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THE REPLACEMENT OF THE PENDULAR DYNAMIC ABSORBER WITH A ROTATING MASS

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Abstract: *The paper aims to study from a theoretical point of view the replacement of a pendulum dynamics absorber with a rotating mass which develops the same dynamic effect as the dynamic absorber. The dynamic absorber is an oscillating system which is attached to a structure in order to eliminate its vibrations. In practice, they are used to reduce the torsion vibration amplitudes of crankshafts.*

. **Key words:** *dynamic absorber, rotating mass, torsion vibrations.*

1. INTRODUCTION

The dynamic absorbers represent one of the means of reducing vibrations and they have multiple usages in technology. Several studies aimed to find an increase in the efficiency of the dynamic absorber by improving design methods or by optimizing the various parameters. By adding a dynamic absorber to a device, the primary system's degrees of freedom increase by a unit and thus the resonance curve is modified. If the parameters of the dynamic absorber are properly chosen, the resonance curve of the system composed of primary system and absorber has a minimum declared value in a frequency area in which the primary system has only one maximum. Thus there is a significant damping in the primary system vibrations in the vicinity of its resonance.

Usually, the dynamic absorber is superior to any isolation system because it can be easily tuned so that it works in the range of the frequencies that need to be eliminated. Using a dynamic absorber is recommended when the intrinsic frequency of the primary system is close to the frequency of the disruptive forces.

From a practical point of view, the dynamic absorber acts on the primary mass with a force which bears the same frequency as the disruptive force only in the opposite direction.

This is why it can be used to reduce unbalanced forces which appear in the functioning of various machine parts.

The dynamic absorber can be designed at the same time with the structure whose vibrations must be eliminated or can be added later on. Also, it can act upon the entire structure or can be attached to the element whose functioning produces vibrations in the overall structure.

The dynamic absorber is also used to reduce the amplitude of the torsion vibrations in the case of crankshafts. This aspect is taken into account when replacing the pendulum dynamic absorber with a rotating mass. According to the studies presented in previous papers, in the case of two, three, four and five reduced masses with a dynamic absorber attached, the dynamic absorber does not increase the number of resonance events, irrespective of the order of the harmonica which produces the forced vibrations.

The crankshaft of a piston engine forms an oscillating system together with the mobile pieces attached to the shaft.

In this case, the crankshaft is acted upon with periodical forces that are produced by the pressure of the gasses in the cylinders acting upon the pistons and by the inertial forces of the moving masses belonging to the mobile parts. Under such periodical forces, the crankshaft executes torsion and bending oscillations.

The amplitude of the torsion oscillations can become dangerous when resonance occurs, that is when the rotation of the shaft becomes equal to one of the critical rotations. However, only a part of the extremely large spectrum of critical rotations can cause an unacceptably high amplitude in the torsion oscillations.

2. THE DYNAMIC STUDY OF THE MECHANICAL SYSTEM

This chapter will demonstrate that a pendulum dynamic absorber can be replaced with a rotational mass which develops exactly the same dynamic effect as the pendulum dynamic absorber (fig.1).

The dynamic pendulum absorber is used to reduce the torsion vibrations in crankshafts. To show how these absorbers work, we take a circular mass rotating at a constant angular speed ω_o with a mass m and length l pendulum attached in point N. The distance from suspension point N to the rotational axis of the disc has been marked with L.

The inherent pulsation of the pendulum is expressed by:

$$\omega_p = \sqrt{\frac{L}{l}} \cdot \omega_o \qquad (1)$$

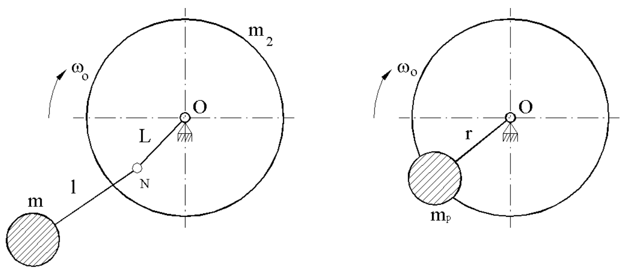

Fig.1 Pendulum dynamic absorber can be replaced with a rotational mass

The rotating mass m_p is constant for a certain order x of the harmonica of the periodic disruptive force which acts on the mechanical system but changes the value according to the x order.

We take a circular disk that constitutes on eof the reduced masses obtained by the reduction operation from a crankshaft which rotates around a fixed axis with an angular constant speed ω_o gone over by a vibratory torsion movement with the elongation φ_2 (fig.1).

