

SELF-ALIGNING STANDS ON HYDRAULIC SUPPORTS FOR TESTING PRODUCTS AND SYSTEMS OF AERONAUTICAL AND SPACE-ROCKET ENGINEERING

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A description of the structures of self-aligning (self-balancing) stands for testing products and systems of aeronautical and space-rocket engineering has been presented. The stands make it possible to test products for strength and functionality under centrifugal loads and vibration separately and jointly.

Keywords: *self-aligning supporting device, hydrostatic support, permissible roughness, drifting moments and forces, hydraulic monitor, jet-thrust simulation, overload.*

Introduction. Ensuring flight safety for aircraft and spacecraft under the conditions of increasingly higher velocities and altitudes and loads and overloads requires preliminary thorough tests of structures and control systems under conditions that are the closest possible to the actual ones during the operation of the products.

Formulation of the Problem. 1. Creation of structures of test equipment that ensure the greatest correspondence to the conditions of actual operation. 2. Ensuring the maximum possible correspondence of the level of action of loads reproduced on the stand to their values in flight.

Solution of the Problem. Safe repeat creation of the overloads, velocities of motion, and vibration level of an object is ensured by the test equipment where the rotational velocity and the radius of the setup are monitored with devices for linear and angular measurements. The rotational velocity is monitored by the number of revolutions of the tested object or the drive engine, and the overload is controlled by measurement or with an acceleration transducer (accelerometer).

Structure and Principle of Operation of Test Stands. 1. *Stand for testing active objects of variable mass (operating jet and aircraft engines) for the action of linear and vibrational overloads* [1]. Figure 1 gives the block diagram of this stand. It consists of a self-aligning supporting cylinder 1 immersed in tank 2 with a liquid, a damping cylindrical wall 3 installed equidistantly to the cylinder, platform 4 for the tested object 5 on the upper face of the supporting cylinder, two belts (spaced in height) of controlled damping devices 6, i.e., hydraulic (pneumatic) power cylinders with elastic wheels contacting the exterior surfaces of the supporting-cylinder frames, which are uniformly installed in their circle, and the control system.

The supporting cylinder has a recessed conical bottom 7. A hermetic conical cylinder 8 with an open upper end is installed in line with it at the tank's bottom. Drive 9 of the stand is installed inside the conical cylinder. The size of the recess of the conical bottom of the supporting cylinder and the height of the conical cylinder fitting into it are selected from the condition that an air dome formed between them in filling the tank with liquid keeps the drive engine clear of the liquid. Shaft 10 of the drive is made composite, varying with length (splined joint) and ensuring drive-torque transfer and axial movement from the vibrator.

Vibration device (vibrator) 11 is installed inside the supporting float on the surface of an upper frame 12. Before testing, the float rests on the stand 13 at the tank's bottom. Hydraulic monitor 14 is installed on the load platform; the monitor counterbalances the weight of an object in the initial state in testing and the jet thrust of an engine. The vibration device ensures a prescribed level of vibration loading of the tested object. The weight-carrying capacity of the stand in question determines the volume of the liquid displaced by the float. Perception of the thrust difference

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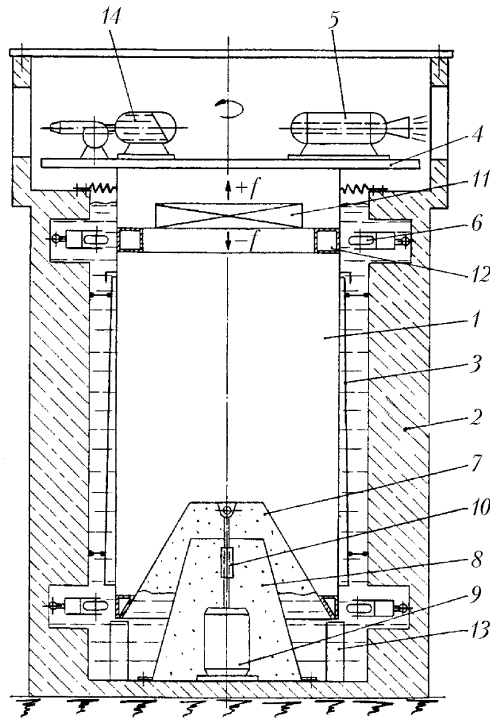


Fig. 1. Diagram of the test stand for active objects of aeronautical and space-rocket engineering.

