Preventing Disasters :

On-Site Frequency Analysis of Jet Fans

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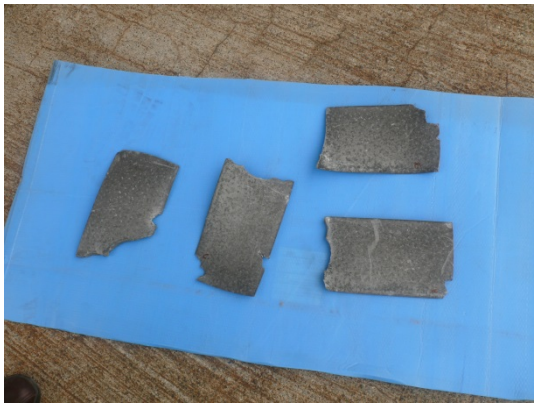
Blade breakage in jet fans, rare but dangerous



Appearance of the fractures :

- All blades are torn off at the blade foot
- one blade showed a large corrosion surface after previous crack formation
- all other blades showed a forced breakage after previous impact load

Cause : Stress corrosion cracking?, Vibrations?

Vibrations in Turbomachines

> Self Excited Vibrations : unsteady air forces cause energy flow from the air into the vibrating blades by phase advance

Occurence with long slender blades with low natural frequencies, hardly possible with jet fans

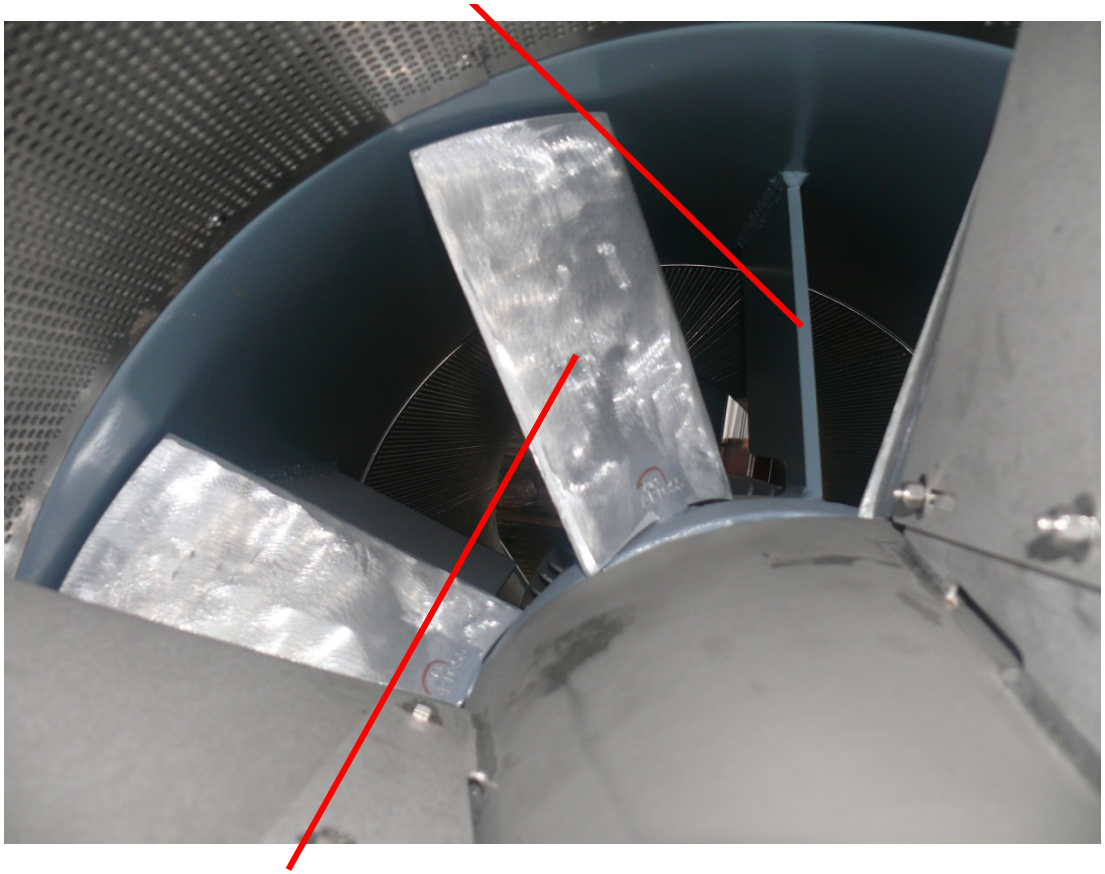
> Forced Vibrations : always existent due to mechanical or aerodynamic excitation

