Recommended initial pressure for the correct operation of vibrofuge based on the conducted research

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Abstract. The article presents the operation of vibrofuge test stand. The main research of the stand operation is discussed. The mode of piston motion in gas spring and gas behavior inside the working spring chamber is shown. Based on the research the recommended initial pressure is calculated, which must be set in spring chamber for the correct operation of the test stand.

1. Introduction

In modern industry test research cannot be excluded from the design life cycle of new products and technical devices. There are special test stands for test research. Test stand is a laboratory equipment that reproduces specialized control tests of any products [1].

Today test stands are divided into load categories. For example, shock tables test products on impact resistance. There are also stands that test technical objects on speed, vibration, compression, bending, temperature, etc.

Complex test stands are of the highest interest. Such stands are capable of reproducing various types of load on the tested objects. This helps to save time and money.

In this work the object of study is a test stand of a centrifuge, on rotor of which an air spring with an electromechanical vibrator - vibrofuge is fixed. Thanks to this design solution, on such a stand it is possible to reproduce loads not only on the centrifugal force, but also on a vibration component. Objects that are usually exposed to stresses are part of the structure of air vehicles (airplanes, helicopters, rockets, etc.).

The main object of this article is to show the main studies carried out in modeling the operation of a vibrofuge and to calculate the recommended level of the initial gas pressure inside the working air spring chamber, depending on the maximum constant speed of rotor rotation.

2. Literature review

On such complex test stands studies were mainly carried out on the parameters that affect the operation facility inaccuracy. For example, an assessment of the influence of Coriolis accelerations and forces on an object under the action of a vibration load in the field of linear accelerations was made [2]. A study was also carried out on the rotor length change during its rotation. The rotor length can be varied through minimal bending due to gravity, therefore it is important to predict the possible rotor length change, since such a prediction can significantly reduce the error [3, 4].
An important factor for the correct operation of the complex test stand is the stable balancing of the moving masses. There are several methods of stable balancing, which are included in design solutions both with the use of pneumatics and without it [5, 6]. One of the solutions is the major theme of this article.

3. Research of the processes occurring during the operation of the vibrofuge

Within this article a model of a vibrofuge test stand is investigated. Its design features were mentioned in introduction. Using the SolidWorks software an approximate model of such a stand were designed (Figure 1).

![Vibrofuge test stand model in SolidWorks](image)

Figure 1. Vibrofuge test stand model in SolidWorks.

Figure 1 shows the following positions: 1 – gravity weight, 2 - test stand rotor, 3 - test object, for example, accelerometer, 4 - electromechanical vibrator, 5 - gas spring.

The main characteristics of the stand, which were specified in the following calculations: - an electromechanical vibrator with a maximum force \( F = 5000 \) N and a maximum speed of \( 2 \) m/\( s \), the vibration frequency of vibrator \( f = 50 \) Hz in the form of a sinusoidal wave;
- the mass of vibrator, piston and table on which the accelerometer is mounted is \( M = 25 \) kg;
- gas spring chamber length is \( L = 0.5 \) m;
- maximum constant rotor speed is \( \omega = 52.36 \) rad/s;
- vibrofuge rotor length from the axis of rotation is \( R = 2.5 \) m;
- gas spring piston area \( S = \frac{\pi}{4} d^2 \) (\( d = 0.320 \) m – piston diameter). As part of the main research of vibrofuge operation (Figure 1), an analysis of the operation of a pneumatic system with an electromechanical vibrator was carried out when the rotor rotates at a constant speed. To identify the nature of piston movement inside the gas spring chamber, we have the following formula:

\[
\frac{dL}{dt} = v_{i-1} dt + \frac{a(dt)^2}{2},
\]

(1)

where \( dL \) – piston movement, \( m \), \( v_{i-1} \) – speed at the previous moment of computation time (at the initial moment of time the speed is equal to zero), \( m/s \), \( dt \) – constant, constant computing step, \( a \) - mechanical system acceleration (electromechanical vibrator, piston), \( m/s^2 \).

