

## Research Article

# Pressure Fluctuations in the Gasostatic Bearing Supply System on Supercritical Operation Mode

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**Abstract:** This study discusses the oscillatory mode occurring in the gap between the stator and the rotor in gas-static bearing during the outflow of under expanded gas jets out of the supply system, which interacts with the surface of the rotor. The results of studies on the oscillation regimes, their causes, mechanisms and frequency characteristics of pressure fluctuations in the working fluid supply system and the lubricating layer of gas bearing. A one-dimensional model of central shock oscillations in a gas jet leaking on a perpendicular barrier is considered. Experiments were carried out. The regions, where oscillation regimes exist are revealed.

**Keywords:** Consumption oscillations, gas dynamics, gas-static bearing, hybrid gas bearing, oscillations, shock-wave structure

## INTRODUCTION

In some cases, gas bearing with forced supply of gas under pressure in the lubricating gap (gas-static bearing) has significant advantages over the gas-dynamic bearing (lift force acting on the shaft is created by the Bernoulli effect) (Bulat and Bulat, 2013b, c).

The task of designing the air supply system to the air gap of gas-static bearing decomposes into three interrelated problems: air supply consumption control, providing maximum rigidity of the lubricating layer; dampening of pressure oscillations and consumption in the supply system and the lubricating layer; optimal distribution of working body for a given base surface of the gas bearing.

The purpose of pressure throttling in the supply system is to provide a single pressure of working fluid supply at differing levels of counter-pressure in the supply holes. The difference in counter pressure occurs due to tilting of the shaft in the bearing and due to the eccentricity of the shaft position in the presence of a radial load on the shaft.

At supercritical pressure drop, the supersonic jet, which can be under expanded or over expanded, depending on the value of counter-pressure flows out of the throttle (in another terminology-compensator or nozzle). It is known that the leakage of jet onto the coaxial or perpendicular to the axis of the wall may give rise to oscillations (Bulat and Uskov, 2012a, b). On the one hand, oscillations are undesirable effect that causing vibration and unstable operation regimes. On the other, the fluctuations of the working body in the

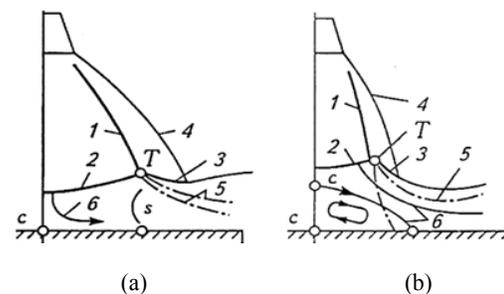


Fig. 1: Shock-wave pattern in front of an obstacle (a, b) during the supersonic jet leakage on it, (a) stationary flow regime, (b) the flow with the central circulation area

1: Suspension shock wave; 2: Central shock wave; 3: Reflected shock; 4: Jet boundary; 5: Mixing zone; 6: Flow line; 5: Sonic line; c: Flow stagnation point; s: Sonic point; T: Triple configuration of shock waves

lubricating layer create an additional lifting force that increases the bearing's load capacity for a given consumption of the working fluid, or improves the efficiency at a given load capacity.

Proceeding from the above, it is important to have an idea about the range of parameters, at which the oscillations can occur and their amplitude-frequency characteristics. Useful is to be able to manage the process of oscillation and their suppression.

During operation of the gas supply system on supercritical regime the supersonic jets flow out from the openings into the nozzles and the lubrication layer and interact with the rotor's surface (Fig. 1). Presence

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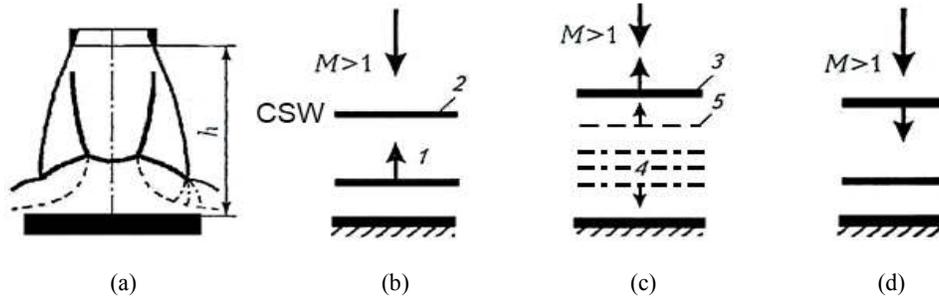


Fig. 2: Scheme of shock-wave process of self-oscillation regime

of the orthogonal barrier in the first barrel of the jet axis leads to a shift of triple shocks configurations near the nozzle, compared with drowned jets toward other (compared with the parameters before the Mach disc in drowned jet) parameters to the central shock wave (Ostapenko and Solotchin, 2012).

### METHODOLOGY

**One-dimensional model of the oscillations cycle:** In the one-dimensional modeling the processes, occurring in the shock layer during oscillation regime, can be explained by the scheme shown in Fig. 2.

