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NEW DESIGN OF THE IMPACT DAMPER

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1. Introduction

In the newest publications of many scientific papers the great interest in vibrations reduction and control can be seen. The authors show the huge significance of elaborating simple and effective methods of oscillations reduction [1-5]. The most important aplications of these vibration absorbers are impacting hammers, gas turbines, tubes in steam generators and their support plates, helicopter and weapon systems, ship trunks.

Simultaneously the patricular interest in vibroimpact vibration absorbers can be seen. There are a lot of papers in which the authors show, that these kind of absorbers are more effective and work in wider frequency range than the traditional ones [6-12]. There are still no simple methods for elaborating the constructions of vibro-impact absorbers and confirming the parameters values for which the vibrations reduction has the practical significance.

In this paper the new construction of the impact damper is presented. It is the first stage of elaborating such a damper. The range of effectivness of impact damper is shown. The new kind of discrette impact map is proposed. It is shown that using this map many aspects of kind of impacts, the energy flew and its dissipation, the reasons for chaotic motions existance can be concluded.

1. The physical and mathematical model of the system

The physical model of this system is shown on the Fig.1. The system consists of three oscillators. The main oscillator is forced by the external harmonic force. It is joined with the classical dynamic damper. This damper is allowed to collide with the third oscillator. The dynamic damper, which will be called the damper, is matched with the resonance frequency of the main oscillator that in the range of its resonance amplitude of its oscillations is decreasing to zero. It is known that this kind of damper is effective just for narrow range of external force frequency. For frequencies that are lower and higher than η=1 there exist two another resonance frequencies η_1, η_2 (Fig.2). In order to decrease oscillations amplitudes in range of theese frequencies, with retain the advantages of the dynamic damper , third independent

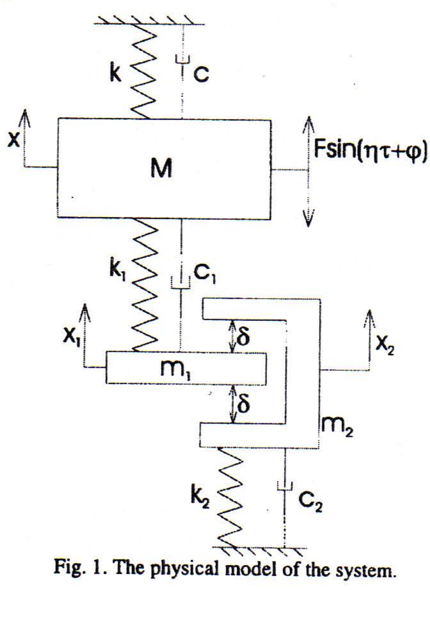

Fig. 1. The physical model of the system.

oscillator was added. This oscillator will be called absorber.

The investigations were based on numerical simulations. The Runge-Kutta method was employed to integrate the differential equations of motion. Impact modelling was based on Newton's law. Mathematical model of the system was such as follows:

$$\ddot{x}+2\gamma\dot{x}+2\gamma_1\sqrt{\mu_1\sigma_1}(\dot{x}-\dot{x}_1)+x+\sigma_1(x-x_1)=q\sin(\eta\tau+\varphi)$$

$$\mu_1\ddot{x}_1+2\gamma\dot{x}+2\gamma_1\sqrt{\mu_1\sigma_1}(\dot{x}_1-\dot{x})+\sigma_1(x_1-x)=0$$

$$\mu_2\ddot{x}_2+2\gamma_2\sqrt{\mu_2\sigma_2}\dot{x}_2+x+\sigma_2(x_2+\delta)=0$$

$$\mu_1(\dot{x}_1'-\dot{x}_1)=\mu_2(\dot{x}_2'-\dot{x}_2)$$

$$\dot{x}_1'-\dot{x}_2'=-r(\dot{x}_1-\dot{x}_2)$$

where:

