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The Concept of Vibration Protection and an Overview of the Global Market of Vibration Protection Materials

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Due to the development of modern technologies, the number of sources initiating vibrations and noises has significantly increased. A variety of techniques are used to eliminate the negative impact of extraneous noise and vibrations.

The article presents the concept of vibration protection, the options and mechanism for selecting coatings, and an overview of the global market for vibration-proof materials. The most common methods of vibration protection are vibration isolation and vibration damping, implemented by using materials with appropriate properties.

Vibration isolation of vehicles is carried out by surface treatment with special mastics or coating with substrates as well as with the usage of hydraulic vibration supports. To minimize the impact of vibrations on buildings and structures, special fastenings and suspensions, vibration isolators, supports, soft rolled and sheet materials are used. For vibration isolation of machine tools and precision equipment, separate supports, a layer of elastic material placed between the machine and the foundation, a floating floor on an elastic base are used. The article presents a brief analysis of metal, rubber and rubber-metal vibration isolation supports in the budget, medium and premium price segments.

Vibration damping is performed using special plates, which are available on the market in the form of rolled materials and multilayer plates. Vibration-absorbing composite polymer coatings based on thermosetting polymers have become widespread. The industry of Russia and foreign countries has established the production of vibration-absorbing reinforced sheet materials. Russian scientists are also actively developing new types of coatings: gradient polymer composite materials, thermoplastic extrusion films, laminated fiberglass polymers, etc.

Keywords: vibration protection, vibration isolation materials, vibration damping materials, vibration isolators, vibration supports, vibration absorbing composites

Introduction

The technological process of forging and stamping production, the operation of metal-cutting machines is accompanied by mechanical vibrations and noise. Vibration processes have a negative impact on the quality of manufacturing products on precision machine tools, machining centers. Vibration isolation of vibration sources or vibration protection of precision equipment are the urgent tasks.

The term "vibration protection" means carrying out a whole range of measures aimed at reducing the impact of vibrations of buildings, structures, equipment, appliances, devices, vehicles to acceptable levels, as well as protecting people from its harmful effects [1, 2]. In practice, the following methods of vibration protection are used [3]:

vibration isolation, i.e. installation of special intermediate deformable elements directly between the vibration source and protected objects;

vibration damping, i.e. attaching an additional dynamic system to an object that changes the nature of its oscillations;

selection and modification of the parameters of the structural elements of the components of the equipment and their foundations, in which the specified mechanical effects will cause less intense vibrations of the object or its individual parts;

detuning from resonances by introducing structural elements with adjustable stiffness;

balancing of lever mechanisms, shafts, cylinders, rotors;

setting the limit values of the structural parameters of the technical condition (defects, deviations), which are sources of vibration of the components of the equipment.

Vibration isolation and vibration damping are the most common methods of vibration protection and are often implemented using materials with appropriate vibration-proof properties [4]. Vibration isolation materials prevent the free passage of oscillatory waves due to the properties of the material itself, i.e. internal losses, by weakening the connections between the vibration source and the protected object. Vibration damping materials

reduce the excitability of the structure by absorbing and converting the energy of mechanical vibrations into other types of energy, most often into thermal.

Vibration isolation materials

Vibration isolation can be active (manageable) and passive [5]. There is also a distinction between vibration isolation of the source and receiver of vibrations [6]. Source isolation refers to protection measures at the source of vibrations (e.g. in railway lines, highways, industrial installations). An example of this is the elastic isolation of the track superstructure or the acoustic decoupling of machinery foundations. Receiver isolation is a technical solution for the acoustic breaking of vibrations directly at the place of their impact. Source isolation is a more effective method of dealing with vibrations. But, since in many cases the source cannot subsequently be isolated, it is necessary to implement effective and at the same time economical technical solutions for vibration isolation of the receiver.

A good example of vibration isolation is the device and design of vehicles. Vibration isolation of the car is aimed at eliminating and suppressing low-frequency noise that occurs directly inside its interior. Compared to high-frequency, low-frequency noises are formed as a result of vibration in individual parts of the car body during its movement. Therefore, in this case, such a set of measures provides for the treatment of the surface of the vehicle with special mastics or coating with substrates that can reduce the intensity of the occurrence and transmission of vibrations [7]. Such materials include StP Aero Plus, StP Silver 3.0 New (Standardplast, Russia); VibroStop 25 (SoundGuard, Russia); KILMAT Car Sound Deadening Mat (KILMAT, Russia); Vibrofiltr PRO-1.5 - PRO4 (Vibrofiltr, Poland), etc.

