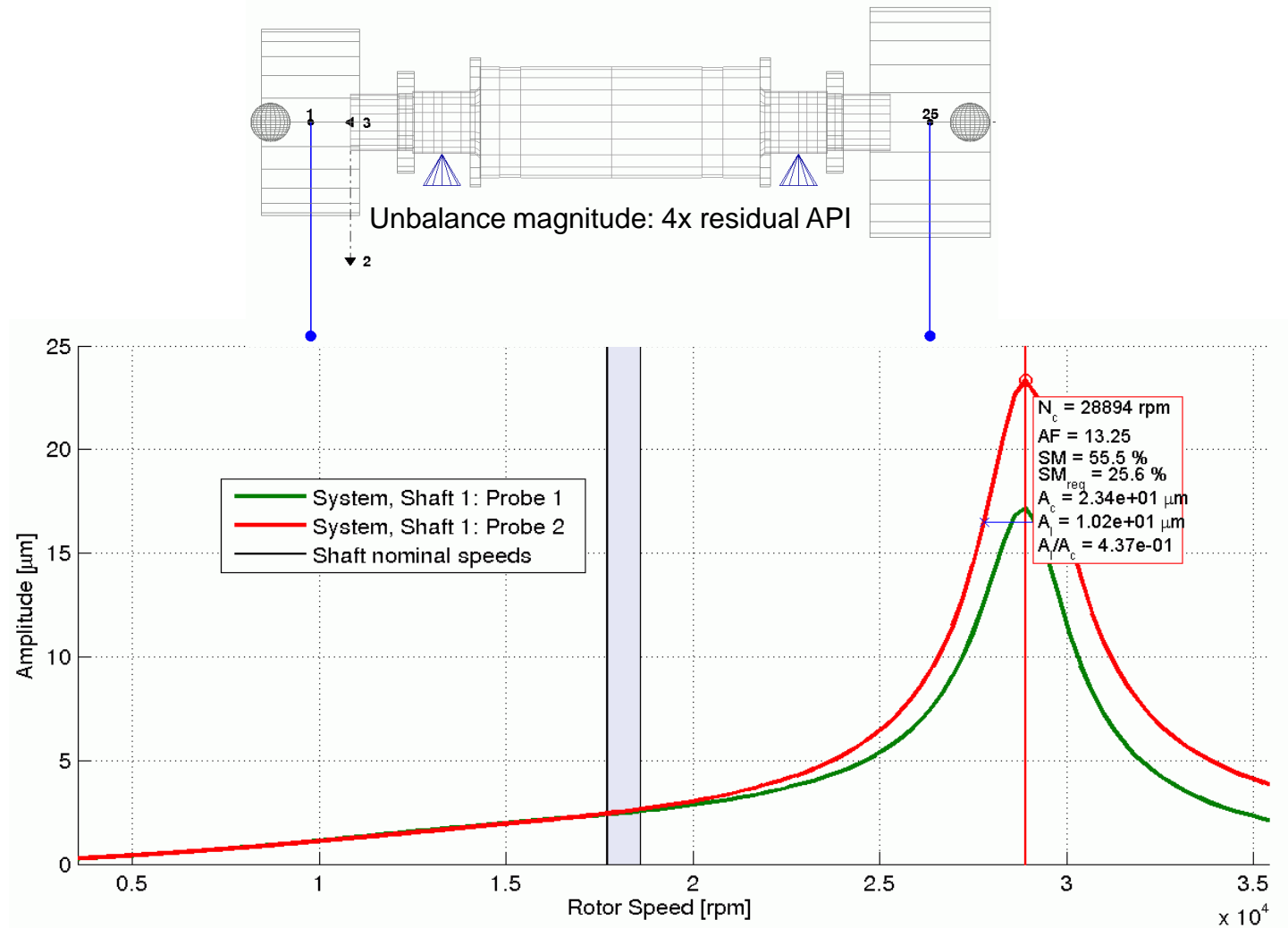
**Cross section and rotor model of the turboexpander TC 400/90**