$$\mu_1=\frac{m_1}{M};\qquad \mu_2=\frac{m_2}{M};$$

$$\sigma_1=\frac{k_1}{k};\qquad \sigma_2=\frac{k_2}{k};$$

$$\gamma=\frac{c}{2\sqrt{k\,m}};\quad \gamma_1=\frac{c_1}{2\sqrt{k_1m_1}};\quad \gamma_2=\frac{c_2}{2\sqrt{k_2m_2}};$$

$$\eta=\frac{\omega}{\alpha};\qquad \tau=\alpha t;\qquad \alpha=\sqrt{\frac{\mathrm{k}}{\mathrm{M}}};$$

$$q=\frac{F}{k};$$

2. The results of numerical simulations

It can be seen from the Fig.1 that in the range of symmetrical clearance, absorber limits free motion of the damper. The value of this clearance was matched with the damper oscillations amplitude in the range of forcing frequency η=1, for the damper and absorber not collide each other. It allows to take the advantages of the dynamic damper application. In the other frequencies, where the damper oscillations amplitude is high, there exist impacts. The energy dissipates as the result of impacts and also, depending on the relative velocity of damper and absorber before impact, energy transmits from damper to absorber or in opposite direction. It allows to decrease the main oscillator amplitude in the range of frequencies η_1 and η_2. The comparison between two resonance diagrams of the main oscillator displacement in cases with the dynamic damper and with the impact damper is shown on the Fig.2. The big effectiveness of the impact damper can be seen on it. The oscillations

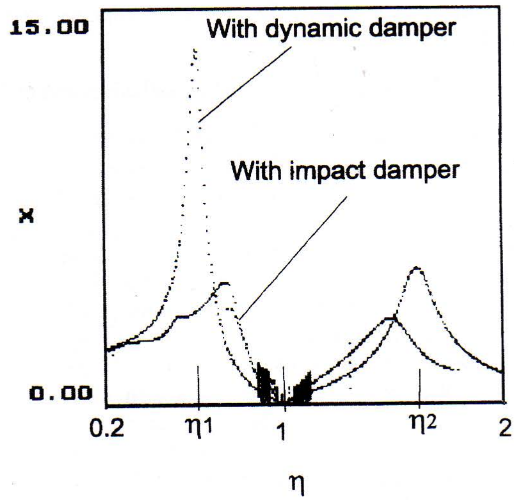

Fig.2. Comparison between two resonance diagrams

amplitude was decreased several times in the range of frequencies η_1, η_2. And, what is very important, it did not cause a big amplitude increase for the other frequencies. According to the earlier declaration for frequency η=1, oscillations amplitude was reduced to zero. The motion in almost the whole forcing frequency is regular. Unperiodic motions exist only in the frequency η=1 surroundings, but it is not of a big importance because of a little oscillations amplitude.