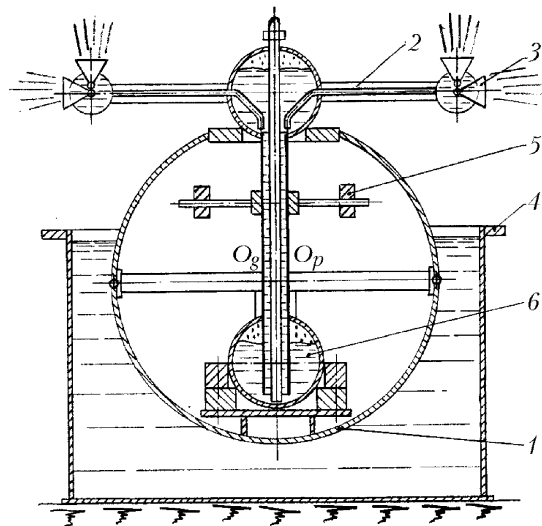


Fig. 2. Diagram of the stand for testing control and orientation systems of aeronautical and space-rocket engineering.

and mass imbalance of the operating hydraulic monitor and tested object is regulated by controlled actuators and the capacity of the support for self-balancing.

2. *Stand for testing control systems of objects of space-rocket engineering.* The purpose of the stand is to ensure the spatial motion of objects with five degrees of freedom and the lowest values of resistance and drifting moments from the arising hydrodynamic forces due to the irregularities and roughnesses of the supporting surface. A stand was developed in a [2] for such a purpose, which represents a spherical shell of diameter 5 m suspended by an air flow above the hemispherical bowl of the stand's base. The air flow moves in the clearance between them with a velocity to 15 m/sec and produces a flow-variable excess pressure of 0.02–0.04 kg/cm².

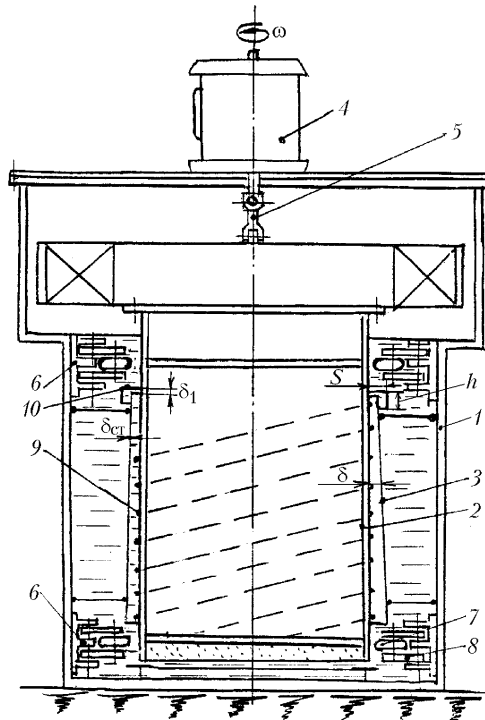


Fig. 1. Diagram of the test stand for active objects of aeronautical and space-rocket engineering.

Figure 2 gives the block diagram of a self-balancing stand [3]. The stand structure includes a spherical shell 1 with a load platform 2 on which the tested system 3 is installed. The spherical shell is immersed in tank 4 filled with liquid. Mechanical 5 and hydraulic 6 counterbalancing devices are mounted on the load platform and inside the sphere 1. These systems ensure the alignment of the centers of gravity and pressure on a movable support at a point that is the center of the sphere. The weight-carrying capacity of the stand in question is ensured by the volume and density of the liquid displaced by the sphere in its immersion in the tank.

When the dimensions of the supporting spheres are equal to those of the gasdynamic stand the running resistances and the degree of influence of the disturbing factors (roughness, surface defects, local imperfections of the shape) in each stand are determined by the hydromechanics of the process of holding them off the ground. The weight of the tested control system is taken to be 5 tons. The angular velocity of motion of the supports is no less than 0.2 sec^{-1} . In the gasdynamic method of holding off the ground, we have air flow past the sphere and the load platform with a tested system in a bounded clearance between the movable support and the base. When the control system installed on the hydrostatic-suspension platform is tested, reactive forces triggering the slow (creeping) motion of the sphere in an unbounded volume of the liquid arise. According to [4], the resistance of individual elements of roughness of different shape and height on the body's surface can vary 1.5–3 times depending on the type of flow and the cross-sectional area of the protruding elements (area of the largest cross section). This largely depends on the thickness of the boundary layer of the flowing medium. In the case of the gasdynamic spherical shell in air flow with a head of 0.025 kg/cm^2 and a velocity of 15 m/sec change in the pressure in the external flow contributes to the transition to a turbulent boundary layer. In the hydraulic support, this factor of flow turbulization is absent and the laminar boundary layer allows a much higher roughness than the turbulent layer without increase in the resistance. Assuming a single value of the permissible relative roughness, we can evaluate its influence in the types of stands in question as a function of the Reynolds number. The critical value of roughness in laminar flow (creeping flow, $Re < 10^5$) is much higher than that in turbulent flow ($Re > 3 \cdot 10^5$):

