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RESEARCH OF THE VIBRATORY FORMATION OF THE COMPASSION OF POWDER MATERIALS BY HYDRO-IMPULSE LOADING

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Modern trends in the field of mechanical engineering require constant improvement of production through the introduction of new methods and means aimed at increasing the reliability of parts and the overall quality of products, while reducing the costs of their production. The reliability of machine parts is determined by various factors, such as strength, resistance to wear, vibration and high temperatures. In order to achieve these reliability criteria, various methods are widely used, such as material selection and the use of technologies aimed at increasing strength and wear resistance, such as heat treatment, surface treatment of parts by various physical methods, and stress reduction.

One of the methods of increasing the fatigue strength and wear resistance of parts includes the use of surface plating on the working surfaces of parts in general and in areas of stress concentration in particular.

The mentioned article carefully analyzes the process of forming metal powders, considering it as a technological operation that leads to the creation of powder forms. A detailed analysis and comparison of the equipment used for vibropress molding of blanks from powder materials is also carried out. The article describes the main technological processes of vibration and shock impact on materials.

In addition, the article offers schemes and methods of implementation of vibration molding of powder materials, as well as analysis and classification of these processes according to their characteristics of vibration and vibration-impact modes. This allows you to understand the effectiveness of various methods and their applicability in specific production conditions, contributing to the further development and improvement of modern technologies in mechanical engineering.

Key words: *forming, surface plastic deformation, hydraulic impulse, vibrating press hammer, hydraulic-pressive vibration exciter.*

Pic. 4. Table. 2. Ref. 11.

1. Problem formulation

One of the ways to increase the fatigue strength and wear resistance of parts is to apply surface riveting on the working surfaces of parts in general and in areas of stress concentration in particular. With the influence of a load that exceeds the elastic limit of the material, plastic deformation occurs, and since the metal hardens during deformation [1-11], this process is called hardening. Most industrial alloys have a polycrystalline structure. When polycrystals are deformed, there is usually no sliding stage, and grain deformation occurs in several sliding systems at once, accompanied by bending and rotation of the sliding planes. The total deformation is small, usually only 1%, and the grains are deformed unevenly due to the difference in their orientation relative to the loads. As the deformation increases, the difference between the materials grains decreases and the microstructure changes: metal grains become more elongated in the direction of plastic flow, which leads to a change in the grain structure of the material's crystal lattice and an increase in the density of defects.

Superficial plastic deformation (SPD) of the part material creates point and line defects, such as linear and helical dislocations, in the crystal lattice on the surface of the part, which increases the resistance of these layers to wear and fatigue failure. The SPD can be implemented in various ways and with the help of devices with mechanical, pneumatic and hydraulic drive. Among them, the hydraulic pulse drive stands out for its compactness and allows the creation of small devices for surface plastic deformation that can be installed directly on metal cutting machines.

The method of restoring parts by plastic (residual) deformation is based on the property of metal to change its shape and size under the influence of irreversible deformation forces. During this process, metal is transferred from the non-working surfaces of the parts to the worn areas. It is important to note that this process can be performed both with and without heating the material.

Plastic deformation of parts at low temperatures requires large external forces to achieve the desired deformation. Usually, this method is used to restore parts made of non-ferrous metals and their alloys, as well as for steel parts with a low carbon content (up to 0.3%), which have not been subjected to heat treatment [1-3].

However, when the parts are heated to a temperature close to their melting point (approximately 0.8-0.9 of the melting point), the forces required for plastic deformation are significantly reduced, usually by a factor of 12-15. At the same time, the physical and mechanical properties of the metal remain practically unchanged. After plastic deformation, the parts can be subjected to heat treatment and, if necessary, machining.

To restore parts in a cold state, we use methods that allow us to restore low-carbon steels and non-ferrous metals. In this case, the structure of the material remains practically unchanged, but an increase in hardness and a decrease in viscosity are achieved. In the case of hot-work recovery, when parts are heated to a temperature between 0.7 and 0.9 of their melting point, this process applies to medium and high carbon steels, as well as alloy steels.

