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Surge Precursors from Compressor Vibro-Acoustic Analysis

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Abstract. The aim of this work is to explore the possibilities to find surge precursors from compressor vibro-acoustic analysis in a condition close to instability. For this purpose, a large campaign of data acquisition has been conducted by Thermochemical Power Group (TPG) of University of Genoa: T100 micro-turbine, equipped with three different volumes, has been sensorized with accelerometers and microphones and data acquired have been analysed with different methodologies in order to find surge precursors useful for the creation of an anti-surge control.

1 Introduction

Recently advanced turbine cycle layouts are being investigated to obtain higher efficiency, they are based on additional components which increase the volume size located between the compressor outlet and the combustor inlet. These volumes have a significant impact during transient operations due to a longer response in the pressurization/depressurization phase increasing the surge risk. For this reason, the definition of surge measurable precursors is very important for the development of a surge prevention system useful for the reliability and hence the commercialization of these advanced turbine-based plants. A new promising research field of surge precursors is the vibro-acoustic analysis of compressor behaviour during the passage from a steady condition to the instability.

2 Vibrational experimental data acquisition and precursors researches

A vibro-acoustic experimental campaign has been conducted on the compressor of a Turbec T100 microturbine inserted in an emulator plant with a modular vessel which permits to choose different volume configurations between the recuperator outlet and the combustor inlet. The plant has been designed to emulate a hybrid system with a Solid Oxide Fuel Cell (SOFC) [1,2] (maximum volume 4.1 m^3) but other two volumes configuration were tested: 2.3 m^3 (simulating the presence of a high temperature storage device) and 0.3 m^3 (an additional heat exchanger). Compressor surge were obtained closing step by step a valve placed on the main stream between recuperator outlet and combustor inlet starting from a stable condition (40kW at a speed about 60krpm). Vibro-acoustic measurements were acquired to characterize the different valve closure conditions during the surge transitory. and during machine run up and run down to find possible system resonances. Siemens Scadas mobile acquisition system was employed to collected data from tri-axial (dynamic response up to 10 kHz.) and mono-axial (up to 55 kHz.) accelerometers and from microphones (2-50 kHz) with a sample frequency up to 200kHz.

In all volume configurations, both accelerometer and microphone signals reveal an increase of the energy content in the sub-synchronous field before surge: the surge incipience adds a broad band noise in the sub synchronous field increasing progressively its RMS value. This broad band source seems to excite the system resonances in particular that around 585Hz (0.585 rev. speed) whose energy content increase before the surge. Microphone signals show an energy increase in a range from 19 Hz to 37 Hz (0.019-0.037 rev. speed) that appear useful as surge precursor.

The blade pass frequency content BPF at about 13kHz has a reduction before surge but it has some side peaks that increase (in number and energy) before the surge. Cyclic spectral coherence transformation confirmed that a range of frequencies between 9.5 kHz-14.5 kHz (9.5-14.5 rev. speed) is involved in more sub-synchronous BPF modulation before the surge. The sub-synchronous RMS energy content of the Hilbert envelope of the filtered signal in that frequency band seems to be an interesting surge precursor.

Another surge precursor can be found analyzing the loss of spectrum stationarity. Sets of 19 successive signal autopower spectra (one for each valve closing) have been taken into account from far to progressively near the surge and their variance spectrum from the average spectrum has been calculated. For all the volume configuration, Sub-synchronous RMS energy value of variance spectrum increases before surge. A non-dimensionalized similar approach can be used for a band around the blade pass frequency.

Assuming surge contributions not synchronous with the machine rotation speed, another surge precursor seems possible to find studying vibrational signal in the angle domain. Having a tachometer signal, filtered vibrational signals in function of time has been converted to signals in function of the machine rotational angle. Through the calculation of the synchronous average of sets of 350 consecutive extracts (one set for each valve closing) lasting 10 complete machine rotations, it has been possible to calculate the variance from the mean of each set. RMS value of these variances represents the energy of all non-synchronous contents in the signal, hence surge precursor contents.

A last possible surge precursor seems can be researched through the application of chaos theory [3] assuming that surge incipience condition can generate a response with nonlinear contributions. From the accelerometer signal integration, attractor can be plotted in the displacement-speed plane. The attractor represents the mechanical behavior of the point (so the machine) where and in the direction we placed the sensor.
The system non-linearity presence may be quantified by considering attractor as a fractal and evaluating its dimension (information dimension). The increase of the attractor complexity before the surge, quantified by the fractal dimention, can be used as a surge precursor.

3 Conclusions

This work resumes the experimental campaign and the surge precursors obtained from vibro/acoustical signals. The surge precursors found seems work for every volume configuration tested and seems to be extendible to larger compressor systems, future works will improve some of these precursors and use them in an anti-surge control.

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