

## OSCILLATOR COUPLING: THE INSTABILITY OF AN AXIAL EQUILIBRIUM SYSTEM OF A TURBO-PUMP

Gautier Verhille, Patrice Le Gal  
Aix Marseille Université, CNRS, Centrale Marseille,  
IRPHE UMR 7342, F-13384, Marseille, France

The very high rotation rates of turbo-pumps require the presence of fluid cavities on the backs of their rotors in order to withstand the forces created by the rotating fluids. These cavities are equipped with fluid inlet and outlet nozzles which, by their pressure drops, control the pressure on the faces of the disks. These cavities thus constitute the Axial Equilibrium Systems (AES) of the pumps as sketched in Figure 1. These systems are self-balancing and the axial position of the rotors is obtained when the pressures on their faces are equilibrated. It turns out, however, that this balance may become unstable when the flow is compressible: in this case a coupling can appear between a Helmholtz type oscillator, involving the the rotor of mass  $M$  and the fluid cavity, and a hydraulic oscillator created by the nozzles. We have then shown that this dynamical system can be described by the following differential equation of 3rd order, with  $X$  the variation of the position of the rotor with respect to its equilibrium position:

$$X''' + \lambda_2 X'' + \omega_0^2 X' + \lambda_1 X = 0, \quad (1)$$

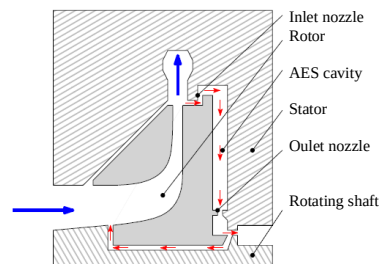
where  $\omega_0$  is the pulsation of the Helmholtz mode of the cavity,  $\lambda_1$  and  $\lambda_2$  two parameters which depend on the characteristics of the upstream and downstream nozzles of the cavity:

$$\omega_0^2 = \rho S^2 c^2 / MV_0, \quad \lambda_1 = K_2 S c^2 / MV_0 \quad \text{and} \quad \lambda_2 = Kc^2 / V_0$$

with  $\rho$  the density of the fluid,  $c$  its speed of sound,  $M$  and  $S$  respectively the mass and the surface of the stator,  $V_0 = S h$  the volume of the cavity of thickness  $h$ .  $K$  is the algebraic sum of the upstream and downstream pressure drop coefficients and is given by the partial derivatives respectively at  $X$  and  $P$  held fixed:  $K = (\delta Q / \delta P)_X$  where  $Q$  is the total flow rate passing through the cavity, and  $K_2 = (\delta Q / \delta X)_P$ .  $K_2$  characterizes the stiffness of the nozzle. The stability of the solutions of the dynamic system (1) is given by the Routh-Hürwitz criterion [1], which states that the solution is stable if  $\omega_0^2 > \lambda_1 / \lambda_2$  and therefore the instability of the AES is likely to occur when the stiffness of the nozzles is greater than a critical value that depends on the fluid compressibility:

$$K_2 / K > \rho c^2 / h$$

Following this theoretical analysis and in order to study this instability experimentally, we have designed a rotor-stator cavity whose stator is mounted on an elastic membrane in order to be able to move axially. The geometry of the nozzle, a conical valve placed at the center of the stator, was selected following preliminary pressure drop measurements. The experiments were carried out in a fluid (sulfur hexafluoride,  $\text{SF}_6$ ) pressurized between 20 and 70 bar and which has the advantage to have near its critical point, a low sound velocity ( $c \sim 100 \text{ m / S}$ ) and a low kinematic viscosity (20 times smaller than that of water). This allowed us to explore a wide range of parameters with highly turbulent ( $\text{Re} > 10^7$ ) and compressible ( $\text{Ma} \sim 0.5$ ) flows in experimental devices of relatively small size ( $\sim 10 \text{ cm}$ ) and yet in similarity with actual turbo-pumps. After having characterized the Helmholtz oscillator of our system, in particular by studying its impulse response, we have succeeded in demonstrating for the first time in the laboratory the occurrence of this instability. The measurements of the instability thresholds are in very good agreement with the predictions of our theoretical model. Finally investigations on the sound emitted by the AES instability show that the Helmholtz mode is not the only excited mode, as a quarter-wave axial acoustic mode is also detected.



**Figure 1.** Sketch of a pump with its Axial Equilibrium System (AES).

### References

- [1] Y. Rocard. *Théorie des oscillateurs*, Paris, édition de la Revue Scientifique, 1941.