Notes regarding the supply and drain pressure effects on a squeeze film damper

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Abstract: *Squeeze film dampers (SFD) are perhaps the most efficient devices that, can be used nowadays to control the shafts in airworthy turbo-compressors. Various other devices can be successfully used in land-based rotating machinery; however, due to space and weight constraints they can not be used for the lateral vibrations control in on-board ball bearings supported turbines. SFDs are basically thin oil films (surrounding the ball bearing housings), that provide the stiffness and damping required for adequate shaft behavior in conjunctions with various elastic elements and anti-rotational devices Fluid films in SFDs are strongly influenced by the oil supply and drain pressures. Some aspects regarding the effects of the supply and drain pressures on a SFD are discussed below.*

Key Words: *Squeeze film dampers (SFD), hydrodynamic bearings, rotor dynamics*

1. INTRODUCTION

Improving turbomachinery performances requires continuous increase in shaft velocity; nowadays it is common for turbomachines to operate above several critical speeds. The dynamics of the shaft is therefore extremely important; hence the damping and stiffness of supports (in conjunction with the stiffness of rotors) must be carefully tuned. Land operating rotors can be installed on a wide variety of supports; both fluid film bearings and ball bearings are acceptable and (as, in many cases space and weight are not very critical concerns) various types of dampers can be included (as needed) in the supports to adequately adjust their dynamic coefficients.

Due to flight safety regulations, in aviation, the rotors of the turbo-compressors in the aerospace propulsion systems must be supported by ball bearings. This requirement is natural giving the nature of the failure in ball bearings and in hydrodynamic fluid film bearings. Failure of the fluid film bearings often occurs without early warning signs, however, ball bearings malfunction is usually preceded by (and associated with) vibrations which can be detected early enough to avoid catastrophic engine collapse in flight. However, ball bearings have very high stiffness and very low damping, so additional damping must be somehow introduced into the system for adequate behavior of the rotor. On the other hand, weight, is a very strong concern for aviation, and, in many cases, space restrictions are also quite severe. Consequently, most of the rotor supports tuning devices that can be utilized for land-based rotors are not suitable for air-worthy rotors. In most cases, the proper setting of the rotors' supports properties in aerospace engines can only be done with Squeeze Film Dampers (SFD).

Squeeze Film Dampers (SFD) are, basically, thin oil films that surround the location (usually a ball bearing housing) where additional damping is needed. They are called Squeeze Film Dampers because, although they belong to the hydrodynamic bearings, the spinning of the surfaces separated by the oil film is restricted (to avoid journal bearing types of instabilities) and the hydrodynamic force is only due to the squeeze motion, the pressure supply and drain system and sealing. Figure 1 shows a schematic of a SFD with seals, pin and an element of an elastic support ("squirrel cage").

Squeeze Film Dampers have been subject of intense research for several decades and probably hundreds of papers have been dedicated to them, as shown, for example in Refs 0-0; however, choosing the proper stiffness and damping for a rotor is not an easy task, Ref. 0. Cavitation may appear, especially when the supply and drain pressures are low, turbulence, Ref. 0, may play its role at high velocities, and moreover, fluid inertia may have a contribution at high Reynolds numbers, Refs. 0-0. However, the literature research shows that the impact of inertia effects, is not very significant until the Reynolds number approaches 4, and, similarly, the turbulence effects have a significant contribution at Reynolds numbers well above 1. On the other hand, cavitation is an important issue only if the supply and drain pressures are low, which is often not the case in pressurized bearings. The supply and drain pressure, though, always have significant contributions, and this paper will address briefly some aspects regarding the supply and drain pressure effects on a squeeze film damper operating at low Reynolds numbers.

