Experimental Characterization of Unsteady Forces Triggered by Cavitation on a Centrifugal Pump

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Long Abstract

Introduction

Propellant feed turbopumps are a crucial component of all liquid propellant rocket engines due to the severe limitations associated with the design of high power density, dynamically stable machines capable of meeting the extremely demanding suction, pumping and reliability requirements of modern STSs (Space Transportation Systems).
The attainment of such high power/weight ratios is invariably obtained by running the impeller at the maximum allowable speed and lower shaft torque. Therefore, operation under cavitating conditions with lighter, but also more flexible, shafts is tolerated, exposing the turbopump to the onset of dangerous fluid dynamic and rotordynamic instabilities triggered by cavitation.
When designing a turbomachine, particularly one which has to operate at high speed, it is important to be able to predict the fluid-induced forces acting on the various components of the machine. The study of radial and rotordynamic forces on turbomachines components, by means of analytical/numerical and experimental approaches has been extensively carried out in the last 50 years by many researchers all around the world. However, the experimental characterization of the influence of cavitation on these phenomena is still very poor even if it is a common operational condition in space application. Moreover, it is extremely important since the occurrence of cavitation drastically modifies the inertia of the fluid surrounding the impellers and, in turn, the critical speeds of the machine. The experimental characterization of the unsteady fluid forces/moments acting on space turbopump impellers as a consequence of the onset of the most dangerous types of cavitation-induced instabilities is here described and analyzed.

1. Methods

The Cavitating Pump Rotordynamic Test Facility (CPRTF, Figure 1, see [1] for further information) at SITAEL (formerly ALTA) is specifically intended for the experimental analysis of relevant phenomena on space application turbopump impellers with particular attention to cavitation related phenomena.

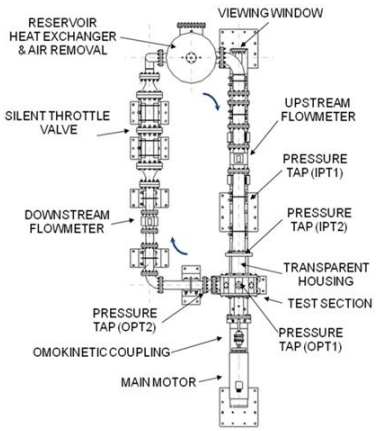

Figure 1. The CPRTF lay-out in SITAEL S.p.A.

In order to relate the fluid instabilities with the unsteady forces acting on the pump, the experiments have been carried out by jointly using a rotating dynamometer, and a suitable number of piezoelectric pressure transducers (PCB, mod. S112A22) flush-mounted on the machine casing. The dynamometer has been placed downstream of the supports, between the pump and the rotor shaft, in order to avoid the influence of seals and bearing forces. The positions of the pressure transducers have been chosen in order to evaluate and identify the nature of the fluid instability (rotational/axial), and thus different axial and azimuthal positions have been exploited as in Figure 2.

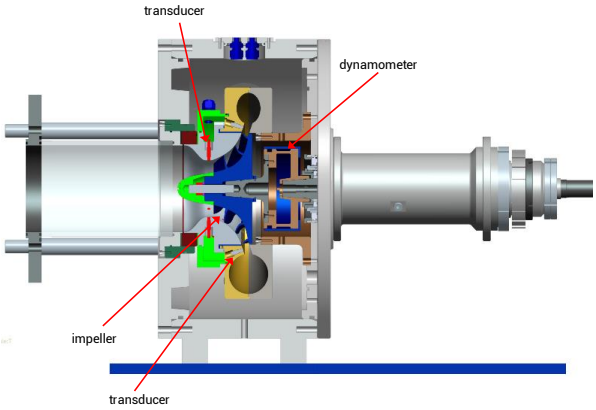

Figure 2. 3D cut-off with a sample of the transducer positions for instabilities characterization.

The impeller, the diffuser, and the volute (see Figure 3) have been designed according to the procedure described in [2,3,4].

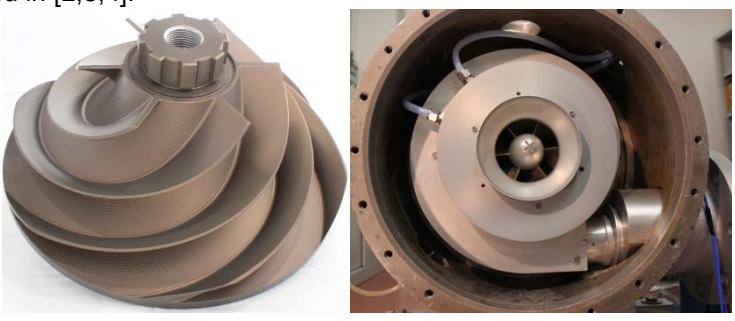

Figure 3. Centrifugal impeller (left) and test assembly (right).

The tests have been carried out at suitable cavitation numbers and mass flow rates in order to investigate the typical specific modes of flow instabilities and the corresponding unsteady forces on the impeller.

References

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[3] Valentini D., Pasini A., Pace G., Torre L., and d'Agostino L., 2013, "Experimental Validation of a Reduced Order for Radial Turbopump Design," in *49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference*, San Jose, California, USA.

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