Summary

In the last decades and more recent years, motivated by the Industry 4.0 framework, health condition monitoring of rotating machines based on vibration measurements and changes of modal parameters, such as natural frequencies and damping ratios, has experienced considerable development. Several reasons have contributed to this development and growth. Nowadays, displacement, velocity, and acceleration sensors needed to monitor vibration responses and to predict the condition of the rotating machines are much cheaper, more reliable, smaller, and in some cases, miniaturized, facilitating their integration into machines considerably in a non-invasive way, i.e., without disturbing the work process which the machines are designed to. Moreover, the rapid development of electronics and computational power, i.e., the capacity to store vast amounts of data and perform fast computational calculations – allow engineers to apply health condition monitoring not only to large power rotating machines but also to the ones of small and medium power.

Rotordynamic testing is frequently performed using electromagnetic shakers or active magnetic bearings coupled to the shaft end of rotating machines. In the last case, active magnetic bearings are used as a calibrated electromagnetic shaker. Even though the shaft end is excited by electromagnetic forces without mechanical contact, an additional machine component is added to the rotating machine, changing its layout and dynamics. It can be argued how non-invasive such a testing procedure is. Non-invasive excitation sources are rarely used in rotordynamic testing. This PhD project tries to give an original contribution to rotordynamic testing using non-invasive techniques, i.e., non-invasive sensing and excitation.

The main hypothesis to be proved during the PhD project is that, in the case of turbomachinery, the aerodynamic forces coming from the seals, which are sources of instability and vibration problems, can be decomposed into two parts: i) a large component which significantly dictates the steady-state operational conditions and ii) a small component which will be considered as a white noise non-invasive excitation with enough energy to influence the system's dynamic behaviour under such conditions, facilitating the use of OMA techniques.

The hypothesis is proved using three different experimental setups:

1. A rotor-bearing-foundation setup with neglected aerodynamic forces.
2. A rotor-bearing-foundation setup affected by two gas seals in a back-to-back configuration.
3. A cantilever beam under several boundary conditions.

The PhD thesis is based on five original technical articles. The articles P1 and P2 are devoted to the theoretical and experimental understanding of the dynamic interactions among components, like rotating shafts, passive and active magnetic bearings, control systems, and flexible foundations with and without aerodynamic forces coming from gas seals. P3 and P4 are dedicated to investigating OMA techniques, and P5 links OMA techniques with rotor-bearing-seal-foundation dynamics exploring the seal forces as a non-invasive excitation source to OMA. A brief overview of the findings in each of the five articles is provided in the following: P1, where vibration amplifications are proved to be reduced in the machine response by integrating mode shapes of the foundation structure into a model-based control design; P2, where the influence from neglected dynamics on rotordynamic seal force coefficients and the prediction of machine instability is investigated through three baseline models; P3, where the accuracy of well-established OMA methods and a technique to calculate a representative modal parameter estimate for a group are investigated; P4, where it is tested if uncertainties of a modal parameter estimate can be described via the standard deviation of a set of the modal parameter estimate based on multiple estimation methods and varying data acquisition settings; and finally, P5, where an automatic modal parameter identification algorithm using the technique developed in P3 is built and successfully used on vibration measurements to identify modal parameters for the bed plate of the foundation when the setup is excited by aerodynamic seal forces.

Furthermore, it is demonstrated and proved using setup number 2 – a prototype of a centrifugal pump – that the identification of the centrifugal pump's supporting structure is possible using non-invasive identification methods when the machine is excited by seal forces.