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ROLLER VIBRATION ABSORBER FOR HELICOPTER MAIN ROTOR HUB

by

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WSK PZL SWIDNIK CO.
(POLISH AVIAT.WORKS)

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1.ABSTRACT

During the first flight of PZL-Sokol helicopter equipped with a main rotor composed of 4 epoxy-glass lades,it was found out,that the level of loads on the rotor head arms, as well as the level of vibration inside the helicopter cabin, were alarmingly high. Modification made in the blade construction /tunning natural frequency reduced the loads on the rotor head arms but the vibration level inside cabin remained exceptionally too high and increased with flying speed.

Through analysis it was found that use of a dynamic vibration absorber in the rotor head should reduce the vibration to the level not exceeding the relevant standards and regulations. It was decided to add to the main rotor head a dynamic roller vibration absorber of the Solomon type so far it seems to be the only construction of this type which works succesfully on the serial helicopter. The absorber works successfully within entire range of operating conditions. This paper covers the progress in development of absorber. The attention is paid mainly to tests and measurements.

2.NOTATION

R - distance from center of rotation to center of arm bushing, [m].
D - diameter of arm bushing, [m].
d - diameter of roller, [m].
m - mass of roller, [kg].
Φ - hub rotational angle, [rad].
α - roller degree of freedom, [rad].
I_o - roller moment of inertia, [kgm^2].
x_h, y_h - hub coordinates,[m].
ω - rotor angular speed, [rad/sec].
β - measured angle of roller position, [rad].
γ - roller spin, [rad].
$e = (D - d) / 2$ [m].
N - number of rotor blades.
P - per one revolution.

3. INTRODUCTION

In Poland, the first dynamic wibration absorber was installed on the helicopter main rotor hub in 1950. It was of bifilar type and fulfilled its role successfully.

This paper relates to PZL-Sokol helicopter equipped with one 4-blade fully articulated main rotor with blades made entirely of epoxy-glass composites.

The maximum helicopter take-off is 6400 kg. The helicopter is designed, constructed and tested in Transportation Equipment Factory PZL-Swidnik.

During the first flight of the helicopter, it was found out, that in hovering, vibration level inside cabin as well as in other points of the fuselage was within expectations. Vibration started however to increasing with forward speed and reached hazardous level at high speed. The diagram in /Fig.1/ illustrates the problem.

One the basic of numerical analysis it was found that vibrations were excited by forces perpendicular to the rotor shaft axis. The results of the computation were verified by means of strain gauge measurement of share forces and bending moments along the rotor shaft lenght. Special attention was paid to the determination of natural frequencies and the corresponding modes of helicopter vibration. One frequancy was almost equal to the /4P/. The resonanse of the frequancy /4P/ appeared. The change of rotor shaft angular speed gave positive but still insufficient results. However, such a change may cause the worsening of the helicopter characteristic. Therfore, most attention was devoted to the application of the rotor head vibration absorber. To solve the problem, it was decided to use the absorber of the roller type, /Fig.2/ so far never used on the other helicopters. It was proved, quite properly. It has a number of advantages when comparing it to absorbers of the bifilar type used commonly.

4. MATHEMATICAL MODEL OF ROLLER ABSORBER

Fig.3a illustrates scheme of the dynamic model that was applied to describe the roller diceplacement. It is convenient to describe the roller movement using the Lagrange's secund order equations. When the roller rotates withaut slip, position of the roller center inertia coordinate system (x,y) is determined by the relations:

$$x = R\cos\Phi + e\cos(\Phi+\alpha) + x_h$$
$$y = R\sin\Phi + e\sin(\Phi+\alpha) + y_h \qquad (1)$$

The roller kinetic energy for the inertial system (x,y), is expressed as

$$E_k = \frac{1}{2} m\,[\dot{x}_h^2 + \dot{y}_h^2] + \frac{1}{2} I_o\,[\dot{\phi}^2 + 2\frac{e}{d}\,\dot{\alpha}^2] \qquad (2)$$

By substituting (2) to Lagrange's equation, the equation decribing movement of the roller and rotor hub center, is obtined.