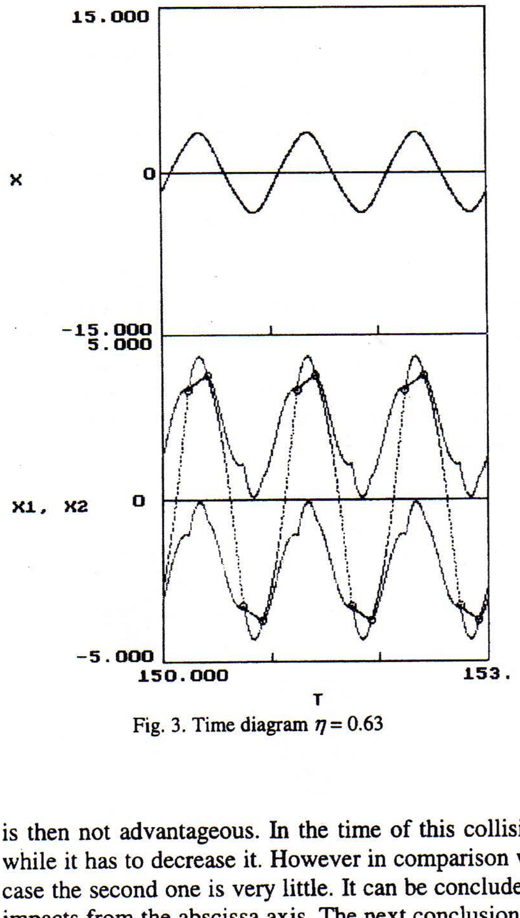

Fig. 3. Time diagram $\eta = 0.63$

The time diagram for frequencies lower than η=1 is shown on the Fig.3. For giving the reasons of amplitude decreasing the picked out frequency was $\eta = \eta_1 = 0.63$, where decreasing is very large. The motion is periodic with symetrical impacts in both the absorber stops. There exist four impacts during one forcing frequency period. For the same frequency the impact map of the new kind is shown on the Fig.4. There is the velocity of the damper on the horizontal axis and the velocity of absorber on the the vertical one. The picked out points are before and after impact. In order to make this map more clear there are points of the different impact kind only. As the choice criterion $v_1 > 0$ was applied. On the map there are two straight lines with equations $v_2=v_1$ and $v_2=-5/3*v_1$. It is very easy to prove that in case $\mu_1=\mu_2$ if before impact point is in the area $v_1> v_2>-5/3\times v_1$ then the energy flew in time of impact is from the damper to absorber. Therefore this is the area of effective working of the impact damper. On the Fig.4. it can be seen that one impact is in the effective area whilst the second is not. The second impact is then not advantageous. In the time of this collision absorber increases the damper energy while it has to decrease it. However in comparison with the amount of energy flew in the first case the second one is very little. It can be concluded from the velocity value before and after impacts from the abscissa axis. The next conclusion that can be drawn from the impact map is the state of damper-absorber system energy before and after impact. It allows to estimate the energy dissipation in the time of each collision. This dissipation is put into the mathematical model of the system over the restitution coefficent r=0.5. The amount of energy dissipation depends on this coefficent and on the relative velocities of damper and absorber before impact. In case $\mu_1=\mu_2=1$ the energy of this system equals the half of the radius of the circle with the center in beginning of the coordinate system on which the point lies. Comparing the before and after impact radius energy dissipation can be found. From the map it can be seen that for the frequency η_1 in each impact case about 25% energy of the damper-absorber system is dissipated. Concluding from the energy flew and its dissipation for forcing frequency η_1 the reasons for the impact damper effectiveness can be seen.

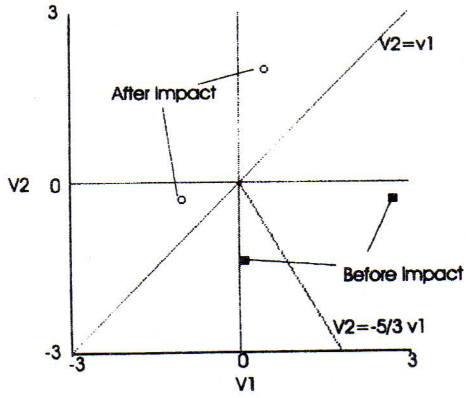

Fig. 4. Impact map $\eta = 0.63$

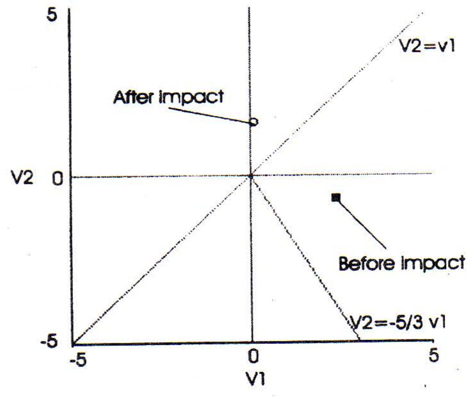

Fig. 5. Impact map η=1.63

In the range of the forcing frequencies higher then η=1 the motion of the system is periodic with two symetrical impacts of the damper against two absorber stops in time of one force period. The impact map for frequency $\eta=\eta_2$=1.63 is shown on the fig.5. The impact points lie in the effective area of impact damper working so it means that the of energy flows from the damper to absorber during each collision. In addition during the time of each impact the damper-absorber system dissipates about 35% its energy. And in result of this flew and dissipation the main oscillator amplitude decreases to the very low level.