# ROTOR DYNAMIC BEHAVIOR (ANALYSIS)



**Campbell diagram and mode shapes**

# ROTOR DYNAMIC BEHAVIOR (ANALYSIS)



**Unbalance response with API evaluation**

# ROTOR DYNAMIC BEHAVIOR (TEST)

**Compressor Room**

T1	26.1 °C
T2	26.1 °C
P	6.05 bar a

Tamb OUT 19.7 °C  
 Patm OUT 0.977 bar  
 Relativ Humidity OUT 47.6 %

Qm1 3.1 kg/s  
 DPEo 68 mbar  
 PEO 10.49 bara  
 TEO 82.10 °C

TE1 78.34 °C / Max.diff. 0.26 %  
 PE1 10.45 bar a / Max.diff. 0.08 %

$\frac{PE1}{PE2} = 4.038$

TE2 0.25 °C / Max.diff. 0.13 %  
 PE2 2.59 bar a / Max.diff. 0.25 %

PE TIP 0.92 bar a  
 PE REF 3.97 bar a

PC TIP 2.101 bar a  
 PC REF 0.974 bar a

TC2 22.08 °C / Max.diff. 120.32 %  
 PC2 0.98 bar a / Max.diff. 0.07 %

Qm2 0.0 kg/s  
 DPCo 0 mbar  
 PCo 0.983 bara  
 TCo 20.46 °C

4-20mA Analog output

Nr2 0  
 Nr3 0  
 Nr4 0

TC1 22.82 °C / Max.diff. 171.70 %  
 PC1 0.98 bar a / Max.diff. 0.04 %

Tamb IN 22.2 °C  
 Patm IN 0.977 bar  
 Relativ Humidity IN 30 %

Rotation Speed  
**19,592** RPM

Nozzle Command 41 %

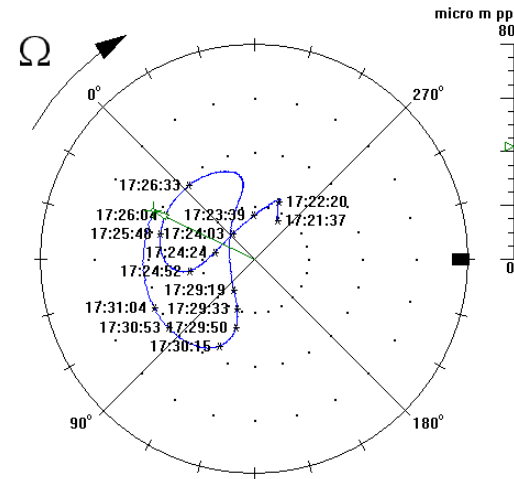
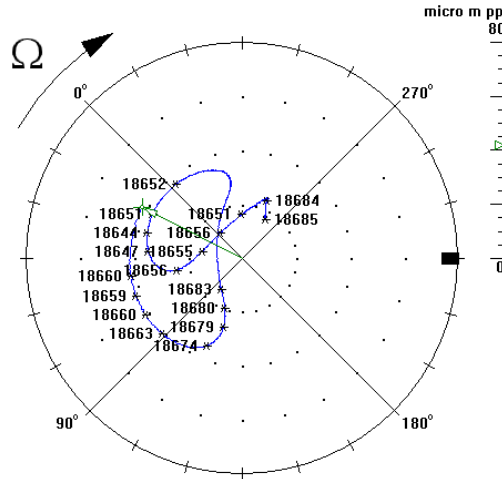
**CRYO STAR** TEST BED  
 Expanders & Compressors

TC F1171-1 12:06:54 PM 10/11/02

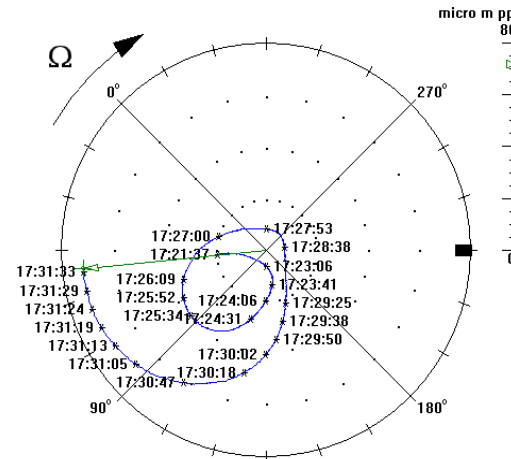
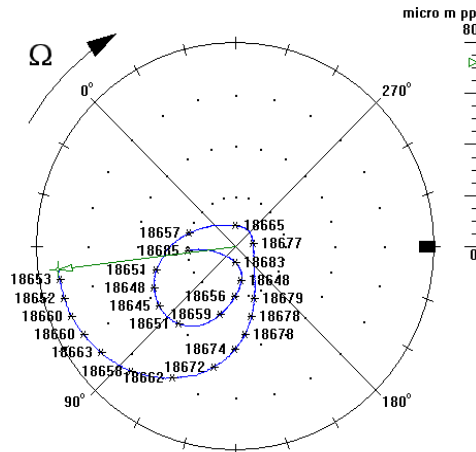
Buttons: Point instantly, System, Stability, Start/End, Pause

Test bed computer mimic

# ROTOR DYNAMIC BEHAVIOR (TEST)



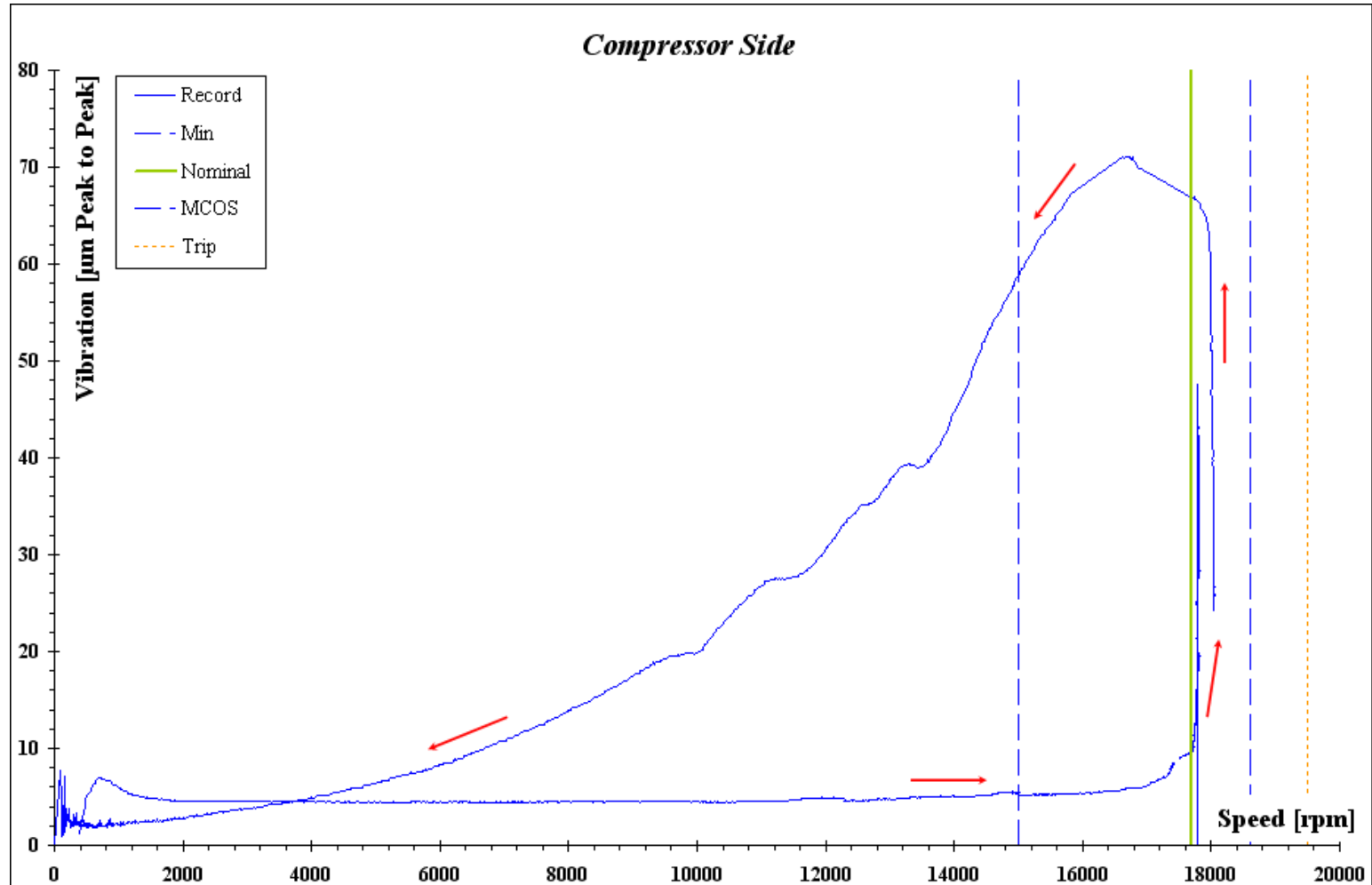
**Spiral vibration in 1xN polar plot – expander side**



