Actuators of the Seismic Vibrations Sources

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***Abstract* — The article reviews the design of actuators of vibrations seismic sources, their advantages and disadvantages. The conclusion about the prospects of the elastic sheaths use is made.**

Keywords* — *sources of seismic vibrations, oscillating modules

I. INTRODUCTION

The article [1] concludes the perspective implementation of the vibration sources which design and technological capabilities depend on the individual design components, including the actuators design.

To conduct vibroseis works there are different types of devises widely used such as electromechanical and electrohydraulic depending on the type of energy they convert. Depending on the required task other types are also used such as pneumatic, piezoelectric, magnetostrictive, and electromagnetic [2].

II. MECHANICAL SOURCES OF SEISMIC VIBRATIONS

Mechanical emitters are designed on the base of electromechanical rotational power devices in which the vibrational forces are created by circumferentially move of the unbalanced mass.

There are planetary device (mass moves on a circular track directly), and unbalanced mass device (weight is mounted on the shaft). For force orientation in a certain direction it is necessary to use two rotating masses in either of oscillating modules.

Unbalanced mass oscillating modules (Fig. 1, *a*) consists of two semimodules. Oscillating module is two coupled semimodules, which unbalanced mass *1* and *2* simultaneously and in phase rotate on the shafts *3* and *4*, which are mounted on a common platform *5,* in opposite directions. The produced force is controlled by the mass movement in relation to shafts using rods *6*, *7*. This type of oscillating module features masses rotating in opposite directions and generates the perturbing force (Fig. 1, *b*) which is constant directionally and unequal in magnitude:

$$F=2mr\omega^2\sin\omega t; \qquad (1)$$

where m – unbalanced mass; r – circle radius; ω – circular frequency.

There is strict programmed control of frequency and the vibrations phase in the source in the accepted technology for seismic works.

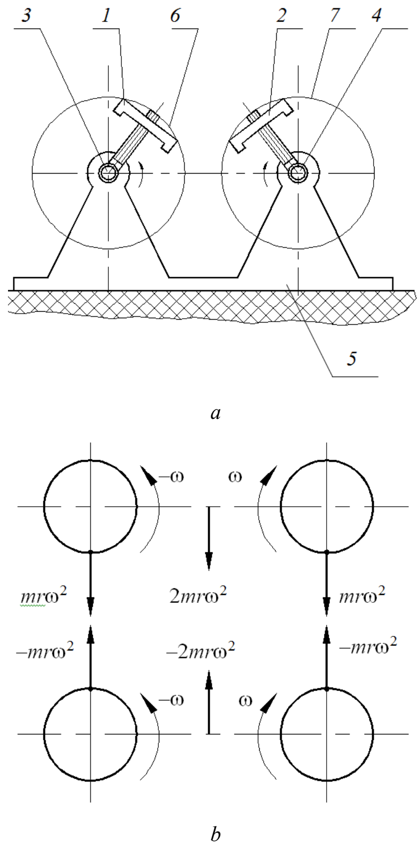

Fig.1 Unbalanced mass oscillating modules:
a – structural diagram; *b* – vibration forces forming diagram

It is also necessary to stabilize the amplitude of the vibrator force or control it in the frequencies operating range, that is especially important for this class of vibrators which have a quadratic dependence of the force amplitude on the frequency [3]. As seen from the specific dependence it is necessary to change mass or radius to adjust the excited force.

Vibration frequencies adjustment is produced by an electric engine. In this oscillating module scheme designe (operating mechanism) all changes in the source of current design of oscillating module are related to the amount of semimodules and the design of unbalanced masses.

Fluid [4, 5] can be used as unbalanced mass. The vibration exciter considered is a balanced cylinder rotating about an axis perpendicular to the axis of the cylinder. There is a piston within the cylinder, the piston's center of mass in the rest position has a small eccentricity in relation to the axis of rotation. Both the cylinder piston sides are filled with fluid and connected with a channel passing through the end of the shaft, which is controlled by the valve.

When the valve is closed vibration exciter spins up to maximum speed, corresponding to the upper operating frequency range. The amplitude of power at a given frequency is determined by the small eccentricity of the piston. When the speed of rotation reducing, the valve is opened, and the eccentricity of the piston under the action of centrifugal force increases, increasing the amplitude. Thus, by changing the eccentricity, the amplitude loss of vibrator force is compensated.