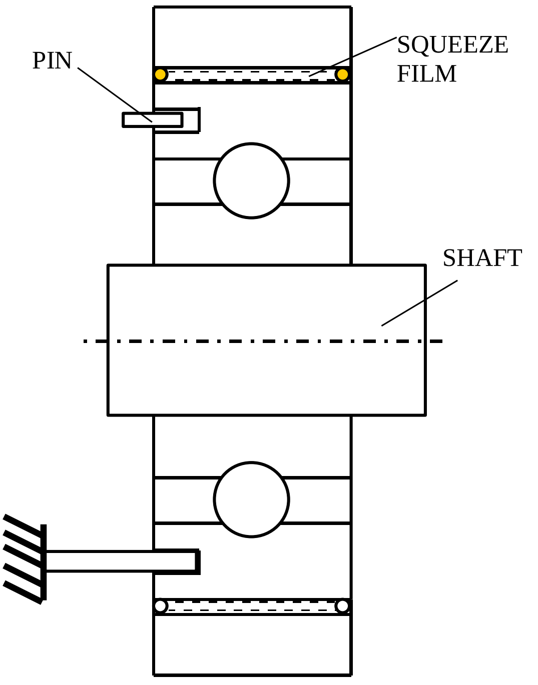

Fig. 1 - SFD with pin, O –rings and an element of an elastic support ("squirrel cage")

2. ASPECTS RELATED TO THE MODELING OF SFD

As it is the case with any damper, knowing the forces that appear in the SFD for various operating conditions is mandatory for properly designing the rotor-supports assembly. For moderate Reynolds numbers, the pressures in the thin oil films can be obtained from the well-known Reynolds equation,

$$\frac{\partial}{\partial\theta'}\left[\left(1+\varepsilon\cos\theta'\right)^3\frac{\partial p}{\partial\theta'}\right]+r^2\frac{\partial}{\partial y}\left[\left(1+\varepsilon\cos\theta'\right)^3\frac{\partial p}{\partial y}\right]= \\ 6\eta\left(\frac{r}{c}\right)^2\left(2\dot{\nu}\varepsilon\sin\theta'+2\dot{\varepsilon}\cos\theta'\right) \tag{1}$$

with Dirichelet boundary conditions at supply and drain locations, where the pressure is known, and/ or Neumann boundary conditions where flow rates are known.

Except for simplified geometries, the solutions are obtained using numerical methods. The pressure variation with respect to the circumferential coordinate θ is similar to the image from/in Fig. 2.

In the region where surfaces are approaching each other (a.k.a. the "positive squeeze area") the pressure is high and forces that appear oppose the relative motion of the surfaces. In the region where the distance between the surfaces increases (in the moment "the snapshot" on the pressure distribution is taken), that is, in the "negative squeeze domain", the model predicts low pressures, or even cavitation (gaseous cavitation or even foam if air entrainment is possible, or vapor cavitation when ambient air can not enter the damper), unless the supply and drain system are pressurized to compensate the pressure drop.

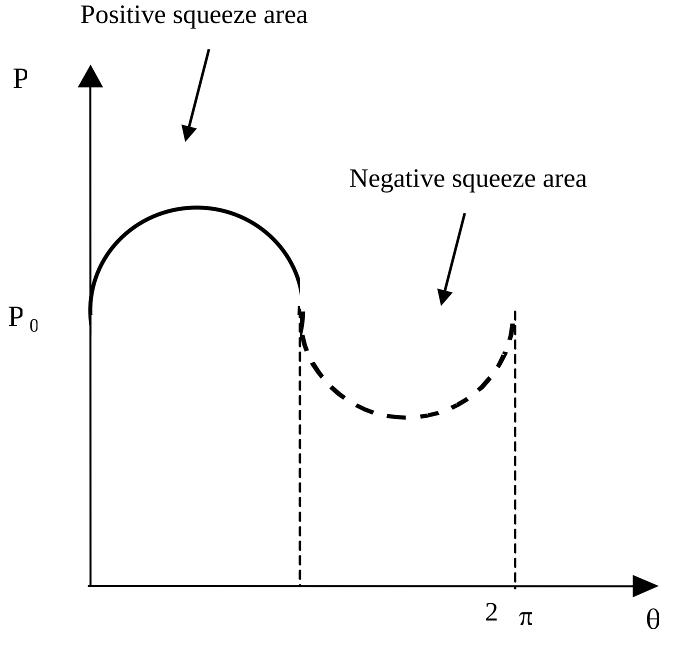

Fig. 2 - 2D pressure distribution in a SFD

Figure 3 presents a commonly used arrangement, a damper with circumferential grooves and oil supply and drain holes located in the grooves.