**Spiral vibration in 1xN polar plot – compressor side**

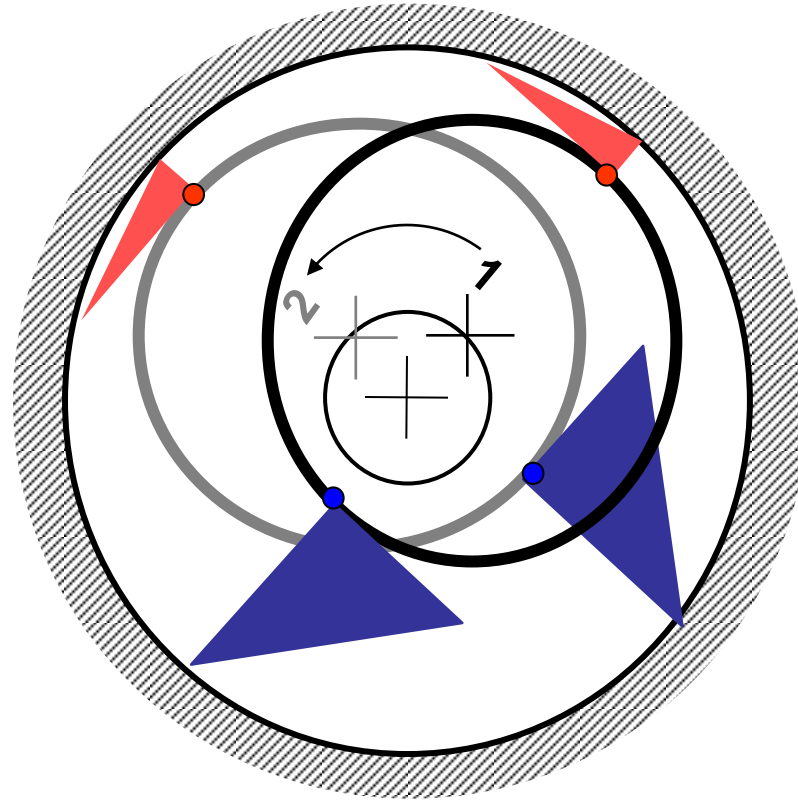


# ROTOR DYNAMIC BEHAVIOR (TEST)



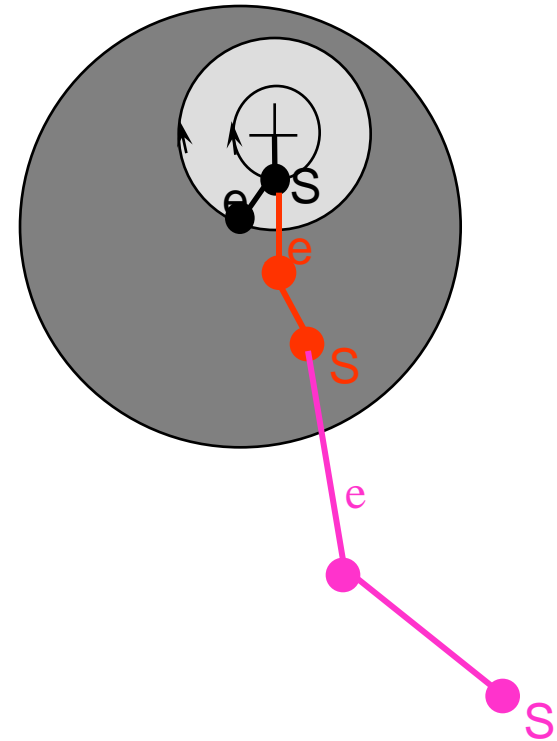
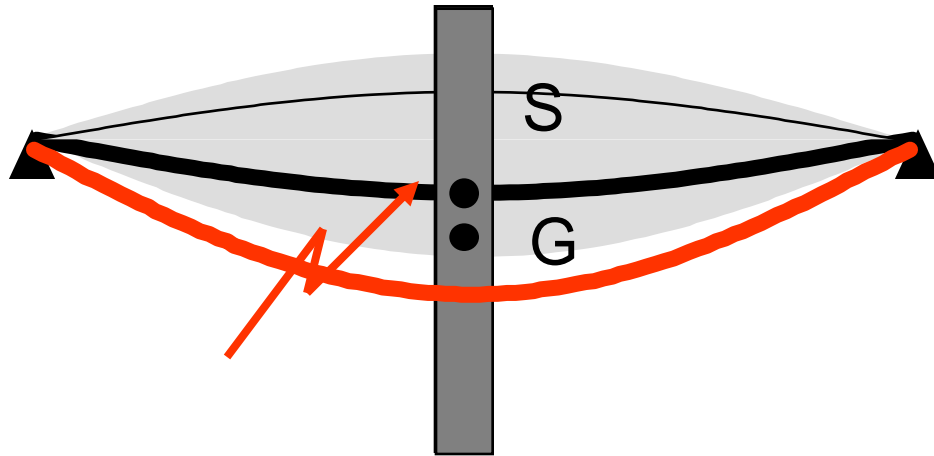
**Vibration hysteresis in Bode pot**