Rotary vibrators are the most economical in power consumption. The essential advantage is the separate control of vibration parameters: frequency of the drive motor and the amplitude of debalanced masses forces. The main drawback is the excitation of a signal with rectangular envelope.

III. HYDRAULIC SOURCES OF SEISMIC VIBRATIONS

According to the principle of creating an alternating fluid flow and the control of actuator power unit there are two classes of hydraulic vibration devices: vibrators with throttle and volume control.

In the hydraulic vibration devices oscillation is excited by creating variable (pulsed) fluid flow placed into the working chamber of the actuator of the pump station.

In throttle vibrating devices the working fluid flow is converted into an alternating flow by any of distribution devices (throttle, spool, valve, etc.).

There are three types of these devices: pulse (open with the separate control valve), guarding and self-oscillating [2, 6, 7, 8].

Pulse vibrators are the mechanisms where the oscillatory load (oscillations of the actuating element) is excited by a pulsed flow of the power fluid. An example of this vibrator is shown below (Fig. 2). The actuating element is presented in the form of a spring-loaded piston *1*, placed in the body of the hydraulic cylinder *2*. The piston movement control is carried out by hydraulic directional valve *3* controlled by electromechanical transducer *5*.

For 4- edged spool the piston traversing speed is [26]

$$V = \frac{1}{F} \cdot \mu \cdot l \cdot x(t) \sqrt{\frac{(P_{pr} - \Delta P)}{2}}; \qquad (2)$$

where V, F – motion speed and area of the piston; μ, l, $x(t)$, P_{pr} – flow coefficient, the length of the working perimeter, the pass port opening, spool supply pressure; ΔP – differential pressure in the hydrocylinder shells due to the load.

From (2) it follows that the main parameters association in hydrovibrator with throttle regulation is essentially nonlinear.

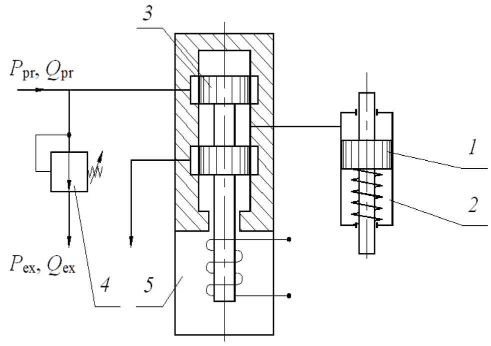

Fig. 2. Basic diagram of the D- action vibrator

This leads to the fact that for nonlinear distortion compensation the special control circuits are used including the correcting elements which make the vibration device construction more complicating.

On the base of the simple spool structure (Fig. 2) it is impossible to obtain high power oscillations. It is necessary to increase the spool size, and the motor power. To avoid this in throttle controlled hydraulic vibrators additional amplifying stages are used.

The example of vibration device with additional amplifying stage is illustrated in fig. 3. The vibration exciter is a massive double action cylinder *4* with piston *5* inside, act as the inertial mass.

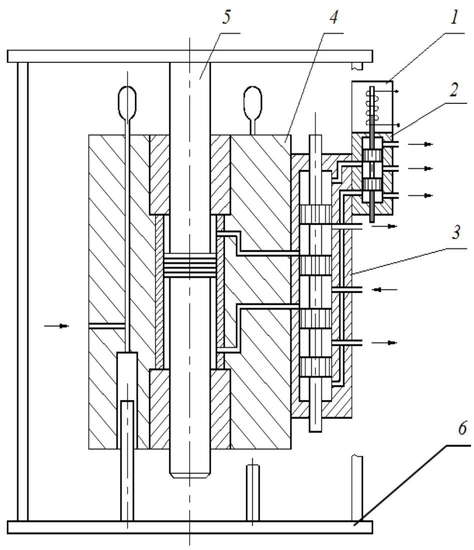

Fig. 3. Vibration exciter with 2 stages electro hydraulic transducer

The fluid flow in the hydraulic cylinder is regulated by the electrohydraulic converter *1*, controlling the spools of the first *2* and of the second *3* stages.

For the vibrator to operate it is necessary that the base plate *6* moves in synchrony with the voltage changing of the control signal placed to the transducer. It is achieved by the special system of phase correction comprising speed sensors, acceleration sensors, spool displacement, etc.