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This method is based on restoring the dimensions of the surfaces of the parts by moving the metal in their volume. For this purpose, special devices such as dies, punches, and mandrels are used, and forces exceeding the yield strength of the material are applied.

2. Analysis of recent research and publications

The process of forming metal powders is a technological operation that leads to the formation of a powder molding, i.e. an object with a certain shape, size and density. Under the influence of forces, the volume of the bulk material decreases and the powder is compacted. This process differs from the deformation of a solid because the volume changes but the geometric dimensions remain unchanged. Compaction of the powder is achieved by molding it in metal molds or elastic shells. Metal powder molding can be divided into several methods: pressing; isostatic molding; mouth molding; rolling; slurry molding; pulse and vibration molding. All these methods of forming metal powders can be compared to the pressing process [1-3].

Impulse forming of metal powders or powder forming is a process in which compaction occurs under the influence of shock waves during a short time interval that does not exceed 1 second. This method was developed to produce large-sized pressed products from powders that have limited ductility and for high-density composites.

The equipment for vibropress molding has common design solutions regarding the location of executive bodies, but they differ in the type of drive that generates vibrations. Therefore, they can be classified as follows.

Vibration presses with hydraulic drive, which are based on conventional single- and double-rack hydraulic presses (picture 1), with upper or lower location of the drive of the working link 1, provide one-sided periodic loading of the workpiece 4.

There are also developments of hydraulic vibrating presses for double-sided pressing, but they have not been widely used [2-7].

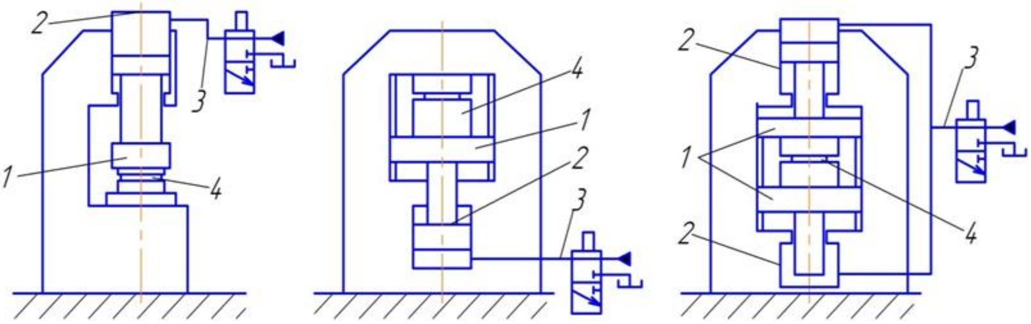
The use of hydraulic vibration exciters of various types in the drive of the working link has determined the variety of types of hydraulic vibratory presses that have been developed and created by various design and research organizations.

All types of hydraulic vibration exciters used in the drives of vibratory presses can be classified as pulsator and self-oscillatory [2]. The specific design of pulsator vibration exciters attracted the attention of developers of vibropressing equipment, but due to a number of significant drawbacks identified during operation, they have not been widely used.

The disadvantages of pump vibration exciters include the following:

- Intensive heating of the working fluid in closed hydraulic systems, and the problem is even more acute in the case of spool vibration exciters with forced mechanical opening.

- Significant power losses when adjusting the volume of fluid due to an increase in its supply to the hydraulic system at a constant speed of movement or rotation of the distributor, which simultaneously complicates the drive and regulation of the required energy to perform one working cycle [2, 4].



Pic. 1. Vibration presses with hydraulic power drive [2]

Using of self-oscillating hydraulic vibration exciters with mechanical and hydraulic feedback in the drives of vibrating presses made it possible to slightly expand the capabilities of these presses when adjusting the load parameters.

Despite the fact that vibration parameters depend on the piston load and that vibration operation is accompanied by noise and shock loads, self-oscillatory hydraulic vibration exciters have been widely used in real designs of hydraulic vibratory presses [2, 3].