◇ Mechanical excitation : mass unbalances, bearing damages, vibrations in the suspension

◇ Aerodynamic excitation : aerodynamic interaction of rotating and fixed parts
unequal blade pitch
wrong incidence angle of blades

Aerodynamic Excitation in Jet Fans

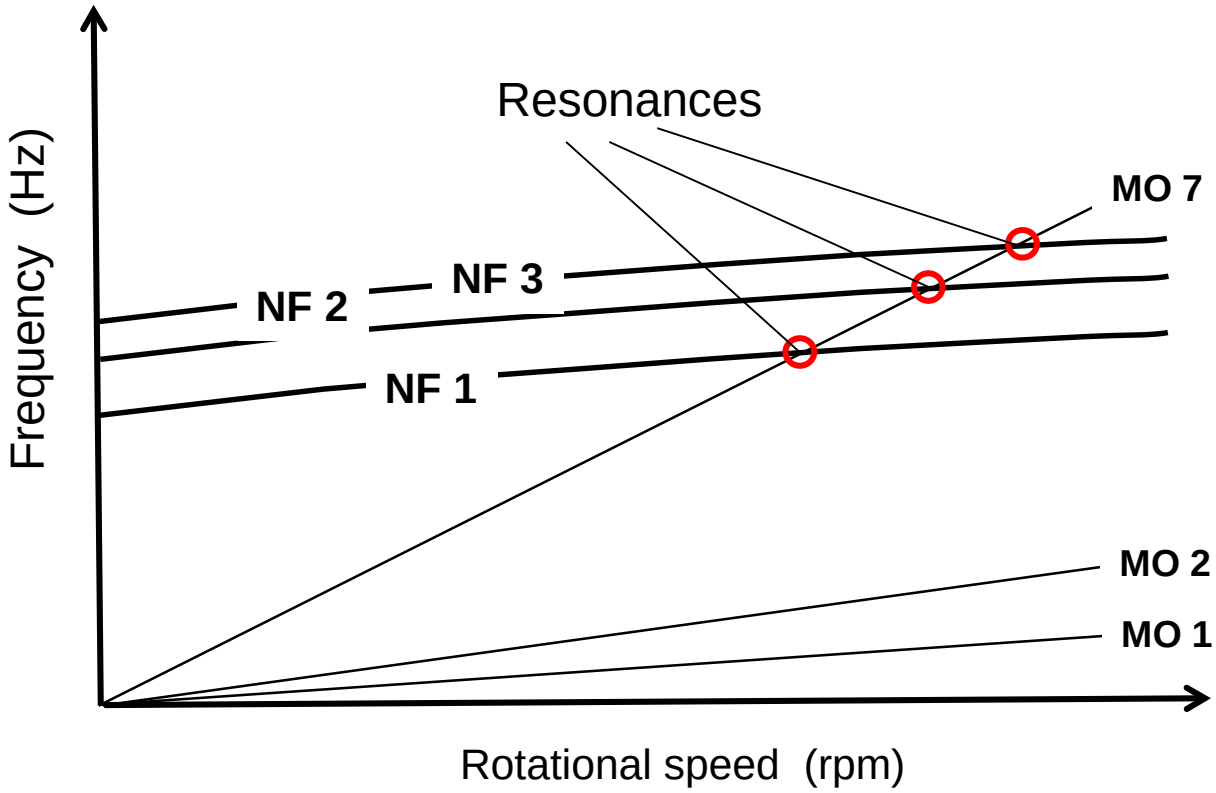
Excitation of struts by n_l rotating blades per rotation



Excitation of rotating blades by n_s struts per rotation

Campbell-Diagram, Principle

Display of the structure natural frequencies and the speed dependent excitation frequencies (machine orders) for the detection of resonances