Shock wave 1 shows the result of the central flow locking beyond the central shock wave by peripheral that reaches the surface of the barrier at some distance from its center (Fig. 2a). Wave travels from the obstacle on the subsonic flow (Fig. 2b), reaches a stationary central shock 2 and interacts with it. As a result of the interference the central shock is transformed into a shock wave 3, contrary to the supersonic flow and directed to the nozzle (Fig. 2c). Note that with the shock wave 1 the triple configuration travels along the shock 1 as well. Since the intensity of the shock 1 (Fig. 1), when approaching the nozzle, decreases, the difference in gas-dynamics variables in the flows, separated by a tangential discontinuity decreases too. Reflected rarefaction wave 4 propagates in the direction of the barrier across the flow or deceleration area behind wave 1 (Fig. 2c). Contact discontinuity 5 separating the flows behind the shock wave 3 and rarefaction wave 4 can move to the nozzle.

Reflection of wave 4 from the obstacle occurs in the form of a rarefaction wave that moves to the nozzle and, after refraction at the contact discontinuity 5, catches shockwave 3. As a result of the interference of the shock wave is converted into 3 carried-off (drifting in the terminology described by Gorshkov *et al.* (1993) shock wave 6, which runs towards the barrier relatively to the supersonic stream at the subsonic (Fig. 2a). The velocity of the flow behind the drifting shock wave can remain supersonic, thus the leakage of this flow onto barrier may lead to the occurrence of the shock wave 7. Increased pressure at the barrier removes the "blockade" of the central flow and it leaves the shock layer. Note that the triple configuration, associated with

the shock wave toward the obstacle leads to increase of the differences between the dynamics variables at the tangential discontinuity promoting new blocking of the central stream. Without going into the details of these processes and into the analysis of moving triple configurations, which is performed in book of Naberezhnova and Nesterov (1976), it can be postulated that the shock-wave processes will lead to the scheme in Fig. 2b that initiated the description. The above scheme explains the mechanism of self-oscillation regime internal feedback.

Thus, a self-oscillation regime of interaction between the supersonic jet and the barrier is conditioned by the uneven distribution of the parameters in jet and depends on geometric and gas-dynamic parameters of the nozzle, barrier dimensions and its distance from the nozzle.

### RESULTS OF EXPERIMENT

Figure 1 shows the experimental plots of static pressures change on the barrier in under expanded impact jet at different distances between the nozzle exit and barriers  $h$  (hereinafter all linear dimensions are referred to the nozzle exit radius  $r_a$ ).

At certain distances  $h$ , depending on the Mach number  $Ma$  of nozzle and outflow non-calculability, pressure in the center and on the periphery of the obstacles are the same (Fig. 1, c-curve 2). These distances approximately correspond to the beginning of self-oscillation regime (Uskov *et al.*, 1987).

The occurrence of this mode happens suddenly, during small change in  $h$  and is characterized by large pressure oscillations at the barrier. Triple configuration T becomes non-stationary and makes intense oscillations between the nozzle and obstacle. Within the shock layer the traveling waves of compression and rarefaction and sometimes the shock waves appear, which is confirmed the experimental data (Al'basarov, 1991) and numerical calculations (Omelchenko and Uskov, 1995; Uskov, 2000).

The joint effect of the geometrical and gas-dynamic factors on the flow structure and self-oscillations parameters during the interaction between supersonic jets and normally located flat unlimited or

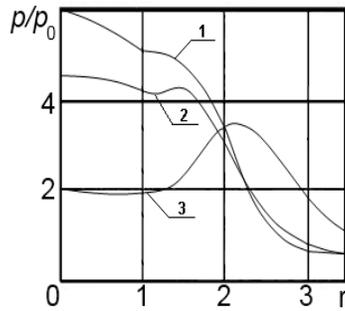


Fig. 3: Typical static pressure distribution, (b) along it ( $Ma = 2, n = 2.45$ );  $v-1-h = 3.5, 2-h = 4.25, 3-h = 9$

limited barrier is manifested through the generalized similarity parameter  $x^* = 2 Ma (\gamma n)^{0.5}$ ,  $\gamma$  - the adiabatic index. If you change the value of the ratio  $h/x^* = H$  in the system "jet-hedge", the stationary and non-stationary regimes of flow take turns.

To simulate the jets outflow from the gas-static bearing feeding system nozzles, the conical Laval nozzle with a number of  $Ma = 1.5$ , half-angle of  $5^\circ$  and a radius of the outlet section  $r_a = 5$  mm was used. Experiments were conducted in the following ranges of parameters:  $\gamma = 1.4, Ma = 1.5, n = 3$  and  $5, r_{pr} = 2.5, 2.8, 3.45, 3.8, 4.6, 5.28, 5.72, 6.27, 6.9, 7.45, h = 3-16$ .