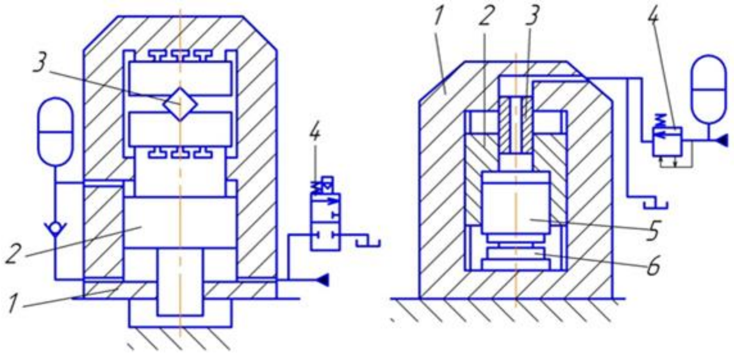
Initial versions of hydromechanical self-oscillatory vibration exciters with a gap in the rigid mechanical feedback on the movement of the working body had limited kinematic and power characteristics and were suitable only for laboratory models of vibratory presses, such as HPP (hydraulic punching press) presses.

In terms of operational reliability, manufacturability, and the ability to achieve the specified load parameters, the most suitable for vibratory hydraulic presses are self-oscillatory vibration exciters with mechanical feedback between the distributor element and the servo valve, as well as with hydraulic feedback based on the pressure drop.

In the classification terminology, these vibration exciters are known as "pulsators" and "pulsator valves". "Pulsators" were used in vibratory presses of the PLP type, while "pulsator valves" were first used in experimental samples of hydroinertial presses (HIP) [3].

A diagram of a pulsating load press of the PLP type is shown on picture 1.2 (a). In the lower part of the double-rack frame 1, there is a linkage drive 2, which acts on the workpiece located in the split stamp 3. The pulsator 4, which is located in the working hydraulic cylinder, creates a periodically varying pressure, which leads to vibratory movements of the working link of the press.

The PTP-100 (top-driven) and PTP-315 (bottom-driven) press models with operating forces of 100 and 315 kN, respectively, were used to calibrate light alloy profiles [3].



a ***b***

Pic. 2. Presses: a – pulsating load press (PLP); b – hydraulic inertial press (HIP) [3]

Hydroinertial presses of the HIP type represent a significantly new approach to vibratory presses, which differ significantly from vibratory presses built on the basis of conventional hydraulic presses. Picture 2 b shows a diagram of a hydraulic inertial press, where the plunger 5 provides a dynamic load on the workpiece 6, which occurs due to the periodic creation of fluid pressure pulses in the cavity of the working hydraulic cylinder. The liquid is supplied to this cylinder through the pulsator valve 4 and the telescopic pipeline 3. However, the results of experiments conducted on the HIP presses did not reveal the advantages of the inertial loading system [3].

Thus, vibration and vibro-impact pressing is widely used not only for forming metal powders, but also for processing plastic blanks, other powder materials, compaction of molding compounds, surface finishing with abrasives, construction and assembly technologies, processing plastic materials under pressure, type testing, loading and unloading operations, drying processes, and other applications (see Table 1).

The equipment used for vibratory molding has various configurations and design solutions, which allows us to consider a wide range of vibratory equipment. However, the design principles of these types of equipment have common features [3, 4].

Table 1

Main vibration and vibro-impact technological processes

Technological process	**Technological operation**	**The method of treatments**	**Industry sector**
Production of product blanks from non-plastic powder materials	Sealing, molding, pressing	VI	Metallurgy, mechanical engineering, automotive, electrical engineering
Production of products from plastic materials by pressure treatment	Pulsating drawing, settling, stamping, calibrating, drawing, rolling	V	Mechanical engineering
Finishing of parts with abrasive materials	Grinding, polishing, hardening, refinement	V	Mechanical engineering
Production of injection molds	Molding, compaction	VI	Metallurgy, foundry industry
Testing of machine components	Resource, boost and other typical tests	V, VI	Instrumentation, radio engineering, aircraft, tractor and machine building
Construction and installation works	Sealing of joints, compaction of soils, concrete, etc.	VI	Building

3. The purpose and tasks of research

Rational selection of hydraulic pulse device equipment with programmable control.