# THE HOT SPOT PHENOMENON

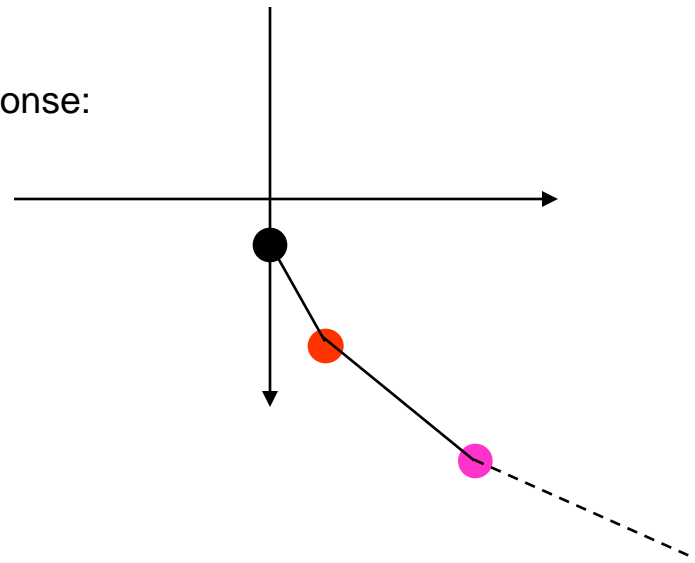


**Hot spot mechanism**

# THE HOT SPOT PHENOMENON

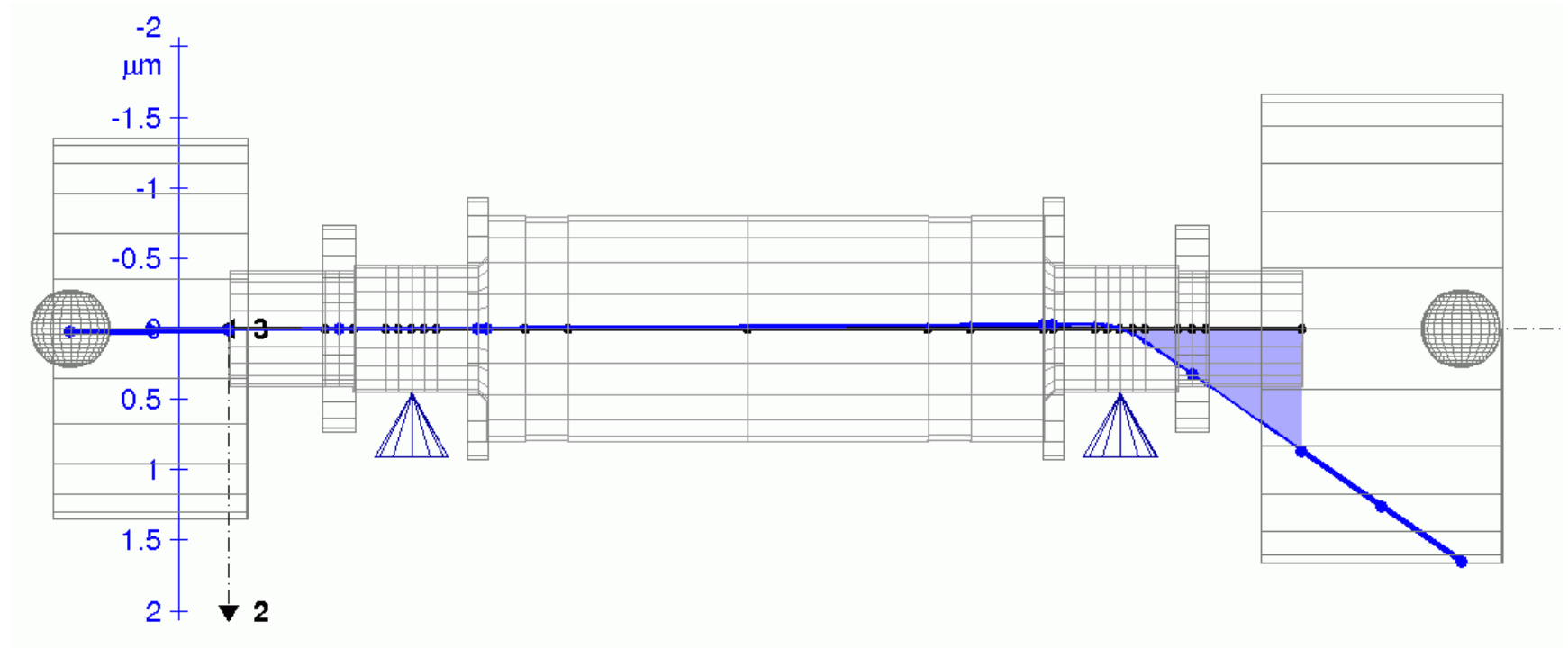


Polar plot of response:



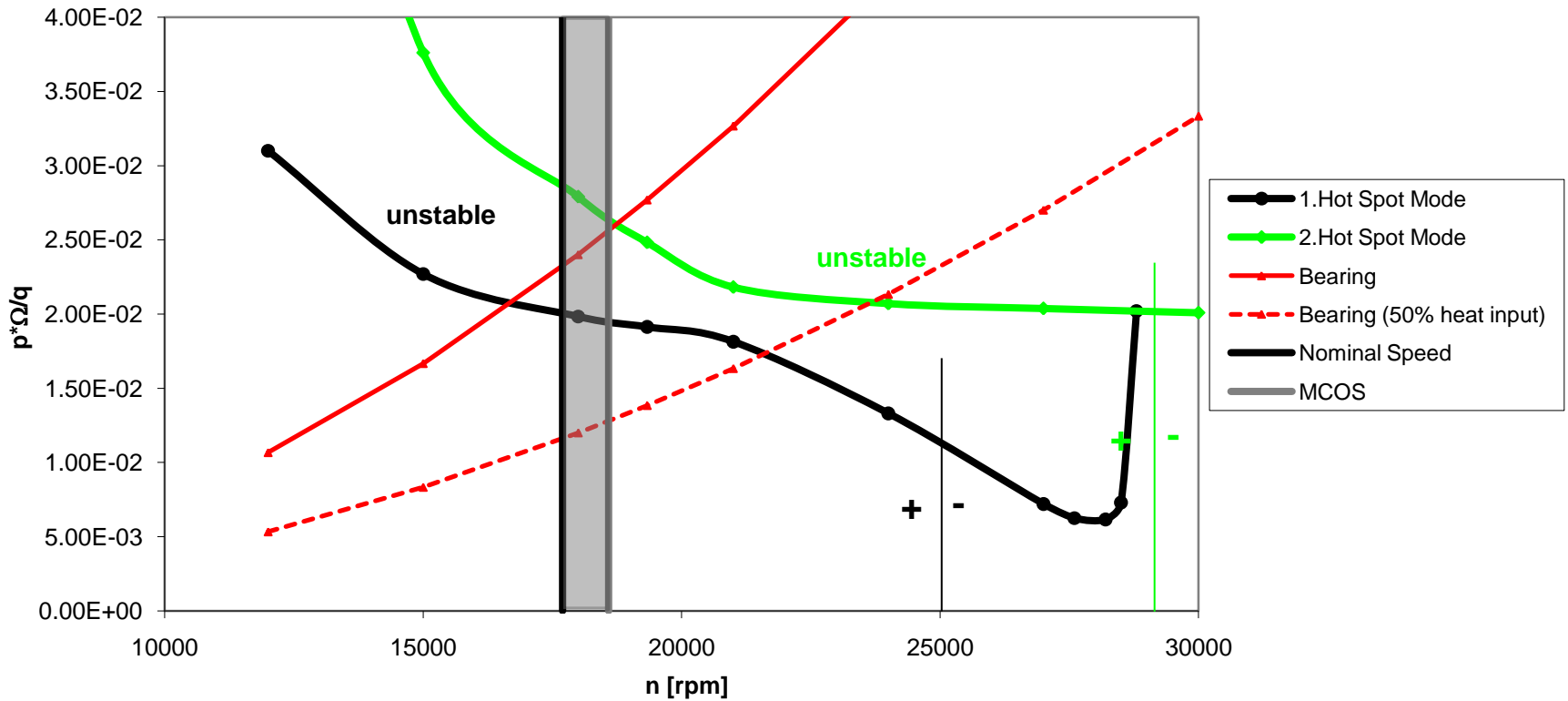
**How does the spiral arise ?**

# THE HOT SPOT PHENOMENON



**Thermal deformation,  
1°C cross sectional temperature difference in comp. bear.**

# THE HOT SPOT PHENOMENON



Hot spot stability chart

# THE HOT SPOT PHENOMENON

## ★ Simplified formula for the estimation of the heat ratio

$$\frac{p\Omega}{q} = \frac{u^2\eta\beta}{\delta^2\alpha}$$

Simplifications best apply to a cylindrical low loaded (centred) cylindrical bearings.

## ★ Parameters

$u$ : Circumferential shaft velocity

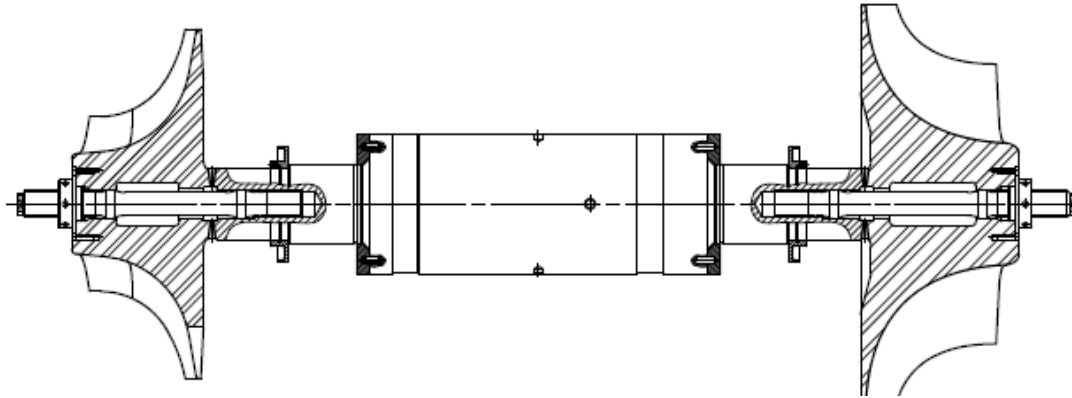
$\eta$ : Viscosity

$\beta$ : Relation between thermal deflection and temperature difference (proportional to width)