Using the given characteristics of the operation facility, formula and the MatLab software, a graph of the piston displacement in gas spring during rotor rotation at maximum and constant speed and during operation of the electromechanical vibrator is built (Figure 2) We also found the ranges of characteristics, at which the correct operation of the operation facility is observed (Figure 3).
In Figure 3, the correct operation of the operation facility can be achieved at any values of electromechanical vibrator forces and rotor speed in the right area of the graph to the solid thick line [7, 8].

In the framework of further studies of the operation facility functioning, it is necessary to find out the behavior of the gas inside the gas spring chamber during the rotation of the rotor at the maximum constant speed. Based on the showed mathematical model, a formula for calculating the gas pressure at each point along the entire length of the pneumatic spring chamber is derived:

$$p = p_1 e^{\frac{\alpha^2 M (r^2 - r_1^2)}{2R}},$$  \hspace{1cm} (2)

where $p_1$ – reference pressure, Pa, $\omega$ – rotor speed, m/s, $M$ – gas molar mass (equal for air $29*10^{-3}$ kg/mole), $R$ – absolute gas constant (equal 8.314 1/(kg*K)), $T$ – absolute gas temperature, K, $r_1$ – rotor length from the...
axis of rotation to the first end of the gas spring chamber, m, r – parameter for setting a discrete section where the pressure level is calculated, m.
Using the MatLab software, graphs of pressure distributions along the entire length of gas spring chamber were built depending on the maximum constant rotor speed (Figure 4).

Figure 4. Pressure distribution inside the gas spring chamber at different rotor speeds.

It should be mentioned that under certain conditions, a vacuum may appear at the first end of the chamber. [9, 10].
The study carried out on calculating the gas pressure in the working chamber of a gas spring, when the rotor rotates at a constant speed, should be taken into account when working with the stand on Figure 1. So it is necessary to calculate the recommended level of the reference gas pressure before starting the operation facility.
The reference pressure level depends on rotor speed. For example, if a small gas pressure is pumped into the gas spring chamber and the rotor is strongly accelerated, then there will be no pressure left to resist the centrifugal force at the chamber inlet, which can lead to structural failure. The reference pressure formula is the following (2):

$$p_1 = \frac{p}{e^{-\omega^2 M (r^2 - r^2_1) / 2 R T}}$$  \hspace{1cm} (3)

where $p$ is calculated by dividing the centrifugal force value by piston cross-sectional area. The only variable that we set ourselves is the rotation speed $\omega$.
So we have table №1, which shows the values of speeds and recommended reference pressure.

| $\omega$, rad/s | Recommended reference pressure, Pa |
|----------------|-----------------------------------|
| 60             | 2812522.40                        |
| 70             | 3835494.11                        |
| 80             | 5020707.57                        |
| 90             | 6370267.15                        |
| 100            | 7886571.82                        |

According to the Table №1, we can build a graph of rotation speed dependence on the reference pressure. The graph is shown in Figure 5.
The relationship shown in Figure 5 is exponential. At the given values of the mass of the electromechanical vibrator with an air spring piston and the length of the vibrofuge rotor and at a rotor speed of 52.36 rad/s (500 rpm), it is recommended to set a reference pressure of 2109730.14 Pa, which is optimal for testing. The maximum value of the reference pressure that can be pumped into the air spring also depends on the material of the air spring and in general on the capabilities of the compressor.

4. Results
As a result of vibrofuge operation studies using software we have found the following:
1) Parameters of correct operation of the facility (Figure 3);
2) the pressure in working gas spring chamber is redistributed depending on the speed of rotor rotation (Figure 4);
3) the method for calculating the recommended level of reference pressure in the working gas spring chamber before starting the operation facility is shown (Figure 5).

5. Conclusion
In this article the operation of vibrofuge test stand was studied, on the rotor of which a gas spring and an electromechanical vibrator are installed. Such test stand can simulate complex vibration force and centrifugal acceleration tests.

The main studies of the operation facility were carried out to set recommendations for the correct operation of the test stand.

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