Another effective method of vibration and noise isolation of transport is the installation of hydraulic vibration supports [8]. Hydraulic supports were first used in the German automotive industry in the early 80s of the last century. Hydraulic supports are also widely used in mechanical engineering. The total number of patents for hydraulic supports in Russia alone since 2000 has exceeded 100 [9-13].

Buildings and structures are subject to active propagation of vibrations over the surface of the ground and building structures. Sources of vibrations are elevator equipment (winches, starters, cabin noises); boiler rooms and heating points; ventilation equipment; various types of vehicles: metro or ground transport, etc. To eliminate vibrations, special fastenings and suspensions; spring, multi-spring and suspended vibration isolators; supports; soft rolled and sheet materials are used [14].

To improve the quality of manufacturing parts on machining centers and precision machines, low vibration activity of the bed is required. The operation of machines located in the same room (workshop) is constantly accompanied by vibration of the beds, calipers, main movement and feed mechanisms. These vibrations are transmitted through the foundation and structural elements of buildings. In this case vibration isolating elements can be represented in the form of [15]:

a) separate supports:

- elastic gaskets of a complex shape;
- spring vibration isolators, the main working element of which is one or more steel helical springs

b) a layer of elastic material placed between the machine and the foundation;

c) a floating floor on an elastic base, which is a reinforced concrete screed arranged on an elastic base over the bearing floor slab of the building.

The effectiveness of vibration isolation is estimated by the transmission coefficient, which has the physical meaning of the ratio of the force acting on the base in the presence of an elastic bond to the force acting in a rigid bond [16]. The lower this ratio, the better the vibration isolation. Good vibration isolation is achieved at K_T = 1/8-1/15. The transmission coefficient can be calculated by the formula:

$$K_T = \frac{1}{\left(\frac{f}{f_0}\right)^2 - 1}, \quad (1)$$

where f is the frequency of the disturbing force; f_0 is the natural frequency of the system on vibration isolators. The optimal ratio is f/f_0 = 3-4.

Five vibration frequency ranges are usually distinguished: infra-low (up to 2 Hz), low (up to 200 Hz), medium (200-2000 Hz), high (2-20 kHz), ultra-high (20-500 kHz and above) [17]. For building structures, the main vibration energy is concentrated in the range below 100 Hz, for machine tools – up to 500 Hz, and for high-speed machines, the upper limit of the range can reach 2000 Hz.

When vibration isolation of machines with operating frequencies less than 20 Hz, spring vibration isolators should be used.

At higher operating frequencies, both spring vibration isolators and elastic gaskets, for example, from the elastomeric material Sylomer SR, can be used (Getzner, Austria) (Fig. 1).

The material made on the basis of foamed polyurethane with a density from 110 to 1200 kg/m^3 has a mixed open-closed cellular structure, high elasticity and is marketed in 10 standard types.

Varying the parameters of the cells allows to produce a model range with a set of properties necessary for solving a wide range of tasks, and to individually select the material for specific conditions and an object [18].

Fig. 1. Vibration isolation mats Sylomer SR
Рис. 1. Виброизоляционные маты Sylomer SR

Getzner also produces steel spring vibration isolators ISOTOP (Fig. 1.2), which consist of two plates with internal threads and a coil spring. The main part of the element is a damping liner made of Sylomer SR, which exactly matches the stiffness of the spring.

Vibration isolators are positioned so that their center of rigidity is on the same vertical with the center of mass of the vibration-isolated installation. At the same time, vibration isolators must have the same draft. Spring vibration isolators are also produced by Hydro Garant (Russia), Stangir (Russia), Kulbit (Russia), Reinicke (Germany) and others.

Spring vibration isolators [19-21], having a lower frequency, provide greater vibration isolation at low frequencies than other types of vibration isolators made of elastic materials. However, elastic gaskets are more effective at medium and high frequencies, since wave resonant phenomena that worsen vibration isolation occur in them at higher frequencies than in springs and, moreover, are less pronounced due to significantly large internal energy losses.

Fig. 2. Spring vibration isolator ISOTOP DSD
Рис. 2. Пружинный виброизолятор ISOTOP DSD

Vibration isolation supports on the world market are presented in the budget, medium, and premium price segments, and there are three types [22]:

rubber (based on synthetic or natural rubber) [23, 24];

metal (for transmission of high frequency vibrations for supermassive machines);

rubber-metal (the most common; in addition to the rubber elements, a metal base is installed to increase the maximum load) [25, 26].