The mass of the disk has been marked with m_2. Instantaneous angular speed is thus equal to:

$$\omega_o + \frac{d\varphi_2}{dt} = \omega_o + f(t) \qquad (2)$$

In (2) ω_o represents the rotation angular speed of the disk and φ_2 an angle that varies in time.

We adopt the Cartesian system of reference Oxy that is represented in figure 2 to which we mark the coordinates of mass m, assimilated with a point-size mass placed in its gravitational centre that coincides with its symmetry centre.

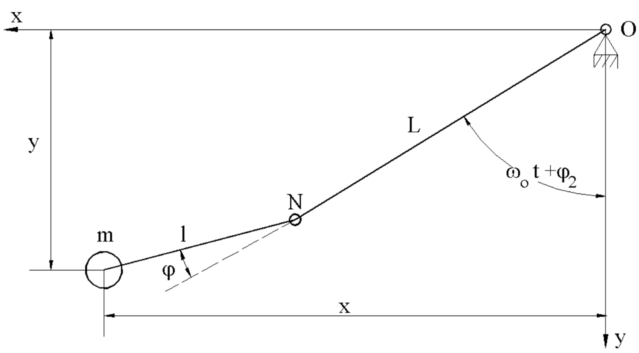

Fig. 2. Cartesian system

$$x=L\cdot\sin(\omega_o t+\varphi_2) + l\cdot\sin(\omega_o t+\varphi_2+\varphi)$$
$$y=L\cdot\cos(\omega_o t+\varphi_2)+l\cdot\cos(\omega_o t+\varphi_2+\varphi) \qquad (3)$$

By a double deviation in connection to the time of expressions (3) we obtain the expressions of the component of the acceleration of the mass m marked on the axes Ox and Oy.

$$\ddot{x} = - L(\omega_o+\dot{\varphi}_2)^2\cdot\sin(\omega_o t+\varphi_2)+ L\,\ddot{\varphi}_2\cdot\cos(\omega_o t+\varphi_2) – l\cdot(\omega_o+\dot{\varphi}_2+\dot{\varphi})^2\cdot\sin(\omega_o t+\varphi_2+\varphi) + +l(\ddot{\varphi}_2+\ddot{\varphi})\cdot \cos(\omega_o t+\varphi_2+\varphi)$$

$$\ddot{y}=-L\cdot(\omega_o+\varphi_2)^2\cdot\cos(\omega_o t+\varphi_2)-L\cdot\ddot{\varphi}_2\cdot\sin(\omega_o t+\varphi_2) – l\cdot(\omega_o+\dot{\varphi}_2+\dot{\varphi})^2\cdot\cos(\omega_o t+\varphi_2+\varphi)-l(\ddot{\varphi}_2+\ddot{\varphi})\cdot \sin(\omega_o t+\varphi_2+\varphi) \qquad (4)$$

We multiply the Cartesian components of the acceleration of the mass m with (-m) to get the carthesian components of the inertial force corresponding to the mass m, which presents four components:

1) $mL(\omega_o+\dot{\varphi}_2)^2$ parallel with ON ;
2) $-mL\cdot\ddot{\varphi}_2$ perpendicular on ON;
3) $ml\cdot(\omega_o+\dot{\varphi}_2+\dot{\varphi})^2$ parallel with Nm;
4) $-ml\cdot(\ddot{\varphi}_2+\ddot{\varphi})$ perpendicular on Nm.

These four components of the inertial force form the axial force that, together with the axial force that is produced in the shaft the Nm of the dynamic pendular absorber, a system of forces in dynamic balance, so the resultant force of the four components of the inertial force must be directed align the axis of the shaft of the dynamic pendular absorber.

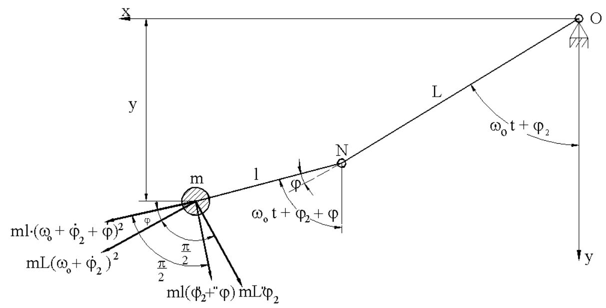

Fig. 3. Components of the intertial force

The four components of the inertial force will be designed on the symmetry axis of the shaft of the absorber, on a normal line to this axis and will be expressed the moment of the total intertial force corresponding to mass m in connection to the fixed centre O of the circular mass m_2 using figure 2 and figure 3.