Based on information above, it can be concluded that it is impossible to obtain large vibrational load without the complicating the structure of the throttle controlled by the hydraulic vibrator device. The disadvantages are follows:

- low efficiency, which even in the zone of optimal loads does not exceed about 40% because only a small part of the input energy is consumed for creation of the workload. The remaining part is converted into heat and used to overcome the hydraulic resistance and fluid throttling;
- dependence of the amplitude-frequency characteristics on the load changes, due to the lack of feedback coupling between the elastic element and the l hydraulic control valve
- intermittent high frequency oscillations due to the hydraulic impacts at the moments when the directional valve of working windows closed off.

Despite of these shortcomings, this type of vibrators are widely used due to high dynamic quality.

The problem of frequency characteristics instability and non-linear distortion compensation was attemped to be solved by the introdusing the unity feedback vibrator into the dynamical system between the operating member and the hydraulic control valve. These vibrators are called–guarding vibrators.

The advantages of guarding hydrovibrators include the possibility to adjust the arbitrary waveform oscillation with little distortion and compactability. The shortcomings include low efficiency, design complexity, the limit of frequency range.

Self-oscillation hydrovibrator is one of a few types of throttle controlled hydrovibrators but they do not have special control systems and do not allow adjusting the oscillation frequency over a wide range. [2] Therefore, these vibrators were not used in the actuator vibration sources of seismic vibrations.

Thus, the main drawback of throttling mechanisms is the high cost of energy and low efficiency [9, 10]. It should be added that the control by all the oscillation parameters occurs in one control channel. This complicates the control and design of the device.

In such machinery a variable flow is created by the hydraulic oscillator – volume pulsator [6, 7, 8]. There is no fluid throttling and thus unnecessary loss of energy in such machinery. It is the key difference from the throttle vibrators. Vibrators have a closed volume of the working fluid, and a supply and energy control functions are combined in hydro-pulsators.

Oscillations generators as hydraulic pumps, are made by axial and radial piston type, can be controlled [11] and uncontrolled [12].

In hydraulic vibration seismic sources controlled piston oscillation generators are used. In such oscillation generators the amplitude of the operating element oscillations is adjusted by the variation of the amplitude in the pulsatile fluid volume in working space (Figs. 4, 5). Oscillation frequency regulation of such vibrators is performed by the driving motor or controlled pump through a hydraulic motor.

The pulsating fluid volume is supplied into the hydraulic cylinder *1* from controlled volumetric axial or radial piston pump *2*. The pulsating occurs due to swash plate *4* (fig. 4) vibrations or the cam *4* (Fig. 5). The piston *3* oscillates at a rate determined by the rotation frequency of the cam or wash plate.

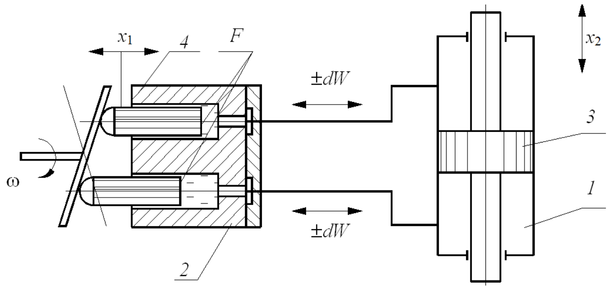

Fig. 4. Basic diagram of axial piston type oscillation generator

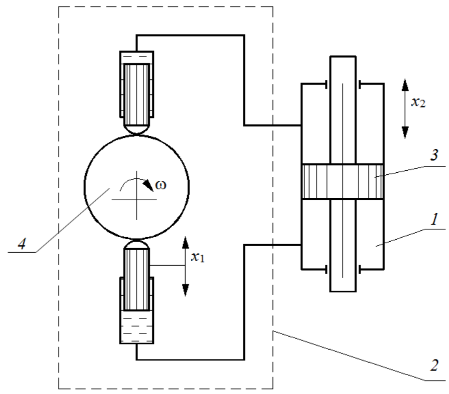

Fig. 5. Basic diagram of the radial piston type oscillation generator

Newly developed design of oscillations generators allows changing the wave form by applying a special profiled shape of the cam and by increase the number of starts of the cam. It is possible to raise the upper limit of excitation frequencies.

All volume controlled vibrators have a robust mechanical structure that leads to almost full independence of oscillations amplitude from power load on the piston. Also these devices have a high efficiency up to ~ 85%. They have low metal intensity allowing to use high operating pressures (up to 50 mPa or greater), thereby creating substantial vibrational load.