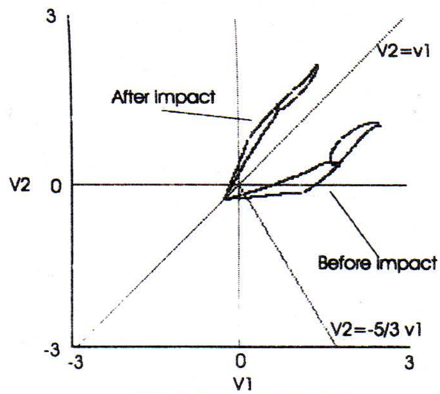

Fig. 6. Impact map η=0.9

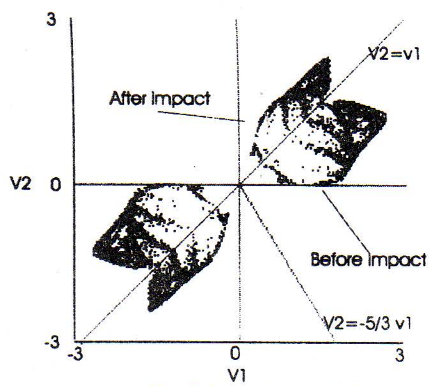

Fig. 7. Impact map η=1.1

The transitions from the system with impacts to the system without impacts and conversely are automatic. They can be seen on the Fig.2 in the η=1 surroundings. Theese transitions are preceded by nonperiodic motions. During the first transition there exist the quasi-periodic motions. The impact map in this case is shown on the Fig.6. If the system is started from two different initial conditions after some periods of its force it achieves the same phase of motion. There is one special point on the map. It is the common point of the before and after impact atractors. It lies on the line $v_2=v_1$ and there is just one point like this. This is the kind of impact with very low relative velocities, and the before and after impact velocities are almost the same. That is the cause for the quasi-periodic motion existance. The same phenomena can be seen on the Fig.7 which shows the transition motion from the system without impacts to the system with impacts. This kind of impact is called the low velocity impact and in this case it is the cause of chaotic motion existance. On the Fig.7 there can be seen more points of this kind. There exist some phases of the system motion where absorber and the damper are very close each other but their relative velocity is almost zero so the contact ensues or does not. This is the so called grazing bifurcation phenomena.

The final effect of the oscillations amplitude reduction is shown on the Fig.8. It is the comparison between two main oscillator resonance diagrams. One of them shows the amplitudes of the main oscillator without any damper, the other shows the amplitudes with the impact damper which was presented. It can be seen that this kind of damper is very effective in very wide frequency range. Just for the under resonance frequencies in the range of $\eta=\eta_1$ oscillations amplitude of the system with impact damper is larger than without the damper.

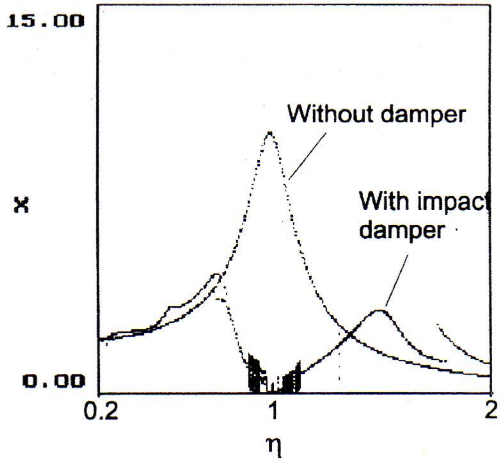

Fig.8. Comparison between two resonance diagrams.

3. Conclusions

It was shown that it is possible to join the impact and the dynamic damper and to match such values of the system parameters that the advantages of each of them can be taken. In almost all the frequency range amplitude was reduced, motion was periodic. In the range of $\eta=1$ the impact damper switched automaticly in to the dynamic damper which is the most effective in this range. It was shown that using the new kind of impact map the energy flew and dissipation can be observed what is very important in the impact dampers design.

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