Theoretical structural dynamic model

$$M\ddot{x} + D\dot{x} + Kx = f_E(t)$$

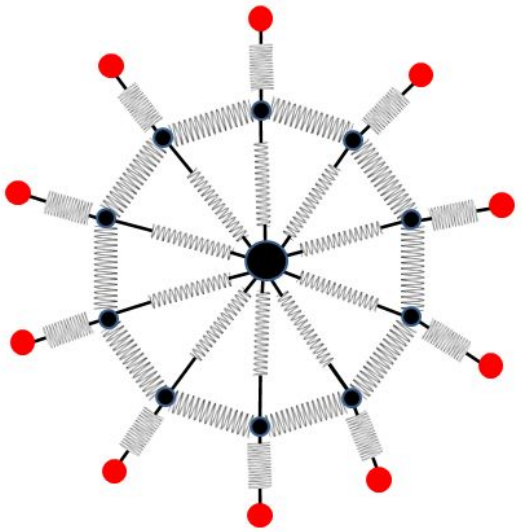
$$D \approx 0$$

$$m_i\ddot{x}_i - k_i x_{i-1} + (k_i + k_{i+1})x_i - k_{i+1}x_{i+1} = 0 \;;\; i = 1, \ldots 2N$$

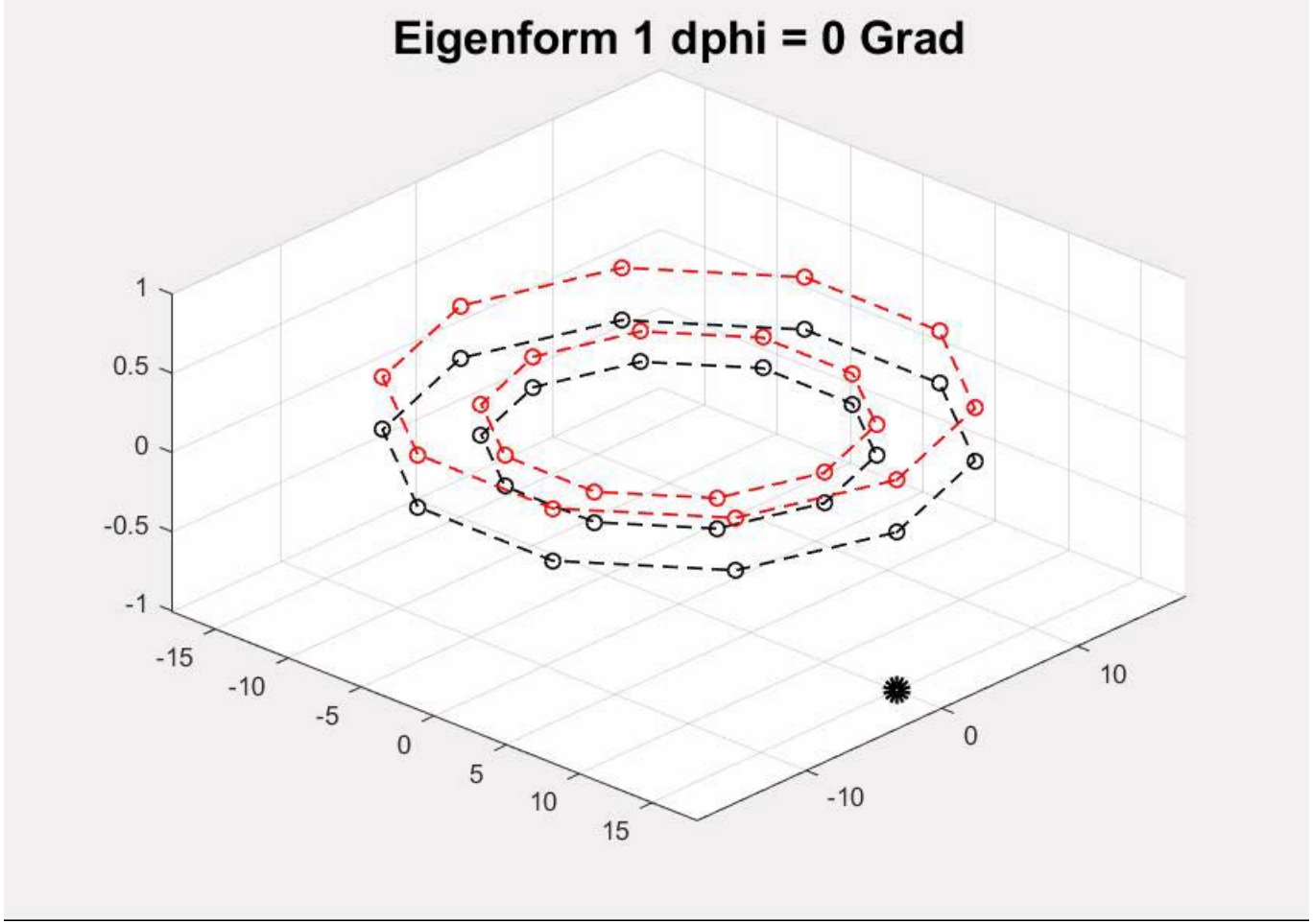
20 Natural Modes are grouped in

- 2 rigid body motions where hub and blade ring are moving in phase or counterphase

- 18 paired motions with the same frequency, but mechanical waves moving clockwise or counterclockwise in circumferential direction (so-called Traveling Wave Modes)