$$k_p \leq l \cdot 100 / Re_l . \quad (1)$$

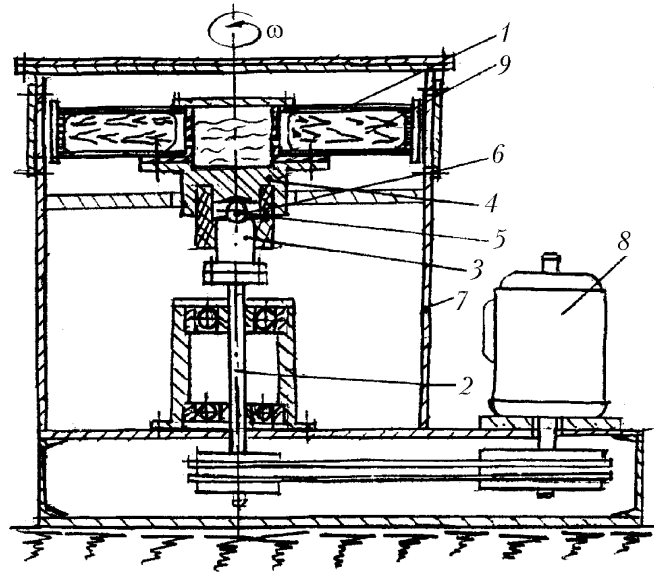


Fig. 4. Diagram of the stand for testing objects of aeronautical and space-rocket engineering for the action of intense inertial forces.

Consequently, in the stand on a spherical hydraulic support, the influence of the irregularities of surface treatment is substantially smaller than in the stand blown with the air flow, the more so as the velocities of motion of spheres in air and in the liquid differ by tens of times. Taking into account that the density of the air flow is dependent on the degree of its compression, we can expect an even larger difference in the degree of influence of identical disturbances on the arising forces and drifting moments for the above types of supports.

3. *Stand for testing products for the action of centrifugal loads.* This stand can be used for testing products of mass from units to tens of tons with a considerable imbalance arising in testing. Figure 3 gives the block diagram of the stand [5–7]. The stand consists of case 1 (tank) filled with liquid, a cylindrical supporting float 2 placed in it and serving for support of the tested objects on the platform end, damping device 3 in the form of a slightly tapered cylindrical shell installed with a clearance in line with the supporting float and connected to the wall and bottom of the case, electric motor 4 with a flexible drive shaft 5, and two damping belts 6, each including wheels 7 with elastic tires, which are uniformly arranged in a circle and are interconnected using rockets 8 hinged on the case wall. The kinematic coupling of the wheels is performed so that a simultaneous radial movement of three of them is ensured in the clearance between the shell and the supporting float. The drive shaft 5 consists of links that are connected by horizontal axes arranged in a circle at equal angles.

Spiral 9 ensuring the axial movement of the liquid flow inside the clearance in revolution of the rotor and the flanged annular disk 10 facing the case bottom and forming the liquid-flow constrictor 7 with the end of the slightly tapered shell are mounted on the exterior surface of the supporting float. The spiral and the constrictor form a radial axial liquid flow in the clearance, which ensures damping of the rotating system [8]. The damping is increased by the corresponding selection of the dimensions of the constricting channel (Fig. 3):

$$S > 2\delta + \delta_w, \quad h > (1.5 - 2.0) \delta_1, \quad \delta_1 < (0.5 - 1.0) \delta. \quad (2)$$

Multiple links and the hinge joint of the drive shaft links ensure the mobility of the drive in the horizontal plane.

The free area between the end of the slightly tapered shell and the annular disk is made smaller than that in the clearance between the float and the damping wall. This increases the pressure in the clearance between them and improves the efficiency of damping of the rotor system. The kinematics of coupling of the damping-belt elements creates contact between the supporting float and the wheels at many points. This results in an elastic restriction of the radial movement of the rotor system in the clearance, keeping it from contacting the damping wall. The possibility of creating test stands of large weight-carrying capacity and required intensity

