The Behavior of the Modal Properties of Weak and Strong Coupled Acoustic Modes at Different Pressure Levels in a Rotor-Stator Test Rig

Botond Barabas, Dieter Brillert, Hans Josef Dohmen, Friedrich-Karl Benra, Chair of Turbomachinery, University of Duisburg-Essen, Duisburg, Germany

Long Abstract

Introduction

The application of high pressure radial compressors is expected to have an above-average growth rate in future. The main application fields of these machines are assumed at oil exploitation sites as re-injection gas supplies or at Carbon-Capture-and-Storage power plants for carbon dioxide compression. Thus, operational pressures and densities of the working fluids are intended to increase. When vibrations are matter of investigations, impellers surrounded by dense gases cannot be treated separately but as a coupled system comprising the impeller structure and the fluid. Their natural modes of vibration can be characterized with the number of nodal diameters and nodal circles. Each nodal diameter natural mode consists at least of two modes with two corresponding natural frequencies. For weak coupling the coupled natural frequencies approximately equal the uncoupled structural and acoustic natural frequency, respectively. When the coupling gets stronger these modes are labeled as structure and acoustic dominant modes. With increasing pressure the coupled natural frequencies are shifted, as past investigations have shown [1]. The quantification of this shift is an important piece for the safe design of high pressure compressors. In addition, the parameters of influence concerning the damping of the coupled system are currently not known. In particular the effect of the fluid on the structure dominant modes plays a crucial role for the integrity of high pressure impellers.

1. Test Rig

At the University of Duisburg-Essen a rotor-stator test rig is operated (Figure 1) to gather fundamental understanding about the influence of high gas densities on acoustic and structure dominant natural frequencies in side cavities of radial compressors. The test rig itself consists of a plain aluminum disk as rotor and plain walls as stator. The main advantage of its design is that contrary to real compressors the excitation frequency and strength can be set independently from gas parameters and disk rotational speeds. Another feature of the test rig is a rotatable pressure transducer inside the cavity wall which enables the identification of the acoustic mode order in circumferential direction. It is based on an idea of rotatable microphones [2].

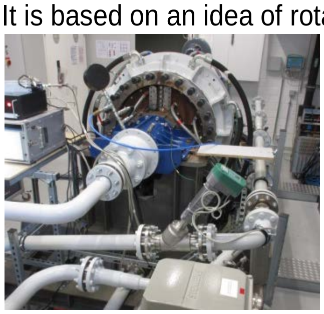

Figure 1: A picture of the rotor-stator test rig at the University of Duisburg-Essen.

2. Results

In Figure 2 and Figure 3 some experimental results of a strongly coupled mode are presented. The diagrams show the results of a strain gage mounted at the disk and a pressure sensor in the front wall, respectively. The fluid is excited with loudspeakers over a frequency range with a constant sweep velocity. A short time Fourier transformation (STFT) is used for the conversion of the signals from the time domain into the frequency domain. The variation of the pressure level corresponds with the third axis pointing to the rear of the waterfall plot. The response amplitudes are divided by the maximum amplitude of the respective sensor. They are plotted over a frequency f* based on the acoustic dominant natural frequency of the mode with four nodal diameters at 1 bar. The gaps between f* = 0.94 … 0.96 for the pressure levels from 1.5 to 4 bar arise from lacking experimental data. The strain gage results at 1 bar show two peaks: A relatively flat one at f* = 1 and a relatively sharp one at f* = 0.93. These resonance frequencies can be observed in the results of the pressure sensor, too. For increased pressure levels, the resonance frequencies diverge from each other. This behavior for coupled modes has been identified also by other researchers in the past. In the figures the sharpness of the peaks, hence the damping, changes with the pressure level. Amongst others, this observation is described and analyzed more detailed in this paper.

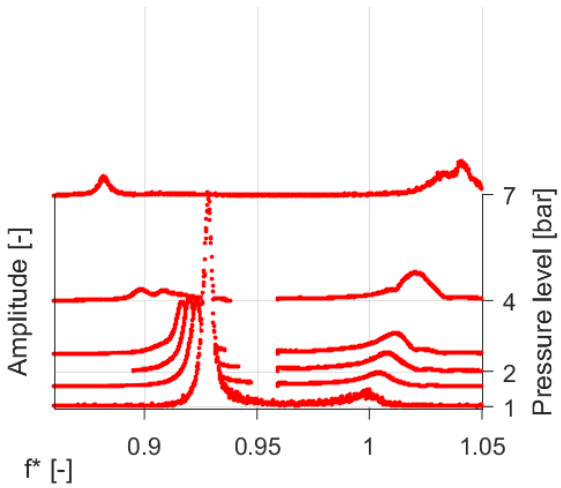

Figure 2: STFT results of frequency sweeps at different pressures (strain gage data).

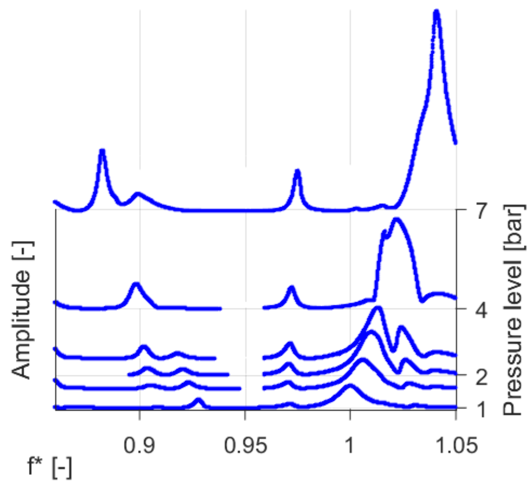

Figure 3: STFT results of frequency sweeps at different pressures (pressure sensor data).

Additionally, experimentally determined modal properties, the natural frequencies and the modal damping, of weakly and strongly coupled modes are compared with each other. Their behavior on the influence of increased surrounding pressure levels is evaluated. Furthermore, the measured natural frequencies are related to an analytical approach from literature and a coupled FEM modal analysis.

References

[1] Y. Magara, K. Yamaguchi, H. Miura, N. Takahashi, M. Narita. Natural Frequency Shift in a Centrifugal Compressor Impeller for High-Density Gas Applications. *Journal of Turbomachinery*, 135:011014-1 – 011014-8, 2013

[2] D. E. Cicon, T. G. Sofrin, D. C. Mathews. Investigation of Continuously Traversing Microphone System for Mode Measurement. *NASA*,1982