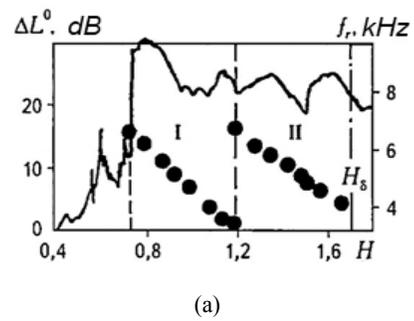
During the experiment, the curves displaying the integral level change of pressure pulsations at the barrier  $\Delta L_0$  as a functions  $h$  with barrier's radius variation  $r_{pr}$  for jets with  $n = 3$  (Fig. 3a) and  $n = 5$  (Fig. 3b) were obtained.

The parameters of the system "central shock wave-a barrier" influence the frequency of pressure pulsations  $f_r$ . The increase of the central shock's distancing form barriers with the growth of distance  $h$ , as well as the value  $n$  and the  $Ma$  number increase are accompanied by frequency decreases  $f_r$ .

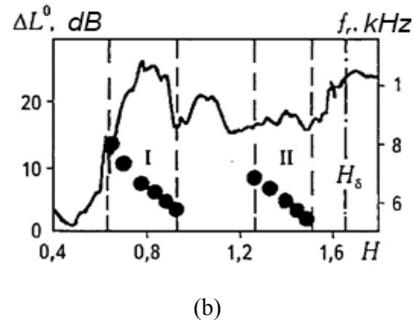
Frequency analysis of non-stationary processes showed that in areas of occurrence and cessation of self-oscillations in the frequency spectra there is only one discrete component, which significantly exceed the broadband background is (15-25 dB).

As the distance  $h$  changes there are two regimes with significantly different mechanisms of maintaining the oscillations occur. The first auto-oscillation regime is characterized by the presence of several discrete components (along with the main tone there are overtones, up to 40 dB higher than the overall level of the continuous jet noise) in the frequency spectrum; powerful oscillations of shock-wave structure and pressure on the barrier with a large amplitude and relatively low frequency. The oscillations have a strong periodic structure.

The presence several (multiple) discrete components in the frequency spectrum is a consequence of the nonlinear nature of the pressure pulsations caused



(a)



(b)

Fig. 4: Amplitude-frequency characteristics of self-oscillations (a)  $r_{pr} = 3.45$ , (b)  $r_{pr} = 7.45$  for  $n = 5$ . Solid curves correspond to the integral level  $\Delta L_0$ ; Dark spots: Fundamental frequency  $f_r$ ; Dashed vertical lines separate the beginning and end of non-stationary regimes; Dash line: Radial flow with the unperturbed first barrel jet  $H_\delta$ ; Numerals I and II denote the first and second oscillation regimes

by the shock-wave processes in the area between the shock wave and the central barrier.

The second regime is considerably shorter (2-5 shorter times relative to the first) and is characterized by a single discrete component (near 40-30 dB) of frequency spectrum, a moderate oscillation of shock-wave structures and pressure at the obstacle (curve II in Fig. 4).

The analysis of amplitude-frequency characteristics of pressure oscillations at the barrier stagnation point (Fig. 3), as well as the boundaries of non-stationary regimes existence allowed to establish, by terms of size, two types of barriers:

- Type "small obstacles of finite size" ( $r_{np} < 2$ ), for which both non-stationary regimes (Fig. 4a) exist, occupying the entire area of the distance  $h$  continuously to the point of the occurrence of the flow with undisturbed the first barrel (dash-dotted line  $N_\delta$ ).
- Type "endless obstacles", in which both non-stationary regimes also exist, separated by the area of stationary flow with a central circulation area (Fig. 1b).

It is the endless barriers that are relevant to the discussed case.

## CONCLUSION

This study reviewed a model of the interaction between a supersonic gas jet flowing out of the gas-static bearing's nozzle with a flat barrier perpendicular to the axis of the jet. The numerical calculations, performed at the ideal gas model in comparison with the experiment revealed the general patterns of the oscillatory regime. It is shown that the oscillations are a consumable nature and can be explained by the periodic locking of the flow behind the central shock wave. Such oscillations (Bulat and Prodan, 2013) are typical as well for other separated flows in the components of aircraft power units, particularly in flows associated with the problem of bottom pressure. The importance of these phenomena requires further research, especially by numerical methods. However, the calculation of non-stationary turbulent regimes, in which the oscillation frequency of shock-wave structure is close to the frequency of large turbulent vortices gathering is associated with considerable methodological difficulties (Bulat and Bulat, 2013a). This requires careful processing and study of computational experiment methods.

At supercritical modes the supersonic gas jets flows, which, depending on the combination of geometrical parameters can be both under expanded and overexpansion, flows out from the gas-static bearing's nozzles. There is such combination of a pressure in nozzle feeders and such distances from the nozzle to the barrier, at which the low-frequency oscillations occur. These oscillations are accompanied by the movement of the central shock up and down, during which a periodic locking and unlocking of the recirculation flow in the central shock occurs. Two ranges of distance between the nozzle and the barrier, at low-frequency oscillations with a discrete frequency exist were found. This type of oscillations by its mechanism is similar to the low-frequency oscillations arising on certain regimes in the bottom areas of missiles and shells.

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