The analysis of forming methods of alternating flow leads to the conclusion that the hydraulic vibratory devices with volume control have a higher efficiency, the ability to separate control of the oscillation parameters (amplitude, frequency and shape).

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Thus, we can conclude that the application of volumetric power control method for the actuator in the hydraulic vibration sources has better potential.

The hydrocylinders and the elastic sheaths are used as elements which convert an alternating fluid flow into the transition of the moving unit in the operating mechanisms due to the ease of implementation.

Hydraulic cylinders function as operating mechanisms of the throttle controlled vibrating devices.

The design drawing of that type of vibrator is shown in Fig. 3, basic diagram – in Fig. 6. The vibrator consists of an electromagnetic transducer *1*, the spool *2* of the first stage, spool of the second stage *3*, the body of the hydraulic cylinder *4*, a piston *5*, a support plate *6*.

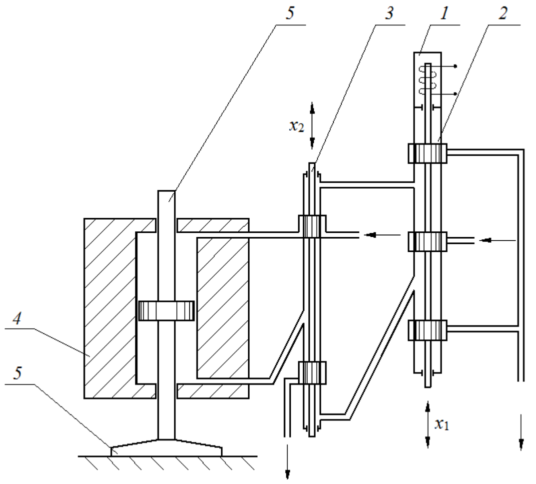

Fig. 6. Basic diagram of the hydraulic throttled vibrator

Sometimes the metal rings with anti-friction coatings are used to reduce friction losses. But in this case the extra fluid leakage possible to happen between the hydraulic cylinder cavities that reduces the useful power.

It should be added that the range of operating frequencies during the seismic works varies from 10 to 200 Hz. Obviously, the operating conditions for rubber seals are hard, especially at higher frequencies of reference stimulus, so the seals resource is low.

There is a great interest to operating mechanisms for which the elastic sheath functions as an operating component. Traditionally, the vibration devices design includes different chamber operating mechanisms such as membrane with an elastic rubber element, silphons and corrugated metal-clad sheaths, deformable in the axial direction [13] are used. But the requirements for high working pressure, determining the amount of the excited vibrational load, speed, high efficiency, determined the implementation of the corrugated sheaths, designed as a high pressure hose in the operating mechanisms of seismic oscillations sources.

Operating mechanisms on the elastic sheaths with pre axisymmetric radial deformation (Fig. 7) with the variable stiffness by changing the medium pressure or by changing of the working area are considered in detail in works [14–16].

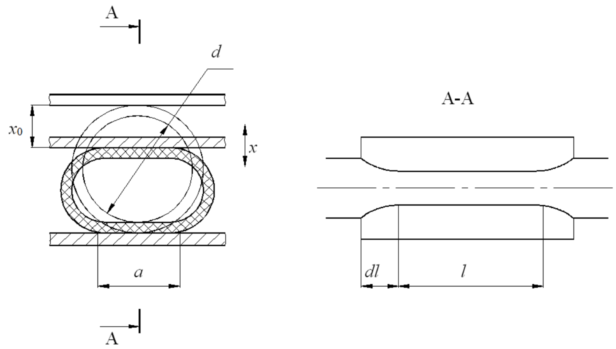

Fig. 7. Elastic axisymmetric preloaded sheaths

The main operating parameters of the sheath is its working area defined by the preload value x_0

$$F = a \cdot l = \frac{\pi}{2} \cdot x_0 \cdot l, \tag{3}$$

where x_0 – pre–value of radial strain; l, a – length and width of preloaded sector.

If the length of preload portion l is small, the edge portions dl should be taken into account in total length.

On the base of actuators of this type, it is possible to create powerful seismic vibrators for deep Earth sensing, as they are able to withstand high pressure [9, 12].