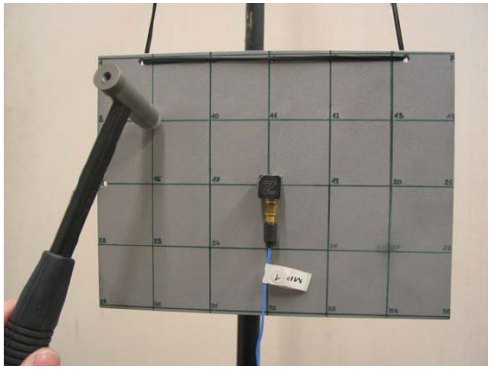


The first 5 natural modes of the blade ring

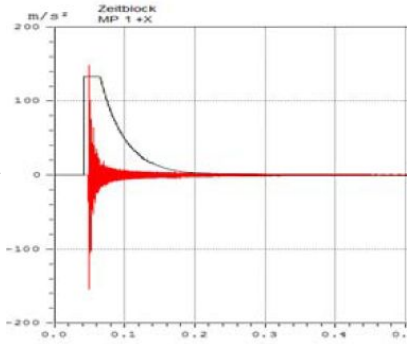


Frequency analysis for detecting blade damage

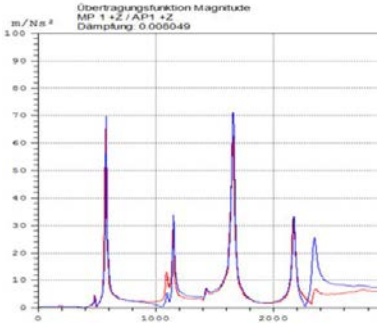
- Regular measurement of the natural frequencies of all natural modes at standstill with impact hammer
- Reduction of natural frequencies is a sign of loss of stiffness, indication of crack formation