Pressure distribution over the film lands varies as shown in Fig. 3 and, within the usual assumptions of the classical Reynolds theory, the pressures in the grooves is constant and equal to the pressure of the oil supply or drain lines related to that groove.

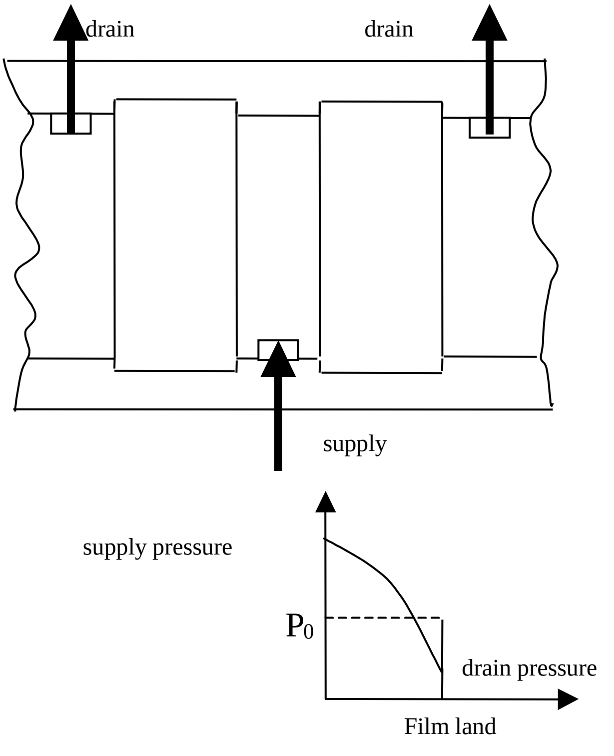

Fig. 3 - Schematics of a possible supply and drain arrangement for a grooved damper and of the pressure drop along the film land, in axial direction

The pressure in the supply and drain lines are therefore very important for the pressure distribution in a SFD and hence for the response of the damper, namely for the forces developed in the damper.

It should also be mentioned that key design requirements in turbomachines include tight tip blade clearances (so the whirl radii must be severely restricted) and also reduced loads transmitted to the structures.

On another hand, the response of a rotor on modern nonlinear supports (including rotors supported on SFDs) is quite complex, and many synchronous and non-synchronous frequencies may appear that can be difficult to analyze at early design stages. Consequently, the SFD design always includes calculations made for shafts executing synchronous whirls on circular centered orbits, see Fig. 4.

The subsequent part of this paper includes a short discussion of the effects of the supply and drain pressures.

A comprehensive analysis exceeds the limits of a journal paper and the pressure distribution in the negative squeeze film area is replaced with a constant pressure so that the area below the pressure distribution is equal to the area below the constant pressure.

Cases of low supply pressures leading to gaseous cavitation are beyond the purposes of this paper, as in practice turbomachinery bearings are not supplied at low pressures.

Increasing the pressure in the supply and drain lines, hence increasing the pressure in the negative squeeze film area was found to be beneficial on the unbalance responses; however, the effect on the transmissibility of the damper is more complex.

