Properties of the rubber vibration isolator of the elevator

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Abstract. The article presents experimental-theoretical studies of rubber shock absorbers of an elevator. Their static and dynamic stiffness in compression and static shear stiffness are determined. Two variants of fastening of rubber prisms were considered: in a cage and without a holder. It is shown that the logarithmic decrement of damping of the rubber cushion lies in the range of values 0.4 ... 0.5.

1 Introduction

Large volumes of construction of multi-storey and high-rise buildings require an increase in the production and supply of elevators. Different working conditions and a large range of characteristics predetermine a significant variety in the design of the elevator winches. Electric lifts with cable winches or traction sheaves and an unobstructed kinematic link to the brake have become widespread [1]. Such designs of elevators have appeared historically, in many respects are convenient in production and operation. One of the drawbacks of elevators is the oscillation of the drive and the elevator cabin. As a result, vibrations and noise can be felt in the cabin and adjacent to the elevator shaft.

2 Literature review

The elevator drive traditionally includes a traction arm, a brake and an electric motor mounted on a frame supported by rubber supports on the base.

The design of the elevator winch requires the safe operation, reliability and safety of the elevator elements, noiselessness and low vibration, the permissible level of acceleration and the accuracy of the cabin stop, and others. For different reasons, the mechanisms for driving elevators do not fully meet these requirements [2, 3, 4]. Research carried out on passenger elevators has shown that noise and vibration on many elevators exceed permissible limits; high-frequency oscillations of the system take place [5, 6, 7]. Noise and vibration significantly reduce the comfort of living in houses, with elevators installed in them.

The dynamics and reliability of the elevator are devoted to the work of many authors, for example, [1 ... 16]. The greatest danger, from the point of view of oscillatory processes, is resonance or near-resonance frequency bands. Various methods are used to reduce

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vibrations: the use of absorbers and absorbers of vibrations, automated control systems with feedback, gearless drive, and so on [5, 7, 8, 11, 13, 14, 15, 17, 18, 20].

However, the proposed methods are often applicable to specific operating conditions and the design of the elevator. In all cases, useful, and sometimes decisive, may be an increase in the damping properties of the dynamic system. With regard to the passenger elevator, we note the importance of the damping properties of the system in resonant zones, even if there is only a danger of passing through resonance at a certain number of storeys of buildings [3, 7, 8, 9, 12, 13]. Especially we can say about high-speed elevators in high-rise buildings: there are noticeable fluctuations in the elevator car not only in the vertical plane, but also in the horizontal plane. At the same time, in medium-height houses, there are spatial oscillations of the elevator drive frames and mainly vertical vibrations of the elevator car. Thus, the task of reducing the oscillations of the elevator is very important.

The elevator drive is mounted on the frame. The frame rests on the base (engine room floor) through rubber cushions. These cushions play the role of shock absorbers: they are usually clamped between twowashers from above and from below and have elastic and damping properties. The task of these studies was to determine the elastic and damping properties of rubber cushions of some models of operating elevators in order to obtain actual data for accounting when solving problems of elevator dynamics [8].

3 Contents of the research

The analysis showed that noise and vibrations are often associated with the emergence of a resonant situation, which can be considered in most cases in the first approximation on a single-frequency (single-mass) dynamical system separately for each resonant frequency. Such a model is described by the equation of forced oscillations for a dissipative system [19]

$$\ddot{q} + 2\varepsilon\dot{q} + \omega_0^2 q = (F\cos\omega t)/a, \tag{1}$$

where $q, \dot{q}, \ddot{q}$ – is the generalized coordinate of displacements, speed and acceleration of the reduced inertia element; ε - coefficient of damping; ω_0 – natural frequency of oscillation; ω – frequency of driving oscillations; *F* – is the force parameter of the external oscillation excitation (force or moment); *a* – is the reduced characteristic of the inertial element (mass or moment of inertia); *t* – is the current time.

The solution of this equation can be an expression for the amplitude of the steady-state oscillations in the form

$$q = q_{CT}\cdot\cos(\omega t - \varphi)/\{[(1-\eta^2)^2 + (\vartheta/\pi)^2\cdot\eta^2]\}^{1/2}, \tag{2}$$

where q_{st} – is the static displacement due to the force parameter *F* ($q_{st} = F / C$); *C* – is the reduced stiffness parameter; θ – is the decrement of the oscillations ($\theta = 2\varepsilon\pi / \omega_0$); η - relative frequency (ω / ω_0); φ – is the phase angle, which is equal to

$$\varphi = arctg[(\vartheta/\pi)\eta/(1-\eta^2)]. \tag{3}$$

From the expression for the amplitude of steady-state forced oscillations, it is well known that one of the ways to reduce resonance oscillations is to increase in some way the energy dissipation of oscillations.