Excitation with impact hammer



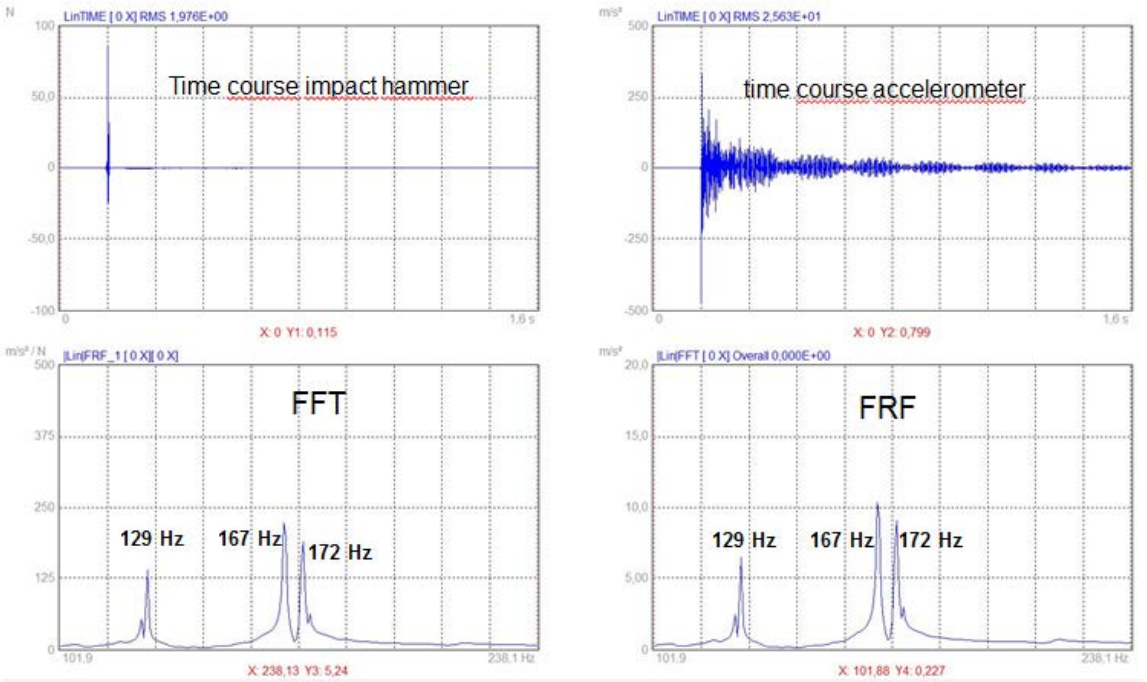
Response signal in time domain



Frequency spectrum

- Regular monitoring of the natural frequencies
- If significant deviations from the original condition visual inspection and replacement if necessary

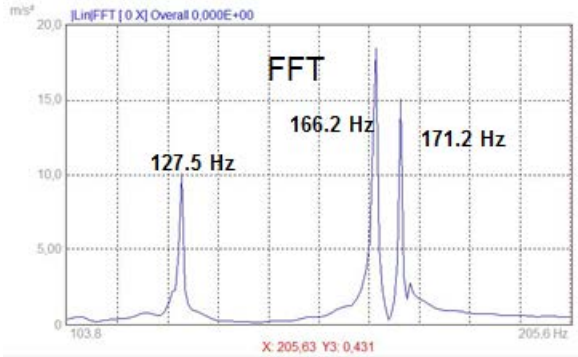
Frequency measurement at a jet fan

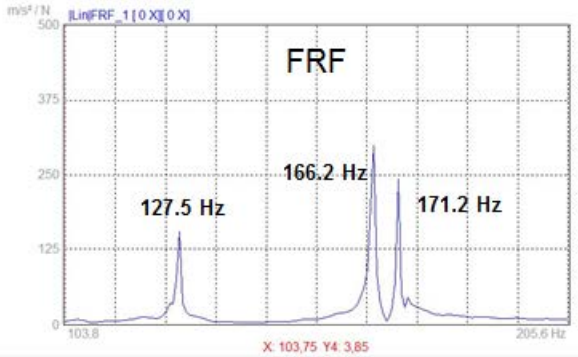


Schaufel Nr.	EF1	EF2	EF3
1	129.3	168.1	172.5
2	-	-	-
3	129.3	168.1	171.8
4	128.7	166.9	171.8
5	128.1	166.8	172.5
6	129.3	168.1	172.5
7	128.7	166.8	172.5
8	129.3	167.5	171.8
9	128.7	167.5	172.5
10	128.7	166.8	172.5
MW +- SA	128.9 +- 0.42	167.4 +- 0.59	172.3 +- 0.35

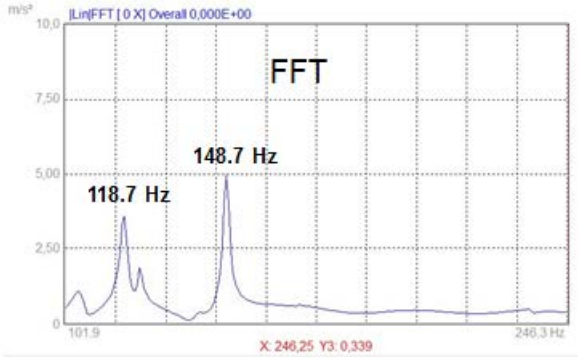
Detecting a crack through frequency reduction