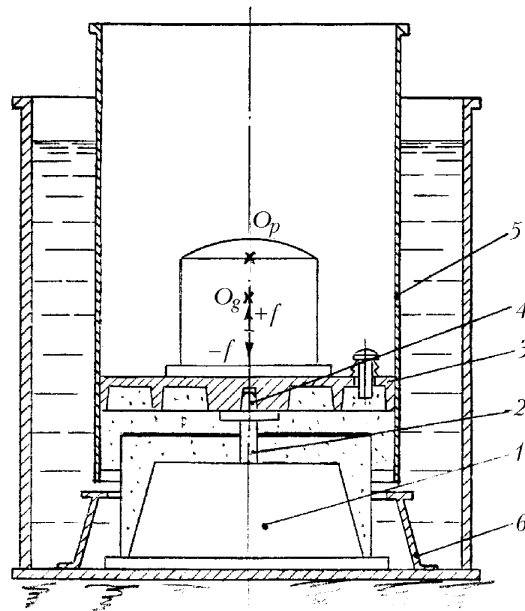


Fig. 5. Diagram of the stand for vibration tests of objects of aeronautical and space-rocket engineering.

of the centrifugal field is ensured by the volumes of the supporting float and the case of its immersion. Comparative computational-theoretical investigations [8] have shown that the energy efficiency of such stands grows with their weight-carrying capacity.

4. *Centrifugal stand of two-sided impregnation of impermeable materials.* Figure 4 gives the block diagram of the stand [9]. The stand includes a self-balancing centrifugal drive, disk chamber 1 with radial arrangement of specimens, which is connected to the central chamber for filling in the impregnating liquid; the latter is connected to the impregnation chambers by radial channels.

The centrifugal drive represents a vertical shaft 2 in rolling bearings and the point of attachment 3 to the disk chamber 1. The attachment point includes a flange cylindrical supporting bushing 4 with an internal elastic cup 5 incorporating the drive shaft on whose end ball 6 is installed in a spherical recess. The drive and the plate are arranged on the axis of a cylindrical case 7 with an end cover. The cup with the hinge and the shaft form an elastic slave pair ensuring the radial and angular displacement of the disk with specimens. The shaft leaves the case via the reference node with rolling bearings and is connected to the shaft 8 of the drive motor through V-belt transmission. After placing specimens 9 in the radial chambers and sealing them hermetically and filling in the impregnating composition into the central chamber up to its absolute filling, we switch on the drive power supply and bring the rotor system to a prescribed rotational velocity. The imbalances of the impregnated specimens in the initial state and in the process of impregnation are compensated by the elastic coupling of the filled disk and the drive shaft, which enables the disk to occupy a neutral position corresponding to the self-balancing of the rotating system. The strong case ensures total localization of emergency start-ups. The stand makes it possible to drive the rotor system up to velocities for which a pressure of tens to hundreds of atmospheres is produced in the impregnating chambers and a uniform centrifugal impregnation of the material's samples is realized. Centrifugal drying and testing of products for the action of centrifugal overloadings of hundreds and thousands of units are possible on this stand.

5. *Vibration stand (shaker) for dynamic tests of heavy large-scale products of aeronautical and space-rocket engineering.* The stand is based on the self-aligning hydrostatic float support for holding the tested system off the ground and balancing. Elastic float-type supports are characterized by the low dynamic rigidity in a wide velocity range. This makes it possible to create an efficient additional suspension of working tables and vibration exciters in testing heavy dynamically intricate products, such as, e.g., aircraft and spacecraft engines. The suspension itself of today's electrodynamic and electrohydraulic vibration exciters has a limited carrying capacity to 10^4 N.