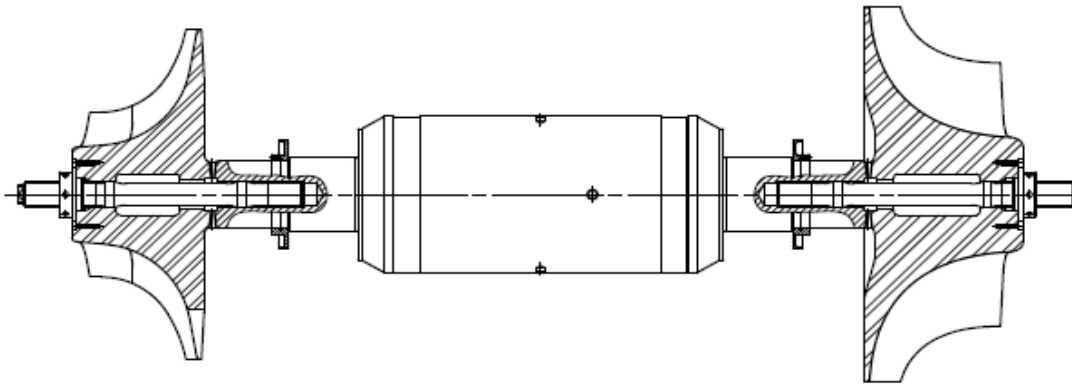
$\delta$ : Clearance

$\alpha$ : Heat transfer coefficient between oil and shaft

# ANALYSED AND TESTED MODIFICATIONS



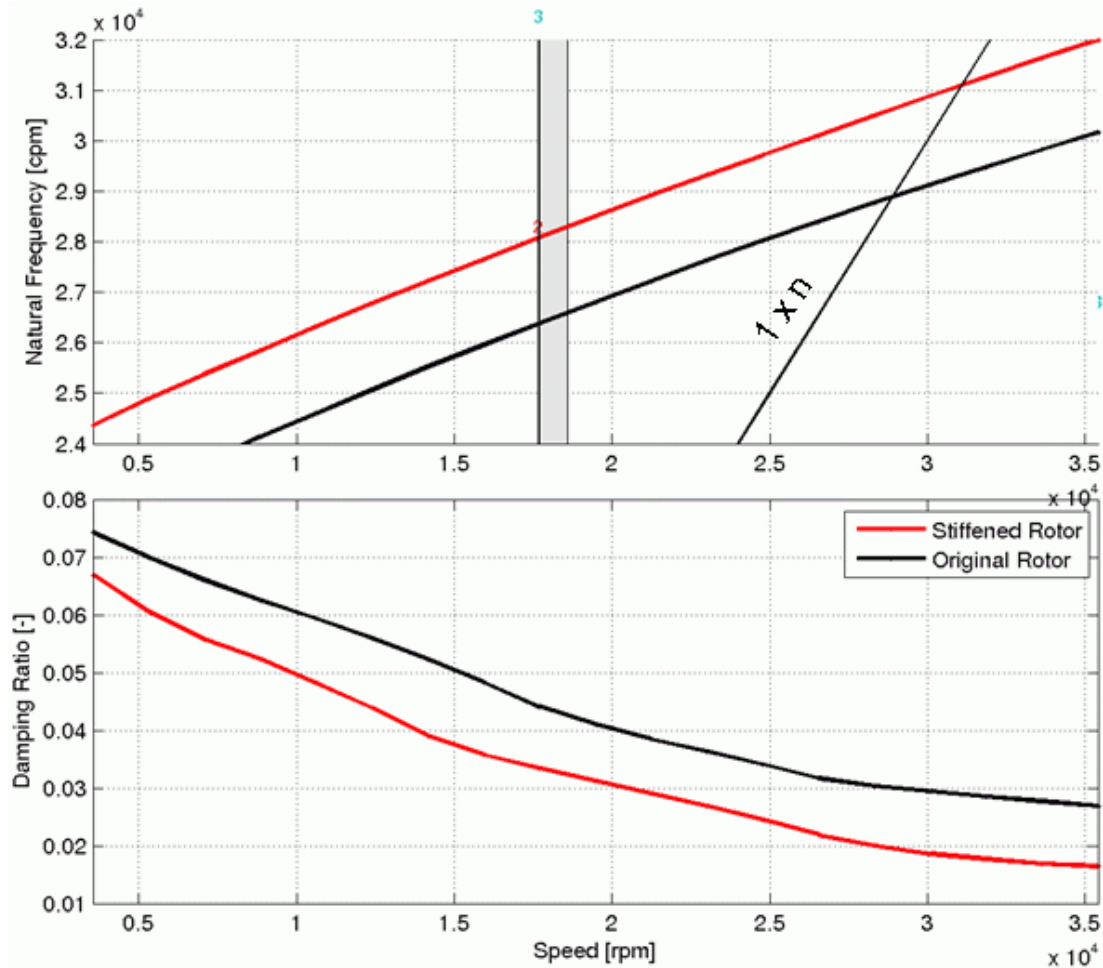
**Original rotor**



**Modified stiffer rotor**

# ANALYSED AND TESTED MODIFICATIONS

★ **Stiffer rotor** → **increased separation margin**

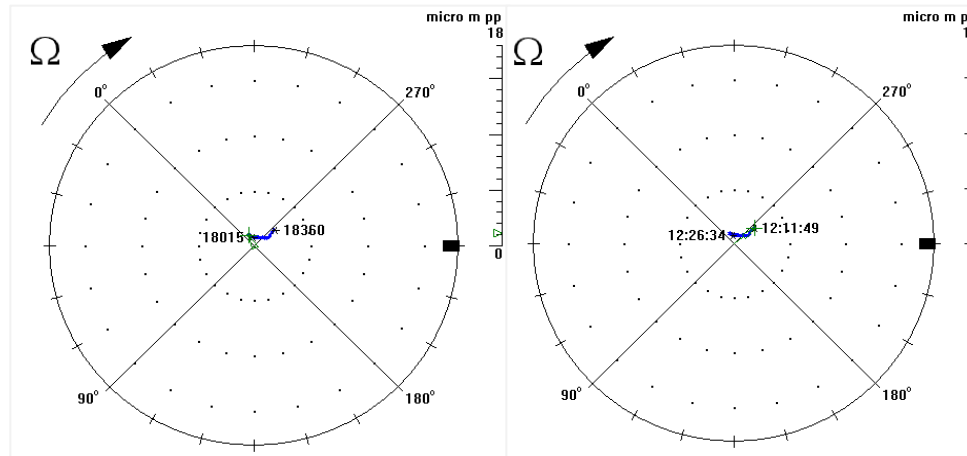


**Campbell diagram bending mode**

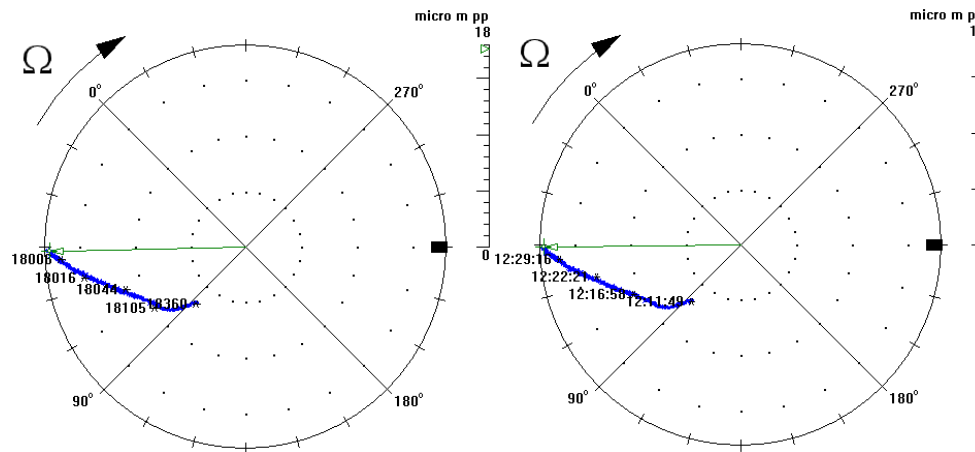


# ANALYSED AND TESTED MODIFICATIONS

## ★ Stiffer rotor



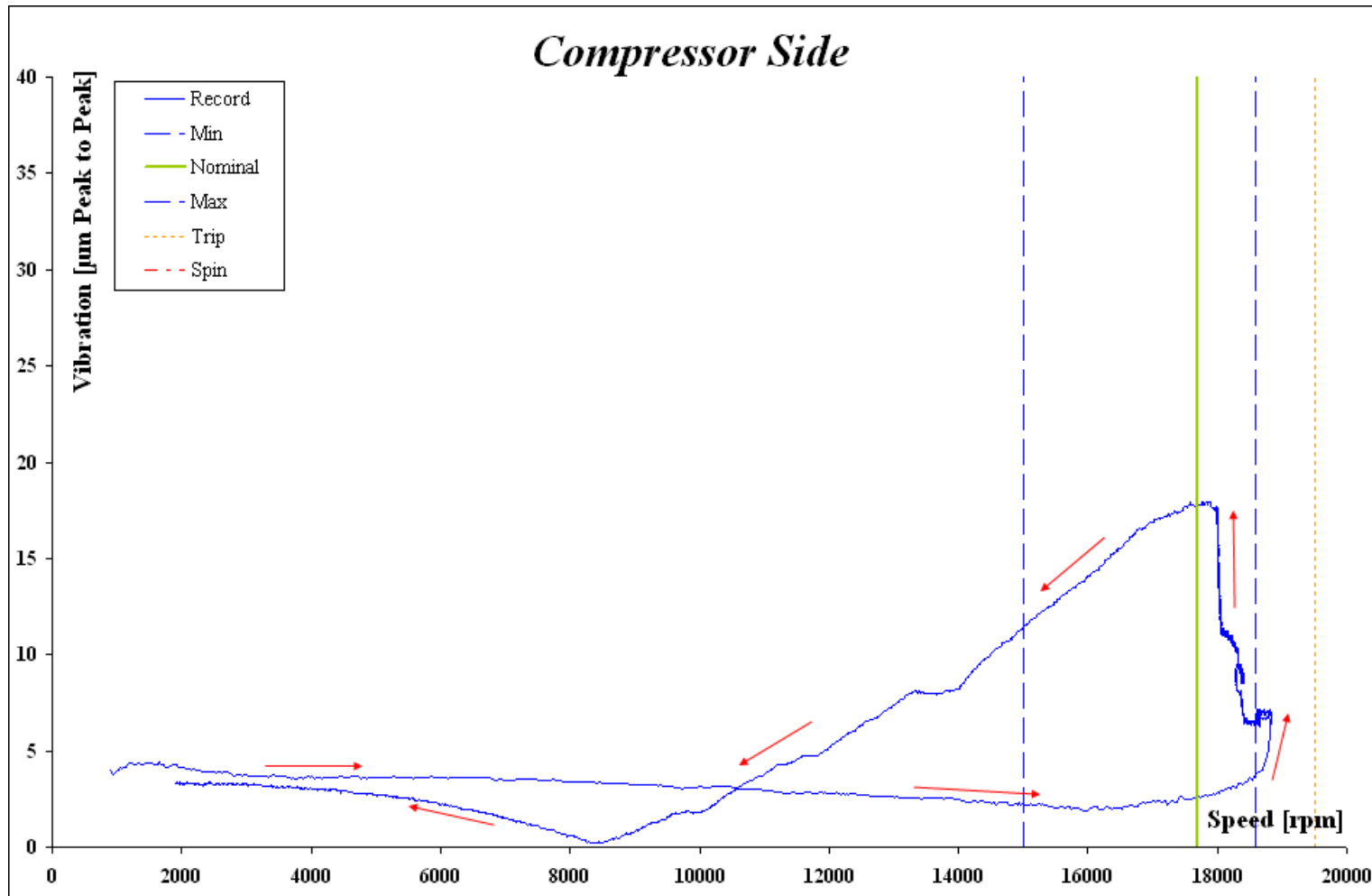
1xN polar plot – expander side



1xN polar plot – compressor side, stiffer rotor