In the simplest configuration (Fig. 8) the plate *3* is installed on the ground. The other elastic shells *2* are installed on the plate. The load *1* (inertial mass) is installed on elastic shells through the plate *4*. The load *1* (inertial mass) provides permanent contact of base plate *3* with the ground surface. Sheaths are filled with fluid at an initial pressure P_0, which is chosen so that under the force of gravity membranes were preloaded by an amount x_0.

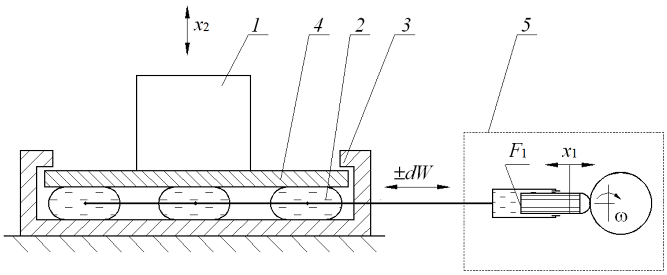

Fig.8. Basic diagram of the surface vibration source

Shells cavities are connected to the volume oscillations generators *5* which provides a periodic fluid volume movement dW

$$dW = W_0 \sin \omega t. \tag{4}$$

Operating mechanisms on elastic sheaths at various generator's commutations permit both rectilinear motion (Fig. 9, *a*) and the angular motion of the moving unit (Fig. 9, *b*).

Thus, changing the number of elastic sheaths and the connection diagram it is possible to implement oscillations of different form.

The main advantages of this type of operating mechanisms are the follows: shells hermiticity, resonant mode capability, frequency and amplitude control independence, ease of implementation, small size, the ability to produce large vibro-traction effort. Unlike piston operating mechanisms it is not necessary to make structural changes by increasing the area of the piston to increase the force amplitude. It is necessary to use hoses which able to sustain higher pressure. The main disadvantage of this operating mechanism is a large load weight *1* (Fig. 8, 9), which is commensurate with the generated force in magnitude and determines the weight of the source.

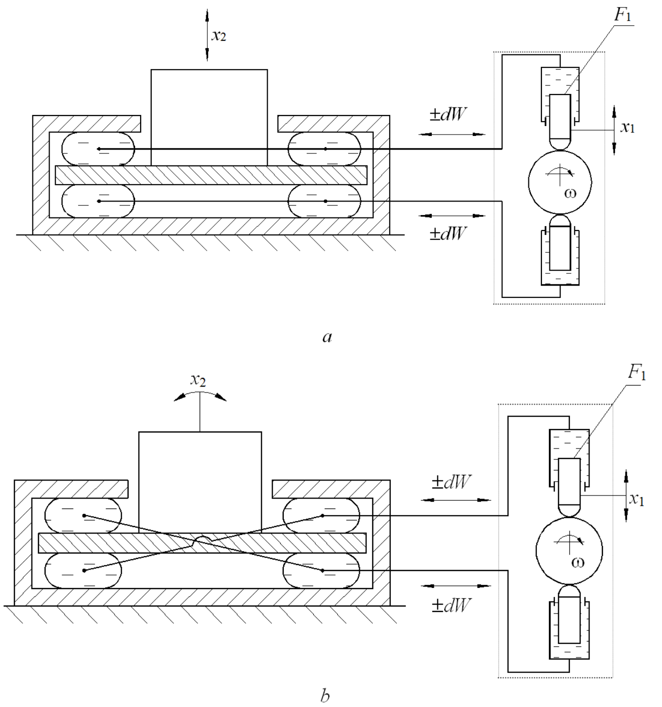

Fig. 9. Different elastic sheaths switching network of the operating mechanism: *a* –vertical oscillations; *b* – swinging oscillations

IV. Conclusion

Thus, from the above analysis of the operating mechanisms and the control methods of their power follows that it is possible to create powerful sources of seismic vibrations on the basis of hydraulic vibration operating mechanisms.

Meanwhile, the implementation of the delivery control method and the usage of high pressure hoses as an actuator body makes possible the adaptable separation of frequency control and amplitude with a total power and high efficiency and simplifies the design.

Thus, we can conclude that the heavy weight of a clamp is one of the main drawbacks of modern seismic vibration sources, limiting the geographical range as well as performance of field woks. Also the development of a vibrating source of regional characteristics of high power should be carried out taking into account the weight and size parameters of the machine as well problems of clamping the base plate to the ground is to be resolved.

This disadvantage can be avoided if inertial mass is replaced by the active periodically dropped weight.

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