To achieve the set goal, the following tasks must be solved:

- Evaluate and analyze the use of programmable hydraulic pulse devices, including their operational efficiency and capabilities.
- Set the technical parameters, requirements and characteristics that correspond to the operation of the hydraulic pulse device with programmable control.
- Choosing the optimal equipment based on an analysis that takes into account technical requirements, financial constraints and market opportunities.
- Analyze the software requirements for controlling a hydraulic pulse device and its integration with the associated technology.
- Draw conclusions to the relevant information.

4. Results of the researches

Pulse powder molding can utilize a variety of energy sources for the load, including electro-hydraulic discharge of a battery of high-voltage capacitors through a water gap between two electrodes, pulsed magnetic field energy created by compressed and combustible gases and liquids, and energy derived from explosives.

The main feature of this method is the use of high loading speeds that exceed the propagation speed of longitudinal elastic waves and reach 50-100 m/s for powders in the state of tamping [3, 4].

This method has its advantages:

- High density achieved at 90% for powders such as titanium, tungsten and molybdenum.
- Exerting large forces exceeding 500 MPa on the executive body.

- High traverse speeds that reduce the forces generated for better workpiece compaction.

However, there are some disadvantages to this method, such as:

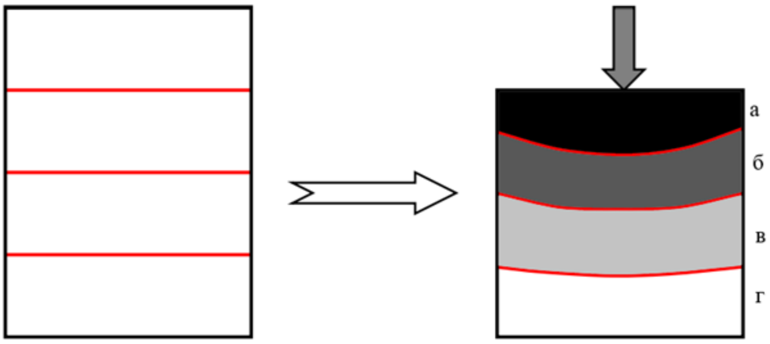
- Increased safety requirements due to the use of explosives.
- High process costs.
- Complexity of the equipment design.

Vibration molding has been widely used in various industries. This method makes it possible to obtain blanks from powdered materials with a density of 65% to 85% at very low loads, amounting to only 0.3-0.6 MPa [4].

The classification of vibration forming processes differs depending on the type of vibration or vibration-impact load used in the process. It depends on whether the load is pulsating or shock (impulse). Vibration and vibro-impact technologies are widely used in the production of powdered material blanks, compaction of molding compounds, surface treatment of parts with abrasives, construction and assembly technologies, processing of plastic materials under pressure, and many other industries. Vibratory and vibro-impact molding is more economical than other pressing methods.

In the case of vibro-impact loading, there is an additional increase in the plastic deformation of the workpiece under the influence of repeated force pulses, which initially cause only elastic deformations. This peculiarity of impulse transmission is noted when vibration impact pressing materials with a small amount of filler in the inertial loading mode.

Compared to conventional pressing methods, vibration impact pressing also has the advantage of forming more uniform workpieces, as the distribution of powder layers in them becomes more even. This result can be important for products with complex configurations and large dimensions [4].



Pic. 3. Density distribution over the pressing volume:
a – zone of the largest deformation; b – zone of medium deformation; c – zone of the smallest deformation; d – zone of minimum deformation [4]

The increased load causes the powder layers to bend along the pressing axis. If the particles initially have the same volume, the upper layers of the powder become thinner, i.e. they have a higher density than the layers below. This situation illustrates the pressure decrease during pressing with distance from the punch.

Vibration has a positive effect, as it helps to destroy the arches that form when the powder is filled and breaks loose bonds between the particles. This brings the effective coefficient of external and inter-particle friction to zero.