$$[4\,\frac{I_o}{m}\,(\frac{e}{d})^2 + e^2]\,\ddot{\alpha} + Re\,\dot{\phi}^2\sin\alpha - \ddot{x}_h e\sin(\phi+\alpha) + \\ + \ddot{y}_h e\cos(\phi+\alpha) + (e^2 + R\,e\cos\alpha + \frac{I_o}{m}\,2\,\frac{e}{d})\,\ddot{\phi} = 0 \qquad (3)$$

Assuming constant angular velocity of the rotor shaft:

$$\dot{x}_h = 0\ ,\quad y_h = 0\ ,\quad \dot{\phi} = \omega = \text{const.},\quad \sin\alpha \approx \alpha \qquad (4)$$

simplified linear equation of the roller movement is obtained:

$$[4\,\frac{I_o}{m}\,(\frac{e}{d})^2 + e^2]\,\ddot{\alpha}\,R\,e\,\omega^2\,\alpha = 0 \qquad (5)$$

Hance, natural frequency of the roller movement is:

$$\Omega = \omega\sqrt{\frac{R}{e}}\;\sqrt{\frac{1}{1 + 4\,\frac{I_o}{m\,d^2}}} \qquad (6)$$

In the equations (3) and (5), damping is neglected. It may have essential influance on the roller movement, and hance, efficiency of the absorber. In Ref.[1,2,3,4] one can find more information about mathematical models of absorbers,both roller and bifilar type. The nature of the damping forces is difficult to evaluate in theoretical way, especially for the absorber of such type. Therefore the attention was paid mainly to laboratory experiments and flight tests.

5.DETERMINING OF THE ABSORBER DIMENSIONS.

The main dimensions of the absorber were determined on the basis of the formula (6), assuming that the natural frequency equals to (3P).The inertia force produced by rollers must compensate the harmful force that excites vibration. The maximum value of this force was determined during flight with V_{max} and during landing approach. During the absorber work, the roller must roll without slipping inside the crank bushing. The roller rotation was determined by value of α /Fig.3a/.

The force produced by the absorber increasas with angle α..However, the angle α cannot exceed some value because slipping appears between the roller and bushing and the absorber loses its features. By means of many exsperiments it was determined, that the angle α should not exceed 30°.

6.MEASUREMENT OF KINEMATIC PARAMETERS

Measurement of the roller displecement was carried out by means of the system whose simplified scheme is illustrated in Fig.3b. By means of two micropotentiometers A and B connected together with telescopic arm, the roller spin angle γ_{meas} and the roller displacement angle β were measured. With maintaining the condition where no slip occurs during rolling, the angle γ_{theor} and β are related to each other, according to geometrical relation

$$\gamma_{theor} = \beta[(2e/d)+1] + (2e/d)\arcsin[(2r/d)\sin\beta] \tag{7}$$

The theoretical angle of the roller's spin γ_{theor} can be determined measuring the time history of β. The γ angle is measured by potenciometer B. Formula (8) exspress the

$$slip = \gamma_{theor} - \gamma_{meas} \tag{8}$$

value and sign of roller slip.

7.ABSORBER TUNNING

Four sets of various diameter rollers were made. They ensured the absorber resonanse frequency within the limits of $(3P)^{+1\%}$. As a criterion for tunning the absorber, the amplitude of vertical acceleration in the cockpit of the /4P/ frequency was assumed. Additional criterion was the phase shifting between the rotor shaft bending moment (3P) and angle of roller displacement α. Fig 4. shows the measurement results for the sets used. On the basis of this and similar diagrams, the best roller set was selected. During flight tests, it seemed that at strong excitating force, when helicopter was approaching landing, the angle of roller displacement α exceeded 30° which resulted in roller slip. Fig.5 shows the diagram which illustrates the roller slip. To increase the absorber reaction force while maintaining small angle α, the absorber construction was changed by increasing length of its arms R. Respectively, other dimensions of the absorber were changed. The absorber having the following main dimensions $R = 450$ mm.,$d = 108.5$ mm.,$m = 7.89$ kg.,$D = 168$ mm. $I_o = 0.139$ kgm^2 worked withaut slip in all the flight conditions, which was confirmed by experiments. Fig.7 illustrates basic quantities characterising absorber efficiency.