There are many ways to reduce or suppress oscillations of a mechanical system [19, 20]. In this study, the elastic and damping characteristics of the rubber support of the passenger elevator are determined.

Rubber cushions had a length and width of 120 mm, a height of 40 mm and chamfers along horizontal ribs of 10 mm. They were placed between two steel washers (cages), covering the cushions chamfered with a slight interference, which created a restriction of rubber deformation.

The static rigidity of the rubber cushion was determined on a screw press: the load was measured with a torque gauge ring with a dial gauge indicator with a tared division price, and deformation by means of a dial gauge with a fission rate of 0.001 mm.

The dynamic rigidity of the rubber cushion was determined on a specially designed impact type bench. The main frequency of the stand was about 25 Hz. It was determined mainly by the rigidity of the rubber cushion under test and was chosen close to the main frequency of the perturbation of the elevator winch with a carrying capacity of 400 kg. The deformation of the pillow was measured using a dial gauge and was duplicated by a special device.

To determine the dynamic rigidity, a stand was designed and manufactured. It consisted of a base on which a bar was installed for the falling load. The load fell freely from a fixed height and hit the second-kind lever, and through the lever impacted the rubber cushion. The impact sites on the cushion were designed so that friction at the points of contact was minimal. The deformation of the pillow was determined by the indications of the indicator.

4 Results and comment

The experiment showed that the static rigidity on the compression of a rubber cushion without a washer proved to be practically constant during the loading process and its value is equal to Cst = 2900 N / mm.

The value of the dynamic rigidity of the rubber cushion was obtained by calculation from the analysis of the first phase of the impact for two cases: cushions with washers and cushions without washers. Average in a series of ten experiments: dynamic cushion stiffness with a small spacer: for a cushion with washers C_{ds} = 4200 N / mm; for a pillow without washers C_d = 3600 N / mm.

Researches have shown a significant excess of dynamic stiffness over static, as well as a noticeable effect of the washers on the dynamic rigidity of the rubber cushion. At the same time, full-scale experiments on elevator winches have shown both greater and damage to dynamic rigidity of rubber cushions with washers from the case without washers.

In addition to the static tests on the compression of the pillows of the elevator drive supports on the screw press, they were also performed for the same two cases of testing unoccupied and involuntary baits for shear. As a result, the stiffness values for the cushion shift were obtained without washers 400±25 N / mm, and for a cushion with washers ~1090 N / mm.

According to the results of tests according to the procedure of work [20], a modulus of elasticity was obtained for the compression of the material of pillows E≅3.4 N / mm2 with a static rigidity of 2900 N / mm of cushion without washers; the elastic modulus for shear of the material of the cushion was equal to G≅1.2 N / mm2. The ratio of the modulus of elasticity to compression to the shear modulus gives a value close to three, which corresponds to a rubber with a Poisson's ratio of 0.5 [20].

To assess the damping properties of rubber cushions in a shear test, load curves were plotted - unloading, which allowed to estimate the absorption coefficient According to the hysteresis loop, estimate the absorption coefficient Ψ and the corresponding logarithmic damping decrement δ close to 0.4 in the hysteresis loop. A similar experiment on the compression and unloading of a rubber cushion without washers with a height of h = 70 mm made it possible to obtain a logarithmic damping decrement of $\delta \approx 0.45$ ($\Psi = 0.6$).

Experimental studies in the conditions of operating elevators with a carrying capacity of 400 and 600 kg made it possible to determine that the own oscillations of the winch frame in the vertical plane are low in shape (the rubber cushions work almost uniformly and the deformation is slightly limited by compression by the washers), which are excited by impact, with a frequency of 30 Hz. (which corresponds to $C_d \cong$ 5400 N / mm), and the logarithmic decrement δ is close to 0.5.

Data on the δ and Ψ material of the pillow under investigation show that it is close to the material of rubber 1378 [20]. It should be noted that the tests were carried out on new cushions. In the reference book [20] it is stated that for the service life of 3 ... 8 years the modulus of elasticity and attenuation can vary by 15 ... 30%.

The results obtained refer to the specific form of the pillows in the form of a parallelepiped with chamfers along the horizontal faces. Shock absorbers of a different shape are known, for example, cylindrical, and for them the numerical values of stiffness and decrement of oscillations can have different values. Here, the volume and properties (material) of the shock absorber can be important. At the same time, the qualitative nature of the studies performed can to some extent be generalized to the basic models of the dynamic elevator system in the part of the elastic or elastic-damper supports of the elevator drive frame.

5 Conclusions

1. Executed studies to determine the elastic-damper characteristics of the rubber pillows of the elevator drive provide an opportunity to assess the appearance and level of oscillations of the elevator when it is created.
2. The use of washers limits the deformation of rubber cushions, which leads to a significant increase in the rigidity of rubber shock absorbers.

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