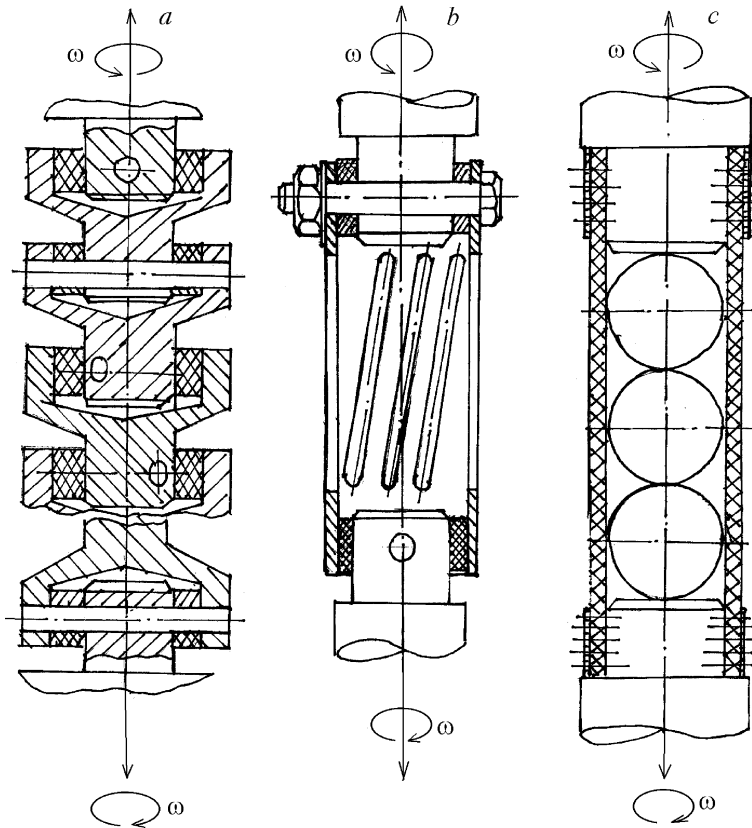


Fig. 6. Three types of a shaft connecting the suspensions to the vertical rotation drives.

Figure 5 gives the structural scheme of a vibration stand [10]. Dynamic tests of products as a unit call for comprehensive design of a system for holding them off the ground, which includes the vibration-exciter case 1, suspension 2, table 3, adapter 4, additional suspension 5, and base 6.

A suspension represents the so-called system for holding products off the ground. Rubber plaits, mechanical springs, and pneumatic elements are used as suspensions in most cases. However, wave phenomena in these elements diminish the accuracy of reproduction of prescribed regimes in the medium velocity range. Additional guide and balancing devices are required for diminishing parasitic transverse vibrations. A float support having a small rigidity and considerable transverse damping is free of these drawbacks. The structure of the system consists of an "air-dome" adapter and a tested product afloat in a special cylindrical case or tank. In the lower air part of the dome, the adapter is connected to the table of the vibration exciter. The air cushion of the float whose lateral surface serves as a damper of transverse vibrations acts as the elastic element. Static balancing of the product with an adapter and a testing system is carried out afloat in front of the connection to the vibration exciter. Depending on the form of the structure of a suspending device (float, hollow cylinder or a hollow rectangular geometric vessel) we can create not only a vibration-testing stand but also a technological system for forming different products from concrete and other materials.

For rotation of hydrogasdynamic supports ensuring free deflection of their principal central axes of inertia from the vertical axis of the stator, three types of a shaft connecting the supports to the vertical rotation drives have been developed. The first type (Fig. 6a) represents a chain of 6-8 tubular hinge links arranged lengthwise in horizontal planes at an angle of 45° to each other and interconnected by the axes. Elastic bushings are set in the gaps between hinges. The second type (Fig. 6b) is a tube with 6-12 through lengthwise cuts of the wall, which are inclined at an angle of $15-30^\circ$ to the generatrices of the tube. The third type (Fig. 6c) is a reinforced rubber hose, the inner space of which is filled along its length with light spheres, e.g., of glass-reinforced plastic preventing the twisting of the shaft.

Design-technological and functional testing of the units of hydrostatic suspension and installation of the centrifuge rotor on a ball with torque transfer by an elastic cup from a reinforced rubber tube have been carried out on the stands at the A. V. Luikov Heat and Mass Transfer Institute. Cylindrical floats of diameter 1 to 2 m and length to 2.5 m with rotors of diameters 5 and 6 m from radial tubes were tested. The rotational velocity of the rotors of the hydrodynamic suspension varied from 200 to 700 rpm; that of the ball-support rotor varied to 400 rpm. To diminish the rotation resistance the rotor tubes were equipped with aerodynamic fairings or were enclosed by the disks.

Conclusions. Based on the considered centrifugal stands, we have shown the possibilities of creating reliable highly efficient large-tonnage equipment on hydraulic supports for various purposes and primarily for testing products of aeronautical and space-rocket engineering. Equipment of this kind will find application in the wood-working, oil, and construction industries. For designing and manufacturing the above equipment, we refer the reader to the A. V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus.

NOTATION

f , vibration amplitude, m; h , flanged-disk height, m; k_p , permissible roughness, mm; l , characteristic length by which the Reynolds number is evaluated, m; O_p , center of pressure; O_g , center of gravity; Re_p , Reynolds number; S , flanged-disk width, m; δ , clearance between the wall of the supporting cylinder and the interior wall of the damper, m; δ_1 , clearance between the flanged disk of the supporting cylinder and the end, m; δ_w , thickness of the shell of the damping wall, m; ω , angular rotational velocity, sec^{-1} . Subscripts: g , gravity-field strength; p , pressure; w , wall; p , permissible value.

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