8.FUNCTIONAL TESTS

The aim of the tests was examining the vibration damper for its race wear interwity and thate wear effect on the vibration damper operation efficiency. The wear measure were differences in the race geometry from the drawing dimensions and the efficiency operation measure were vibrations and loads in a selected helicopter places measured on the helicopter in flight after the determined vibration damper operation duration on a special stand. The stand driven with elec.motor was designed to simulate the vibration damper operation (rpm,vibration amplitude in the plane of revolutions, angular displacement of the rollers). Measurements of the vibration damper for effectiveness have been carried out for the same helicopter.The tests for three pieces of the vibration dampers were carried out. Each of the vibration dampers was operated on the test stand for 1500 hours and every 500 hours has been tested for appropriate operation in flight.The test results were pasitive.

9.FATIGUE TESTS

The purpose of the fatigue tests was establishing the fatigue life of the vibration damper components and the attachment of the vibration damper to the main rotor hub. Three types of the samples were used for the tests. The samples consisted of the original vibration damper components. Totally nine samples (three samples of each type) hare been tests. Loading spectrum was established baving on the inflight test results. Component of the lowest fatigue life was the disc (Fig.6).

10.PROPERTIES OF THE ROLLER ABSORBER

For compariason within the scope of research program, similar test were carried out for the bifilar absorber. Theoretical comparison of both types is described in Ref.[3]. Main dimensions of the both types differed slightly - weight of the roller type was 50 kg., and the bifilar one 56 kg. Operating efficiency of the either absorber was similar. However, production cost of the roller absorber was four times smoller then this for the bifilar one. The overall weight of the roller absorber, including covering elements, is less than 0.8% of the helicopter take-off weight.

The separate problem to be solved, was theselection of materials for the absorber rollers and crank bushing. By experiments the steel ensuring assumed fatigue life of this parts, was chosen. Proper operation of the absorber is influenced by some construction details of the rollers and crank bushing. These details are unique design which is patented.

The roller absorber is sensitive to the external conditions, particulary to water,oil,etc. Therefore, the rollers and crank bushing should be well protected from the environement.

11.CONCLUSIONS

1. According to experience gathered for several years, the roller absorber can be used on helicopter.
2. Production and repair costs of the roller absorber are lover then analogous costs related to the bifilar absorber one.
3. The roller absorber proves its efficiency comparable to that of bifilar absorber.
4. Weight of the roller absorber should not exceed 1% of helicopter take-off weight.
5. The functional and fatigue tests have confirmed the usefulness of the vibration damper choice for vibrations damping in the plane of rotation on the PZL-Sokol helicopter main rotor installed.

References

1. Zurakowski,B.,"A Vibration Absorber for a Hinged-Blade Helicopter Rotor", Prace Instytutu Lotnictwa, 93(2/1983) pp.3-78
2. Mouzakis,T.,"The Monofilar Dual Frequancy Rotor Hub Absorber" AHS Journal,October 1983,pp.22-28.
3. Pasley,P.R,and Slibar,A.,"Optimale Auslegung von Salomon Schwingungestilgern",Ingenieur Archiv,XXIV Band 1956,pp.182-187
4.Marthy,V.A., and Hammond,C.E.,"Vibration Analysis of Rotor Blades with Pendulum Absorbers", AHS Journal, January 1981, pp.23-29.