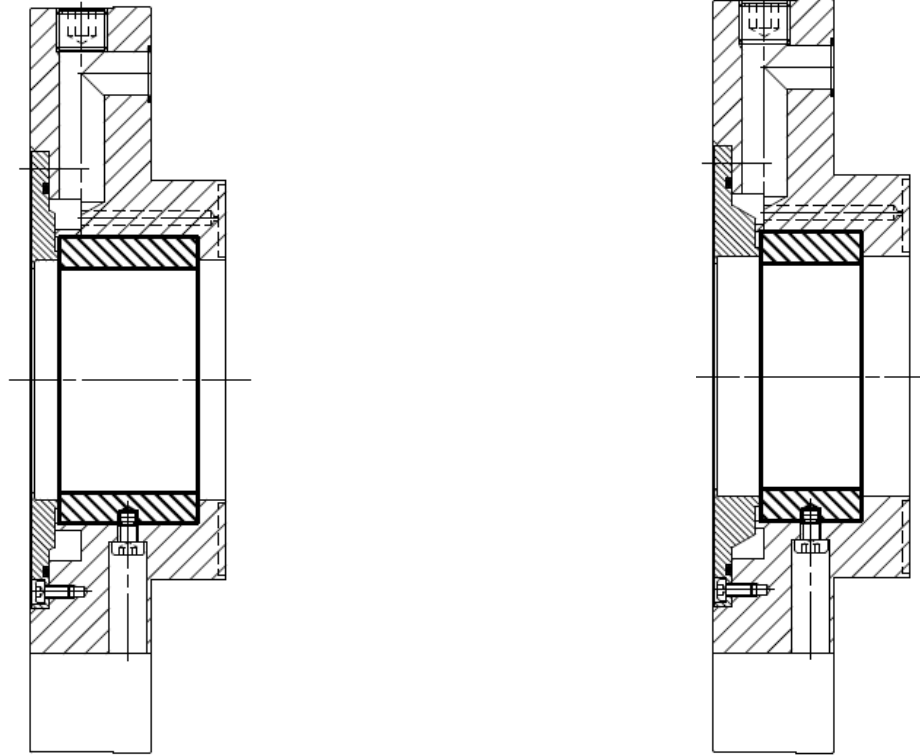
# ANALYSED AND TESTED MODIFICATIONS

## ★ Stiffer rotor



**Vibration hysteresis in Bode pot**

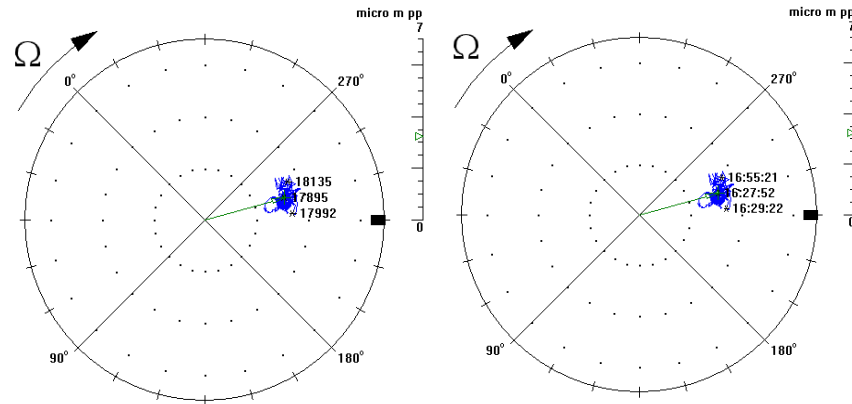
# ANALYSED AND TESTED MODIFICATIONS



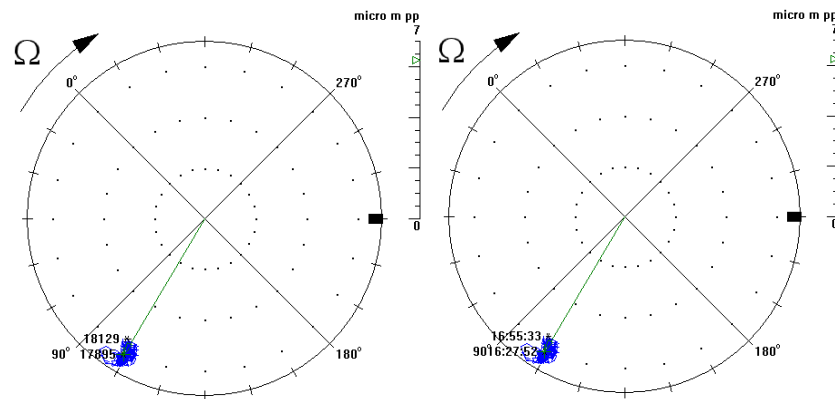
**Original 0.6D and modified 0.4D bearing**

# ANALYSED AND TESTED MODIFICATIONS

## ★ Narrow bearings, reduced oil viscosity



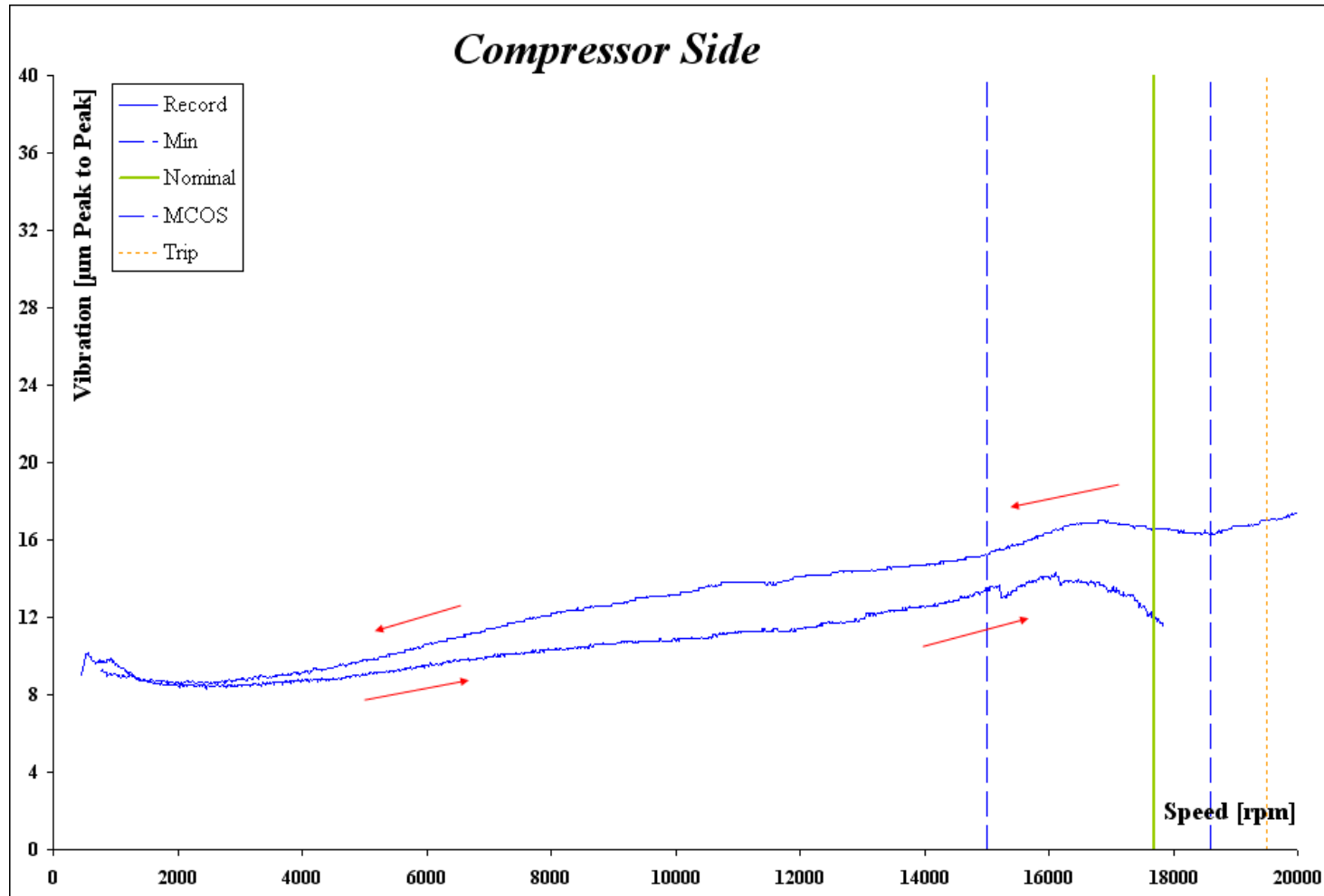
**Polar plot – expander side**



**Polar plot – compressor side**

# ANALYSED AND TESTED MODIFICATIONS

## ★ Narrow bearings, reduced oil viscosity



**Vibration hysteresis in Bode pot**

# CONCLUSIONS

- ★ **A turboexpander was subject to a vibration problem in spite of its robust design. The problem could be clearly identified as a hot spot phenomenon in the bearing (Morton effect).**
- ★ **Classical criteria such as separation margin and damping were not sufficient to predict the problem. These criteria were very favourable in the present case.**
- ★ **The hot spot stability chart helped to assess the risk and corrective measures regarding this phenomenon.**
- ★ **The introduction of narrower bearings and an oil with lower viscosity completely solved the problem in the present case.**
- ★ **This solution cannot be generalised for other cases, especially it may not apply in case of higher bearing loads.**