The best vibration supports in various price segments and their main characteristics are presented in Table 1.

Table 1. **Characteristics of the best vibration isolation supports for machine tools and equipment (R – rubber, M – metal, R-M – rubber-metal, C – composite)**
Таблица 1. **Характеристики лучших виброизоляционных опор для станков и оборудования (Р – резиновая, М – металлическая, РМ – резинометаллическая, К – композитная)**

Brand of vibration support	Manufacturer country	Type	Range of perceived loads, kg	Dimensions, mm	Natural frequency, Hz	Price, rub. (on February 2022)
Budget price segment						
PCA-60	Russia	R-M	30-110	22x80x110	15	505
LME 80 M10	China	R-M	10-350	33x80x110	100	690
OB-31 M16	Russia	M	250-4570	33x142x130	100	720
Middle price segment						
Groz RU59500048	India	C	25-500	45x45x150	50	1600
EM 1.55 M16	Lithuania	R-M	10-190	13x20x13	8	2100
EPC 05-60 M16	Italy	R-M	200-820	160x108x50	10	3000
Premium price segment						
C 2040 M10	Germany	R-M	10-75	76x76x38	75	4000
LME 230 M24	Russia	R-M	4500-7500	54x66x180	25	4100
CP 2090	Germany	R-M	10-75	76x76x38	75	4300

A promising, but so far rarely used type of vibration isolation supports are supports made of composite materials [27]. In most cases, they are multilayer "pillows". They can be used to reduce noise and vibration of generators, transformers, compressors, refrigerating machines, presses, stamping machines, fans, air conditioning systems; be used as vibration isolating supports for active and passive vibration isolation of engineering, technological and industrial equipment, as well as pipelines of engineering networks.

Vibration isolation of machines operated under conditions of constantly changing disturbing influences, in particular on mobile floating minifactories, such as floating workshops (FW) and offshore floating workshops (OFW), is of considerable interest [28, 29]. For these purposes, the scientists of Sevastopol State University have developed special vibration supports adapted to such dynamic conditions [30, 31]. The solutions for active vibration isolation of turbine units on floating bases are also known in this area [32].

Vibration damping materials

Often, when solving vibration isolation problems, there is a need for simultaneous sound and noise insulation. This is true, for example, to protect compressor stations from noise penetration into the environment [33]. By the nature of origin, noise and vibration can be:

- mechanical (due to the imbalance of moving, in particular, rotating masses, impacts in joints, knocking in gaps, etc.);
- aerohydrodynamic (during the inlet-outlet of gas compressors, due to the formation of vortices and inhomogeneities in gas and liquid flows in fans and pumps, self-oscillations in water taps);
- electromagnetic (for electric motors, transformers).

The choice of a set of means to reduce noise and vibration depends on the nature of their occurrence and distribution and is justified by an acoustic calculation, which determines the expected noise levels in the protected room, the required reduction and the measures necessary for this. In this case, vibration damping materials are used, which absorb and dissipate most of the various noises and protect against the effects of suddenly applied, shock, cyclic and other typed of loads [34]. The most used materials of this group are vibration damping plates [35, 36], which are able to dampen vibrations from acoustic and shock noise [37]. On the world market, they are presented in the form of rolled materials with a thickness of 4 and 6 mm and plates with a thickness of 10 and 20 mm, which are manufactured in the factory and represent three functional layers interconnected (Fig. 3) [38].

A layer consisting of a geotextile material is attached to the outer waterproofing layer using a layer consisting of a large number of springs wound from thin (up to 1,5 mm) plastic threads. The main producers of such materials are STC Rezina (Russia), A-Polymer (Russia), ACE Ltd. (Switzerland), AirLoc Ltd. (Switzerland), APSOparts (Switzerland), Misumi (Germany), Mupro (Germany), Fabreeka (UK), Plan Tech (UK), etc.

When the usage of polymeric materials as structural is not possible, vibration-absorbing coatings are used to reduce vibrations [39]. Their action is based on the attenuation of vibrations by converting vibrational energy into thermal during deformation of the coatings. These are, for example, one- and two-component mastics Vibronet-A5 (ISON, Russia), VPM-1 (RealColor, Russia), Adem (Plastpolymer, Russia), etc. The areas of application and requirements for the physical and mechanical properties of vibration-absorbing coatings are shown in Figure 4 [40].