Thus we have the relations:

$$S=Ml\cdot(\omega_o+\dot{\varphi}_2+\dot{\varphi})^2+ML(\omega_o+\dot{\varphi}_2)^2\cos\varphi-ML\cdot\ddot{\varphi}_2\sin\varphi$$
$$0=-ML\cdot(\omega_o+\dot{\varphi}_2)^2\sin\varphi-Ml(\ddot{\varphi}_2+\ddot{\varphi})-ML\cdot\ddot{\varphi}_2\cos\varphi$$
$$M_o=SL\sin\varphi \tag{5}$$

When using the dynamic pendular absorbers, the angles φ and φ_4 are very small and therefore we can adopt this aproximation range

$$\varphi \ll 1; \quad \varphi_2 \ll 1; \quad \sin\varphi\cong\varphi; \quad \cos\varphi\cong 1;$$
$$\varphi\varphi\cong 0; \quad \varphi_2\varphi_2\cong 0; \quad \varphi\varphi_2\cong 0 \tag{6}$$

Taking into account the aproximations (6), the last relations (5) become:

$$\begin{aligned} 0 &= l\ddot{\varphi}+L\omega_o^2\varphi+(L+l)\ddot{\varphi}_2 \\ M_0 &= m(L+l)\omega_0^2 L\varphi \end{aligned} \tag{7}$$

Because the angle φ shows a harmonic variation will be noted:

$$\varphi = A\cdot\cos(\Omega_x t-\varepsilon) \tag{8}$$
$$\ddot{\varphi} = -A\Omega_x^2\cos(\Omega_x t-\varepsilon) = -\Omega_x^2\varphi \tag{9}$$

(9) is introduced in (7) and thus we obtain:

$$-l\Omega_x^2\varphi+L\omega_o^2\varphi+(L+l)\ddot{\varphi}_2=0 \tag{10}$$
$$\varphi=-\ddot{\varphi}_2\frac{L+l}{L\omega_o^2-l\Omega_x^2} \tag{11}$$

(10) is introduced in (7) and we obtain:

$$M_o=-m\ddot{\varphi}_2\cdot\frac{(L+l)^2}{1-\frac{l}{L}\cdot\frac{\Omega_x^2}{\omega_o^2}} \tag{12}$$

or : $$M_0=-m\ddot{\varphi}_2(L+l)^2\cdot\frac{\frac{L}{l}}{\frac{L}{l}-\frac{\Omega_x^2}{\omega_o^2}} \tag{13}$$

respectivelly:

$$M_o=-m\ddot{\varphi}_2(L+l)^2\cdot\frac{\frac{L}{l}}{\frac{L}{l}-x^2} \tag{14}$$

In addition, the harmonic x pulsation is expressed with

$$\frac{\Omega_x^2}{\omega_o^2}=x \tag{15}$$

where x represents the order of the harmonic, that is the number of oscillations that the harmonic executes in a time T_0, in which the shaft executes a complete rotation of 2π rad, and ω_0 is angular constant speed of rotation oforthe reduced crankshaft

For the rotating mass m_p, to be equivalent from a dynamic point of view with the pendulum dynamic absorber, the following requirement has to be met:

$$-m_p r^2 \cdot \ddot{\varphi}_2 = M_o = -\ddot{\varphi}_2 m (L+l)^2 \cdot \frac{\frac{L}{l}}{\frac{L}{l} - x^2} \quad (16)$$

Results the expression of the rotating mass m_p:

$$m_p = m \cdot \frac{(L+l)^2}{r^2} \cdot \frac{\frac{L}{l}}{\frac{L}{l} - x^2} \quad (17)$$

3. CONCLUSION

The relation (14) shows that the value of the rotating mass m_p is independent from the angular speed ω_o, but depends on the value of the x order of the harmonica of the disruptive force applied to the mechanical system.

For the case in which $x = \sqrt{\frac{L}{l}}$ results that $m_p \to \infty$, a situation which should be avoided.

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ÎNLOCUIREA ABSORBITORULUI DINAMIC PENDULAR CU O MASĂ ROTATIVĂ

Rezumat:

Lucrarea de faţă îşi propune sa studieze, din punct de vedere teoretic, înlocuirea unui absorbitor dinamic pendular cu o masă rotativă care dezvoltă acelaşi efect dinamic ca şi absorbitorul dinamic. Absorbitorul dinamic este un sistem oscilant care se ataşează unei structuri în vederea eliminării vibraţiilor acesteia. Ca şi aplicaţii se are în vedere reducerea amplitudinilor vibraţiilor de torsiune a arborilor cotiţi.

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