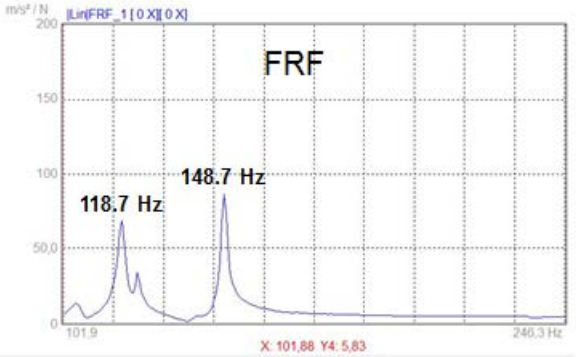
undamaged

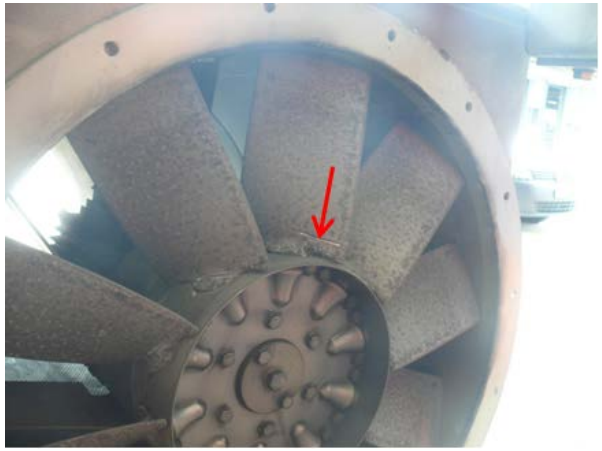




damaged

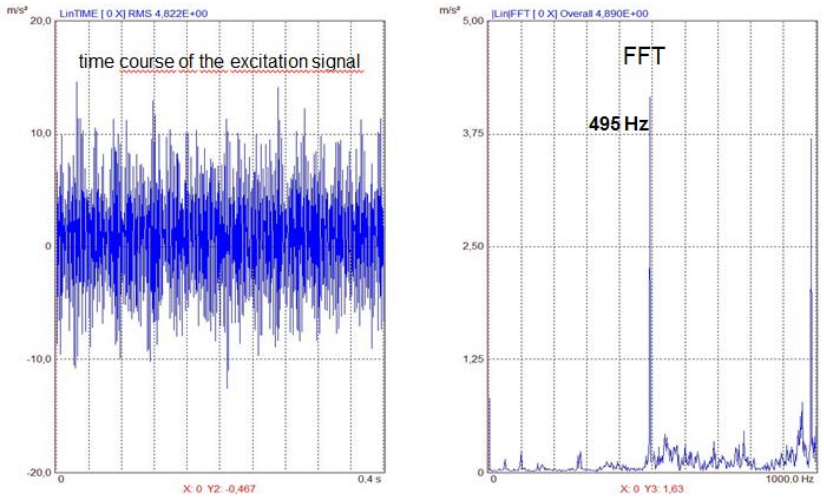




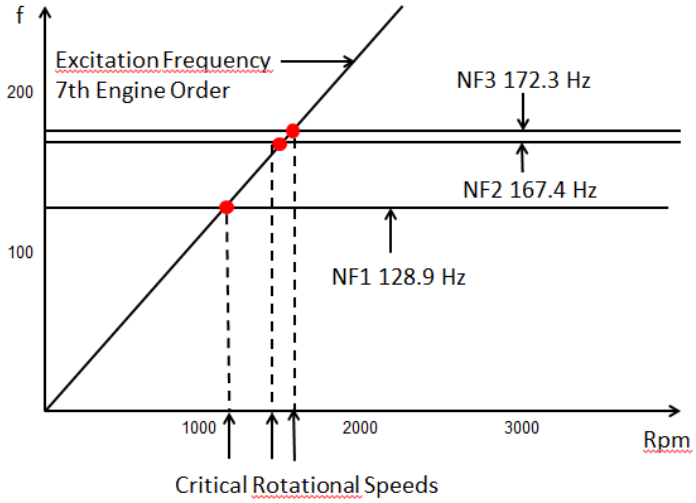


Significant reduction of eigenfrequencies of 2nd and 3rd mode, peak of 1st mode almost vanished

Measurement of forced vibrations on a fan during operation



Time signal of vibrations at the casing



Campell-Diagram of the measured fan

Excitation of the fan wheel : Critical speeds between 1000 and 1500 rpm

Summary

- Frequency measurements with the impact-hammer-method to detect blade damages
- Validation of the method by intentional damage to a blade
- Forced response measurements at the fan casing to detect the excitation frequencies of the fan wheel during operation
- Assessment of critical rot. speeds (rpms) with the Campbell-Diagram

Measurement of eigenfrequencies of fan SV3 in the Flüelen Tunnel