# Sustainable limitation of high-frequency oscillations of elevator cabin

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**Abstract.** In this paper, a problem of sustainable limitation of vertical high-frequency oscillations of elevator cabin in buildings with various number of storeys is considered. To solve this problem, dynamic model of the elevator movement was developed. In the course of analytical and experimental studies, the main cause for emergence of undesirable high-frequency oscillations of a cabin was defined. The amplification factor which is the function of λ and length of cable was determined. The λ parameter is variable, and length of the cable changes depending on length passed by the cabin and is an amplification factor argument. For sustainable limitation of oscillations, use of dynamic dumper of lever type is proposed. Adjustment of the dumper natural vibration frequency in such a way that it is equal to the excitation frequency allows limiting of oscillations of the cabin and the elevator machine to reasonable value irrespective to position of a moving cabin in the shaft. Using dependences and plots which were obtained in the course of scientific analysis and experimental studies, reasonability of dumper application for sustainable limitation of high-frequency influence of the elevator machine on the base and obtaining of solutions of inertial forces equilibration problem was proved.

## 1. Introduction

High-frequency vertical oscillations of the elevator cabin are exceedingly undesirable. Inspections of elevators of different load-carrying capacity allowed defining of main factors which cause considerable excess of high-frequency cabin vibrations over permissible level [1 - 4].

## 2. Materials and methods

Materials of the experimental studies of passenger elevators with load-carrying capacity of Q = 400 kg, speed of V = 1.6 m/s [1 - 15] were used as initial data for solution of the problem of high-frequency oscillations reduction for elevator cabin. The dynamic model of the elevator, including cabin and allowing estimation of the cabin reaction to excitation [1, 3], was developed for solution of the problem. Amplitude elasticity force acting to the cabin $K_d$ divided by amplification factor is equal to:

$$K_d = |[50(\lambda - 1) \cdot (1 - u^2)u + 1 - 2u^2]^{-1}| \tag{1}$$

where initial characteristics of the system and necessary parameters are as following:

λ - parameter equal to $\lambda = \left(\frac{P}{\omega}\right)^2$ where

P - rubber support stiffness ratio - $C_o$ to weight of elevator machine - M,

i.e. $P^2 = \frac{C_o}{M}$;

ω - circular rotation frequency;
u – parameter defined by formula:
$u = \frac{1}{\sqrt{k}}$, where $\sqrt{k} = \frac{\gamma}{\omega} = 70{:}L$.

If parameter $k = \left(\frac{\gamma}{\omega}\right)^2$, where $\gamma^2 = \frac{4c}{m}$, then c - profile stiffness - is defined as $C = \frac{EF}{L}$, where E and F are the cable elasticity module and section area, accordingly, and L is the cable length, m- weight of the cable.

The numerical coefficient in (1) which is equal to 50 was defined on the base of values of dynamic system parameters. Circular rotation frequency ω = 150 1/s and this corresponds to engine rotation frequency ndv = 1,440 rpm. The amplification factor Kd in (1) is function of λ and cable length L. The λ parameter is variable, and length of the cable changes depending on length passed by the cabin and is an amplification factor argument. In work [1], plots of Kd (L) versus λ are provided. So for λ = 1.05, resonance phenomenon is decreased and is shifted to range of length from 60 to 70 m, and for λ < 1, in proximity of 1, trend of coefficient Kd is slightly changed. If the engine rotation frequency changes, it is simple to take this into account in the analysis scheme - numbers 70 and 50 are changed. For relatively small L values, the scheme in which Mk is the cabin weight and weight m is equal to zero is seemed more exact. In this case, amplification factor Kd to be analyzed is equal to:

$$K_d = \left|\left[\left(1{,}4L - \frac{M}{M_K}\right)\cdot(1-\lambda)\right]^{-1}\right|, \tag{2}$$

In Equation (2), 1.4L is a cable portion, and $M/M_к$ is a portion of cabin mass. However it can be suggested that the coefficient determined by formula (1) is more precise. So, for λ ≥ 1 maximum value of $K_d$ coefficient which is determined by formula (2) does not exceed 1 and, in this case, the formula (1) is more correct.

Further it is necessary to come from length of cable L to number of storeys in the buildings. At ω = 150 1/s, the dominant excitation frequency causes a resonance when the elevator cabin is located at 3-7 floors of 25-storey building. It is possible to prevent resonance occurrence by reducing of rotational speed of the engine. It should be noted what when rotational speed of the engine is decreased, amplitude of harmonic influence of inertial forces on unbalanced rotating mass of the elevator machine is also decreased.