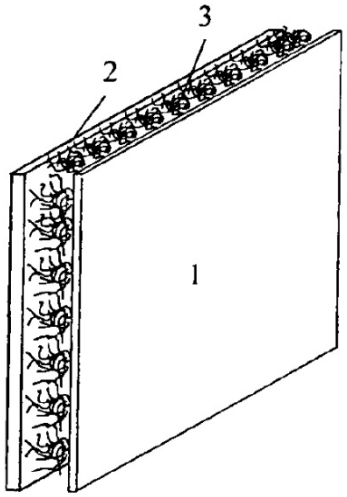

Fig 3. The structure of the vibration-proof damping plate: 1 – a geotextile layer, 2 – a waterproofing layer, 3 – an intermediate layer of plastic springs

Рис. 3. Структура виброизоляционного демпфирующего материала: *1* – слой геотекстиля, *2* – гидроизоляционный слой, *3* – промежуточный слой из пластмассовых пружинок

Vibration-absorbing composite polymer coatings based on thermosetting polymers are widely used. They consist of a binder of epoxy or polyester resin, oligoetheracrylate [41, 42], furan-epoxy oligomers [43, 44] in combination with an organomineral filler – rubber powder [45], or iron powder, granite and kaolin [46].

Gradient polymer composite materials, which have an uneven distribution (gradient) of the composition and properties over the cross section [47, 48]; thermoplastic extrusion films made of polyvi-

nyl acetate and polybutyl methacrylate for usage as the inner layer of metal-polymer-metal layered vibration-damping materials capable of operating in contact with water [49]; layered polymers from structural fiberglass, epoxy rubber adhesive film as a binder and vibration-absorbing layer from thermoplastic polyurethane [50] or fiberglass and vibration-absorbing layers based on thermoplastic polyurethane and modified polyvinyl acetate [51], are being actively developed.

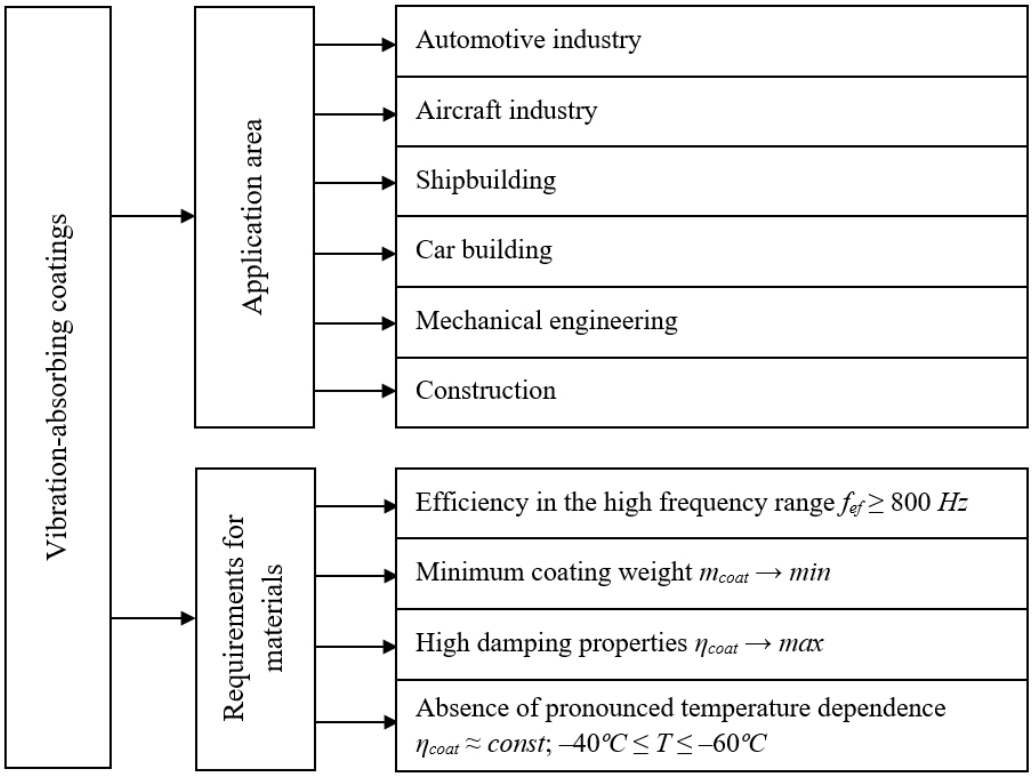

Fig. 4. Areas of application of vibration-absorbing coatings and requirements for them
Рис. 4. Области применения вибропоглощающих покрытий и требования к ним

By the nature of the deformation that determines the absorption of vibration, vibration damping coatings can be soft, rigid, combined and reinforced [52].