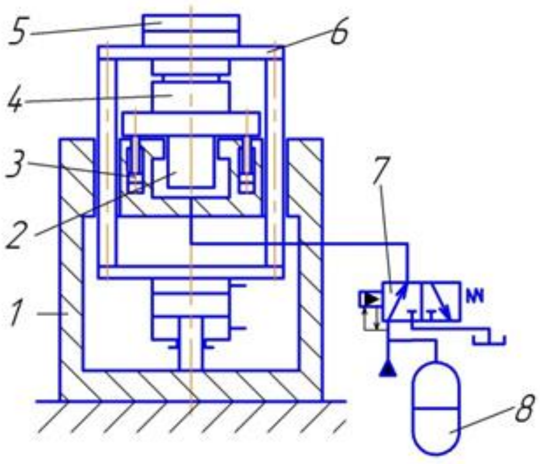
During the directed vibration motion, a small pressure (0.5 to 5 MPa) is applied to the powder particles. At lower pressure values, the powder is loosened, while at higher pressure values, the movement of the particles is blocked. This pressure is usually generated by hydraulic or pneumatic loading devices.

The efficiency of vibration molding depends on the vibration frequency. For small workpieces with particles larger than 100 microns, vibration with a frequency of 100 to 200 Hz is considered effective. For particles with a size of 1-100 microns, the optimal vibration frequency is in the range of 200 to 300 Hz. For particles smaller than 1 micron, a frequency of 300 Hz or more is recommended. It is necessary to maintain the vibration amplitude at a level of at least 0.1-0.15 mm at high frequencies (25-30 g amplitude).

In general, the process time should be no more than 30 seconds, as changes in the properties of the workpieces can occur during prolonged exposure. Optimum compaction is achieved in 2-10 seconds, and this time is virtually independent of the volume of material to be compacted. However, efficiency may decrease when molding materials with less homogeneous particles.

Vibratory molding can be used in the same amount of lubricant as conventional pressing. However, excessive lubricant can have negative effects.

The inertial vibratory press hammer (IVPH) consists of a lower table drive containing elastic return elements and a movable crossbar with a variable inertial mass. The station is equipped with an oscillating vibration exciter with pressure feedback and a single-stroke hydraulic accumulator.



Pic. 4. Inertial vibratory press hammer (IVHP) [4].

The hydraulic pulse drive creates a clear connection between the energy stored in the hydraulic accumulator for one machine stroke and the pressure in the hydraulic system, which allows you to adjust the pulse parameters for the IVHP. The use of an inertial loading scheme on the IVHP in conjunction with an additional static load allows for vibration and load modes for machining large workpieces of type 4 in interaction with a moving crossbar.

The pilot operation of the IVHP has shown its versatility in pressing complex and large workpieces made of carbide-silicon powder materials, high efficiency, and requires further research for the widespread introduction of the IVHP in industry.

There is also considerable interest in hydro-pulse vibratory presses based on existing pulse electro-hydraulic units (EHU) of the “Udar” type. However, the use of electro-hydraulic vibratory presses is not advisable in modern times due to the limited capabilities of such presses. For example, in presses of the Udar type, the electrical (power) part of the machine accounts for 80% of the total volume and transmits the calculated energy of the liquid pressure pulse at a low pulse frequency (no more than 2-3 pulses per minute). If it is necessary to increase the pulse frequency in the EGU and switch to the vibropressing mode, the energy of one pulse is significantly reduced with the same drive parameters, which does not meet the technological requirements, especially when processing large and complex workpieces. The technical characteristics of the vibratory presses that were tested in production conditions are shown in table 2.

The pressing of powdered product blanks in production conditions is mainly carried out using two types of vibratory presses: VP and IVHP, with mechanical and hydraulic drives, respectively. Comparing the characteristics of these two types of vibratory presses, we can highlight the advantages of the IVHP due to the ability to adjust the load parameters and solve a wider range of production tasks. Other advantages of the hydraulic drive make the IVHP more promising equipment, especially when increasing power and generating high working forces, reducing metal consumption, automating the technological process, and increasing the reliability and durability of the machine drive.