If the elevators are installed in buildings with small number of storeys, resonance obertones can be generated, for example, due to kinematic imperfection of worm gear. To reduce resonance amplitude of the elevator cabin, passive dynamic vibration dumper which should installed between frame of elevator machine and its base [2,6,11,12,15] was proposed. Adjustment of the dumper natural vibration frequency in such a way that it is equal to the excitation frequency allows limiting of oscillations of the cabin and the elevator machine to reasonable value irrespective to position of a moving cabin in the shaft. Effective weight of dumper which is more than m (weight of cables) is necessary for effective dumping of oscillations. When the elevator cabin moves it passes phases of dumping and resonance generation. Due to the fact that m is small in comparison with M (weight of machine) these phases are really merged. Plot of function $K_d$ (L) for λ = 3 that correspond to elevator load-carrying capacity of Q = 630 kg and speed of V = 1.6 m/s is given in Figure 1.

The given plot (Figure 1) is presented in two scales for axis $K_d$, being an axis of ordinates. For curve 2, the scale for axis of ordinates is the same as for curve 1, and scale for abscissa axis is 5 times less, at the same L. Length L = 70 m corresponds to the mode when cables act as dumper, and L = 69.65 m – to the resonance mode. The curve 1 shows that at L ≤ of 69 m and L ≥ 70.5 m the amplification factor does not exceed 0.5. In this case it can be assumed that at λ ≥ 3 high-frequency excitation by inertial forces of elevator machine rotating mass does not enter cables hanging device and cabin.

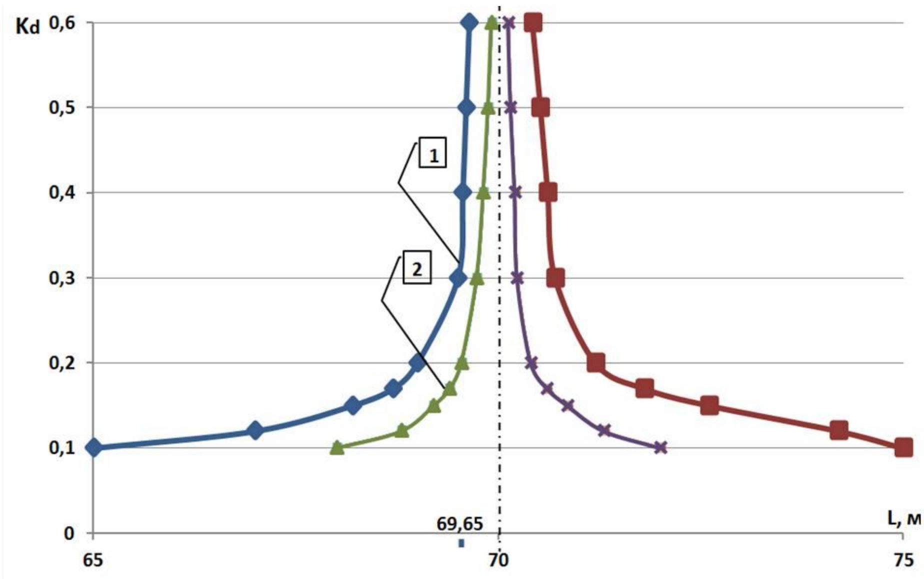


**Figure 1.** Plot of function $K_d(L)$.

The elevator dynamic system is a system with variable parameters which are defined by different length of cables that significantly affects high-frequency oscillations of weight m in resonance area. In this case, dumping of longitudinal vibrations of cables by passive dumper is reasonable and this was confirmed in the course of experimental tests of elevators [2,6,7]. The basis of such problem solution was a well-known solution for single-part linear dynamic system. The numerical solution is based on derivation of obtained for the system formula with step equal to $20\pi/\omega$. This number of steps equal to twenty is sufficient to estimate features of the mode of the cabin passing through "resonance area". The natural oscillations caused by the studied external excitation and preceding the beginning of process are quickly vanish without distorting of obtained solution and especially do not influence its maximum. Using set of equations given in [2], we calculated sequential values of amplitude envelope $\bar{y}$ which are shown in Figure 2.

Curves 1 and 2 in Figure 2 are obtained for logarithmic decrement $\delta$ equal to 0.09, for the case when a cabin moves up and down.

It can be seen in Figure 2 that the curves maximums slightly differ from $\pi/\delta$ corresponding to resonance for motionless cabin. More significant effect for moving cabin is that maximum of curves 1 and 2 are separated by 4 s or 6.4 m. To provide the largest possible reduction of the cabin oscillations, the used passive dynamic dumper should take into account this separation.