Soft coatings intensively absorb vibrations when an integer number of half-waves are applied to the thickness as a result of tensile-compressive deformations in the direction perpendicular to the surface of the damped plate.

Rigid coatings, effective at low-frequency vibrations, absorb energy due to tensile-compressive deformations along the surface of the deformable plate.

Combined coatings are multilayer, with a combination of different types of materials in layers, which provide vibration absorption over a wider frequency range.

Currently, the industry of Russia and foreign countries has established the production of vibration-absorbing reinforced sheet materials [53]. Materials with the best vibration absorbing properties are presented in Table 2.

Table 2. **Foreign and domestic industrially produced vibration-absorbing coatings**
Таблица 2. **Зарубежные и отечественные промышленно выпускаемые вибропоглощающие покрытия**

Name	LD-17 (Antiphon, Sweden)	Dynamat Extreme (Dynamic Control, USA)	Hushmat Ultra (HushMat, USA)	DF-10AL (Noise-buster, RPE Technical Consulting, Russia)
The polymer on the basis of which the coating is made	modified bitumen	butyl rubber	butyl rubber	bitumen-polymer
Reinforcing layer	graphite	aluminum foil	aluminum foil	aluminum foil
Temperature ranges for optimal usage, *°C*	from –10 to +60	from –10 to +60	from 0 to +60	no data
Coating thickness, *mm*	2,5	1,7	1,5	5,5
Specific gravity, kg/m^2	2,3	2,2	1,53	10

A common disadvantage of all the presented materials is their low vibration efficiency at low temperatures.

Conclusion

The market of vibration–proof is very extensive and dependent on external conditions – the general economic situation in the country, suppliers of raw materials, the conditions of the production process and the development priorities of the respective industries.

In 2022, due to geopolitical tensions and the echoes of the pandemic, which destroyed the established logistics ties and supply chains, import substitution is one of the most important tools of the state's economic policy. Today, one of the main vectors of development is the constant expansion of the range of vibration-proof materials produced and used in Russia with a special focus on innovative products.

The task of creating effective means of vibration protection and improving existing ones is complex, contradictory, but more relevant than ever. Its solution is not always obvious and requires a lot of theoretical and experimental research.

The presented review clearly showed the need for research in the area of progressive developments and the introduction of domestic vibration-proof materials, in particular, composite ones, because now the Russian market is 60% represented by foreign analogues.

The purpose of the further research is the creation of a composite vibration support aimed at a comprehensive solution to the vibration, noise and sound insulation problems of precision processing equipment, increasing its productivity, saving resources and reducing the complexity of the manufacturing of parts.

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Понятие виброзащиты и обзор мирового рынка виброзащитных материалов

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Вследствие развития современных технологий существенно увеличилось количество источников, провоцирующих возникновение вибраций и шумов. Для устранения негативного воздействия постороннего шума и вибраций используются самые разные приемы.

В статье дано понятие виброзащиты, описаны варианты и механизм подбора покрытий, представлен обзор мирового рынка виброзащитных материалов. Наиболее распространенными методами виброзащиты являются виброизоляция и вибродемпфирование, реализуемые с применением материалов с соответствующими свойствами.

Виброизоляция транспортных средств осуществляется обработкой поверхности специальными мастиками или покрытием подложками, а также с применением гидравлических виброопор. Для минимизации влияния вибраций на здания и сооружения используются специальные крепления и подвесы, виброизоляторы, опоры, мягкие рулонные и листовые материалы. Для виброизоляции станков и прецизионного оборудования применяют отдельные опоры; слой упругого материала, укладываемого между машиной и фундаментом; плавающий пол на упругом основании. Статья презентует краткий анализ металлических, резиновых и резинометаллических виброизоляционных опор в бюджетном, среднем и премиум ценовом сегментах.

Вибродемпфирование выполняется с применением специальных пластин, которые представлены на рынке в виде рулонных материалов и многослойных плит. Широкое распространение получили вибропоглощающие композиционные полимерные покрытия на основе термореактивных полимеров. Промышленностью России и зарубежных стран налажен выпуск вибропоглощающих листовых материалов армированного типа. Российскими учеными активно разрабатываются также новые типы покрытий: градиентные полимерные композиционные материалы, термопластичные экструзионные пленки, слоистые полимеры из стеклоткани и т. д.

Ключевые слова: виброзащита, виброизоляционные материалы, вибродемпфирующие материалы, виброизоляторы, виброопоры, вибропоглощающие композиты.

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