The choice of equipment for the molding of powdered materials is best considered as the choice of a vibratory press hammer of the IVHP type, which is noted as the most promising at the economic and technological level. The design of the IVHP also allows you to automate the process through the use of software. Modern computer systems and hardware have greatly simplified production automation and allow actuators to be connected to the control system to regulate process parameters.

Such automation allows replacing complex and large-sized computers that used to be located next to the equipment with a control system that includes a control unit, an adaptive part, and information input and visualization elements. Modern software makes it possible to involve specialists without special computer education, simplifying the management process and providing the ability to constantly monitor the technical characteristics of equipment using various types of sensors.

Table 2

Types of vibrating equipment for forming workpieces

Name of the product Characteristics		Maximum working force, kN	Limits of change of stroke frequency, Hz	Limits of adjustment of the working link stroke, mm	Type of drive of the working link	Purpose of the assignment
Type of equipment	VP	200	50	4	M	Production of refractory products from plastic and semi-dry masses
	GIP	2000	1…10	1…10	H	Deposition and extraction of metals
	SPR	3150	50	1	H	Calibration and finishing of pipes and profiles
	IVHP	320	1…40	1…10	H	Pressing blanks from powder materials of molding and core mixtures
	EHU	320	1…55	0,1…1	EH	Pressing blanks from powder materials

However, despite all these advantages of modern automation, the basic principles of actuator movement and design solutions for vibration molding remain the same.

5. Conclusions

Vibration and vibro-impact pressing play an important role in various industries, such as powder metal forming, production of plastic and other powdered materials, compacting molding mixtures, surface treatment with abrasive materials, construction and assembly technologies, and processing of plastic materials under pressure. Vibration equipment has a different configuration and design, which varies depending on the type of tasks performed. However, they have common design principles that are typical for many types of vibration equipment.

Hydraulic inertial presses of the GIP type are a fundamentally new solution in the field of vibratory presses. They differ from conventional vibratory presses, which are based on conventional hydraulic presses, in the way they generate the working force on the workpiece. Hydraulic inertial presses use the inertial principle to generate working pressure on the material being processed, and this represents a new approach to vibration pressing. This type of equipment can be useful in various industries where vibratory molding and compression of materials is important.

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ДОСЛІДЖЕННЯ ВІБРАЦІЙНОГО ФОРМУВАННЯ УЩІЛЬНЕННЯ ПОРОШКОВИХ МАТЕРІАЛІВ ГІДРОІМПУЛЬСНИМ НАВАНТАЖЕННЯМ

Сучасні тенденції у галузі машинобудування вимагають впровадження виробництва нових методів та засобів, спрямованих на підвищення надійності деталей та загальної якості виробів, при цьому зменшуючи витрати на їх виробництво. Надійність деталей машин визначається різними факторами, такими як їх міцність, стійкість до зносу, вібрацій і високих температур. Ці критерії надійності досягаються за допомогою різних методів, таких як вибір матеріалу та використання технологій, що підвищують міцність та стійкість до зносу, такі як термічна обробка, обробка поверхні деталей різними фізичними методами та зниження концентрації напружень.

В статті докладно розглядається процес формотворення металевих порошків, визначаючи його як технологічну операцію, що призводить до створення порошкових форм. Також проводиться аналіз та порівняння обладнання, використовуваного для вібропресового формоутворення заготовок з порошкових матеріалів. Описуються основні технологічні процеси вібраційного та віброударного впливу на матеріали.

Стаття також пропонує схеми та методи впровадження вібраційного формоутворення порошкових матеріалів, а також аналізує класифікацію цих процесів за їх характеристиками вібраційного та віброударного режимів.

Ключові слова: *формотворення, поверхнева пластична деформація, гідроімпульс, вібропрес-молот, гідроприсивний віброзбуджувач.*

Рис. 4. Табл. 2. Літ. 11.

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