The experimental studies of the dumper make it possible to define the high-frequency dynamic system of the elevator more exactly. As a result of analysis and optimization of high-frequency dynamic structure of the elevator, the lever type dumper was recommended. The dumpers researches and tests carried out for elevators load-carrying capacity Q = 400 kg, Q = 630 kg and speed V = 1.6 m/s during 25 months confirmed reasonability of application of lever type dumper for sustainable limitation of high-frequency vertical oscillations of the elevator cabin.

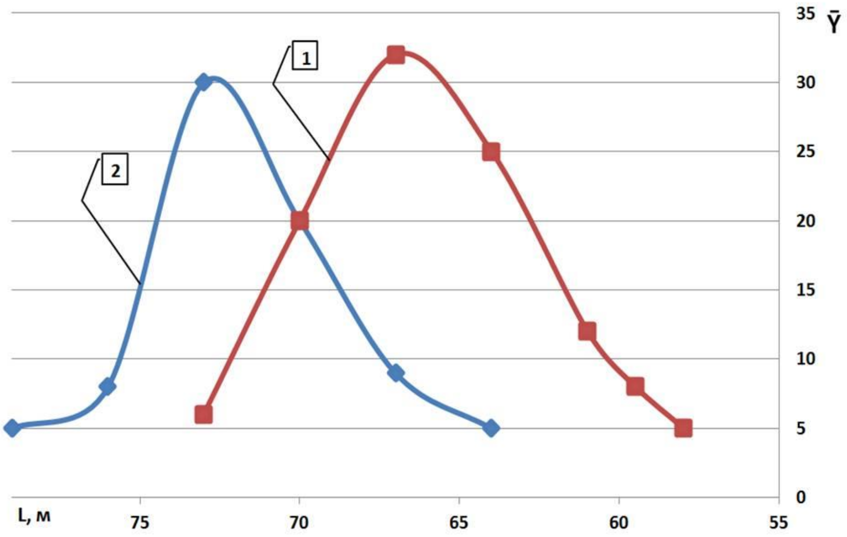


**Figure 2.** Plots of y for δ = 0.09.

## 3. Conclusions

The dynamic model for analysis of high-frequency vertical oscillations of elevator cabin, which allows defining of amplification factor and parameters dependence on cable length is developed. The proposed dynamic model can be used for any elevators with similar design of cabin hanger and type of the drive irrespective of load-carrying capacity. For sustainable limitation of vertical oscillations of elevator cabin, use of lever type dynamic vibration dumper is proposed.

## References

[1] Cherkasov V and Kaytukov B 2011 *Mechanization of construction* **11** 14-17
[2] Cherkasov V and Kaytukov B 2011 *Mechanization of construction* **12** 17-20
[3] Chensuan L, Syaolin V, Tszyanuo L and Sin M 2009 *Scientific and technical magazine about elevators, escalators and cable cars* **3(58)**
[4] Cherkasov V, Skel V and Kaytukov B 2006 *Elastic-damper properties of rubber supports of the elevator drive. The collection of materials of the scientific and technical conference Interstroymeh* (Moscow, MGSU)
[5] Sharapov R and Prokopenko V 2013 *World Applied Sciences Journal* **25(3)** 536-542
[6] Fedorenko M, Bondarenko J, Sharapov R, Markova O, Pogonin D and Pershin N 2015 *Research Journal of Applied Sciences* **10** 653-657
[7] Dani D 2011 Sensors for elevators *Scientific and technical magazine about elevators, escalators and cable cars* **10** 27 - 30
[8] Kondo R, Kigava K, Sibata M, Khasimito Y, Chida A, Marercho K and Ueda T 2011 *Scientific and technical magazine about elevators, escalators and cable cars* **10** 33 – 42
[9] Stepanov M and Mechiyev A 2016 *Mechanization of construction* **7** 49-50
[10] Stepanov M and Mechiyev A 2014 *Mechanization of construction* **12** 44
[11] Pulyayev S, Stepanov M, Kaytukov B, Lukyanov N, Dyakonov N and Kapyrin P 2015 *Mechanical equipment and technological complexes* (Moscow, Tutorial)
[12] Sevryugina N and Babin V 2007 *Construction and road machines* **1** 48 – 50
[13] Sevryugina N and Kuleva N 2016 *The world of transportation and technological machines* **1(52)** 70 – 77
[14] Gustov Yu, Gustov D and Orekhov A 2012 *Mechanization of construction* **12** 26 – 28
[15] Gustov Yu and Kenareykin V 2016 *Lifting and transporting business* **4 – 5** 17 – 19