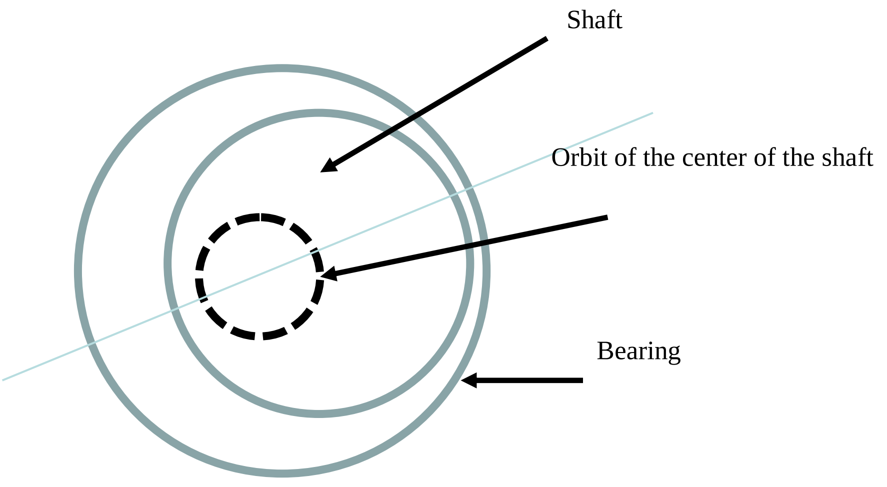

Fig. 4 - Circular centered orbit of the shaft within the bearing in synchronous whirl

Figure 5 shows the forces transmitted through the damper in a circular centered orbit for various pressures in the divergent (negative squeeze) area. It can be seen that the simply dropping of the supply pressure does not always lead to better transmissibility and the proper supply and drain pressures must be selected according to the operating speed of the shaft.

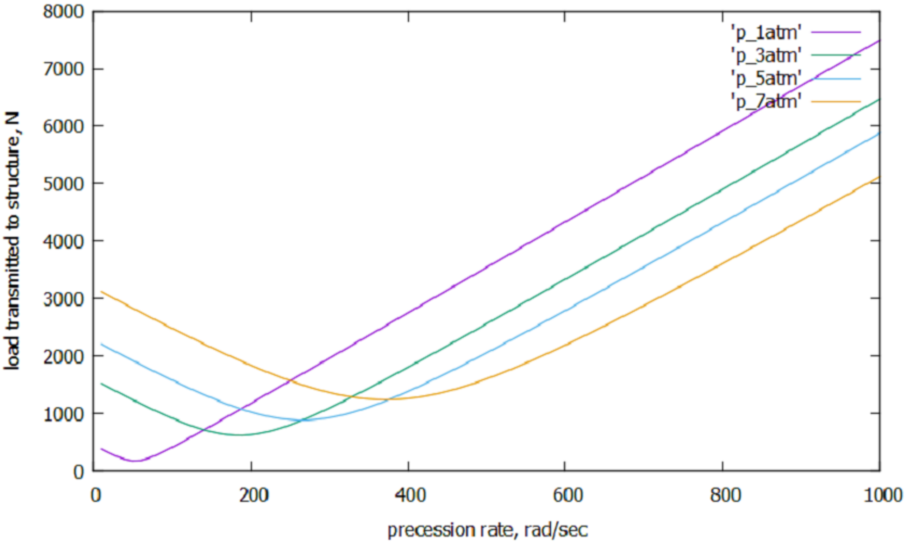

Fig. 5 - Force transmitted to the structure, circular centered orbit

3. CONCLUSIONS

Key design requirements in turbomachines include tight tip blade clearances (so the whirl radii must be severely restricted) and also reduced loads transmitted to the structures. Increasing the pressure in the supply and drain lines, hence increasing the pressure in the negative squeeze film area was found to be beneficial on the unbalance responses; however the proper supply and drain pressures must be selected according to the operating speed of the shaft.

NOMENCLATURE

c	Clearance of the bearing (=0.000129 m)	r	Radius of SFD journal (=0.06172m)
l	Bearing width (=0.0365m)	ε	Relative eccentricity (=0.63)
		η	Oil viscosity (=0.07Pa*s)

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