Full Load String Test Experience on the Instability of a High Speed Back to Back Compressor Equipped With a Honeycomb Seal

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ABSTRACT

This paper describes a recent case of rotordynamic instability occurred to a back to back centrifugal compressor. During the full load string test the compressor showed high levels of subsynchronous vibrations and it could not run through all its operating range. The cause was found in the hardly predictable interstage honeycomb seal dynamic behaviour. As it is well known instability due to the gas seals is a self induced vibration phenomenon caused by the interaction between the gas confined in the seal volume and the rotor. The rotordynamic instability is quite hard to be predicted because the state of the art knowledge about the seals dynamic effects needs to be improved: several analytical models have been developed during the last years but they lack the final validation on a full pressure test rig.

During the first full load test the rotor showed a low subsynchronous frequency (respect to the predicted first natural frequency) which was very sensitive to the differential pressure across the interstage seal and prevented the compressor to run along the whole operative curve (the compressor was stable only on the 40% of the curve). The fact that the vibration amplitude was constant with speed and no aerodynamic excitation was present (no pressure pulsation detected by the proper probes), together with the aforementioned sensitivity to the differential pressure, led the authors to suppose that the instability was caused by the interstage honeycomb seal.

After analytical investigations the depressed natural frequency was explained when the authors noticed that the honeycomb seal code predicted negative stiffness values in the frequency range of interest. The negative stiffness seemed to be controlled by the inlet/outlet radii: giving the seal a convergent conical shape increased its effective stiffness especially at low frequencies. In order to select the proper inlet/outlet radii a sensitivity analysis was led: the impact on system 1st natural frequency and δ was studied (since the tapering produced opposite effects on the seal stiffness and damping properties) and an optimum tradeoff solution was found. After that the new seal design was verified trough a FEA analysis in order to guarantee the desired clearances during operation. Moreover a detailed stability analysis which took into account all the seals effects was performed and it showed the need for shunt holes opening in order to reduce the gas swirl at the seal inlet. After implementing on the rotor these main modifications (convergent conical honeycomb seal and shunt holes) the compressor was successfully retested: it run stable up to the maximum continuos speed (105% speed) at surge condition with very low levels of overall vibrations (especially no more signs of subsynchronous vibrations).