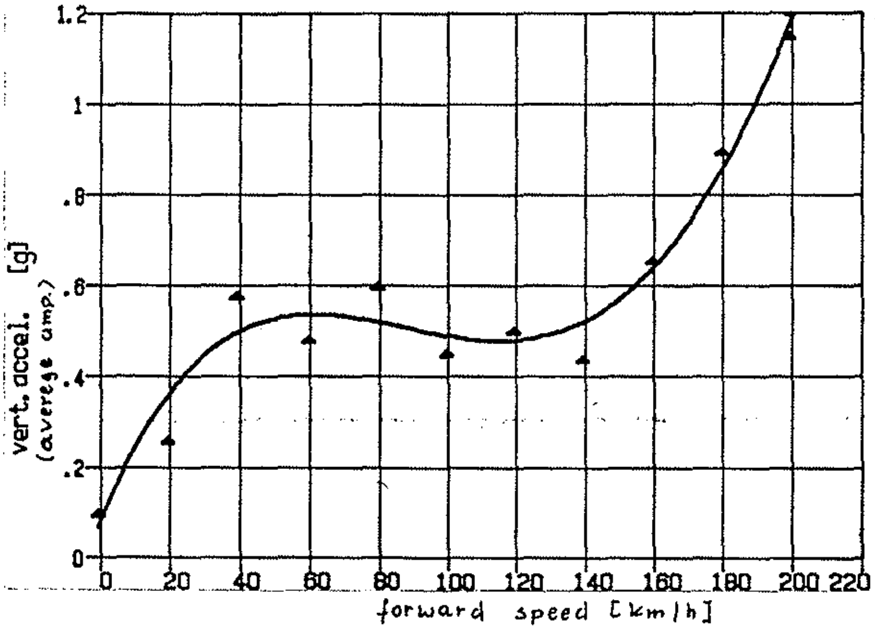

Fig.1 Level of vertical acceleration vs forward speed.

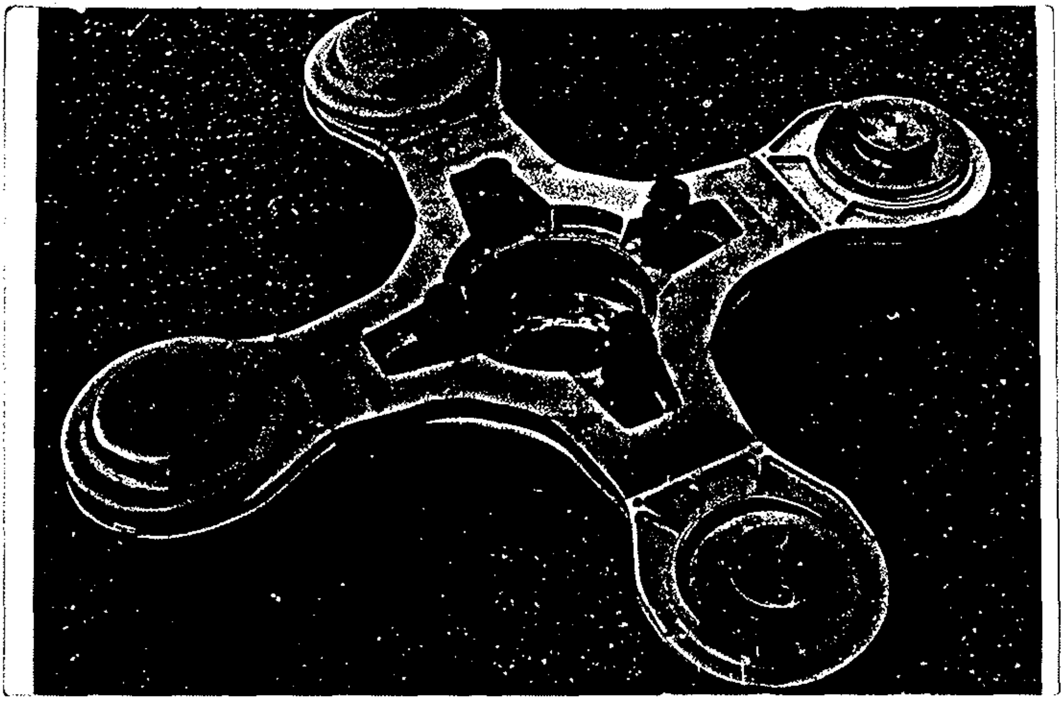

Fig.2 Roller type absorber of PZL-Sokol rotor hub.

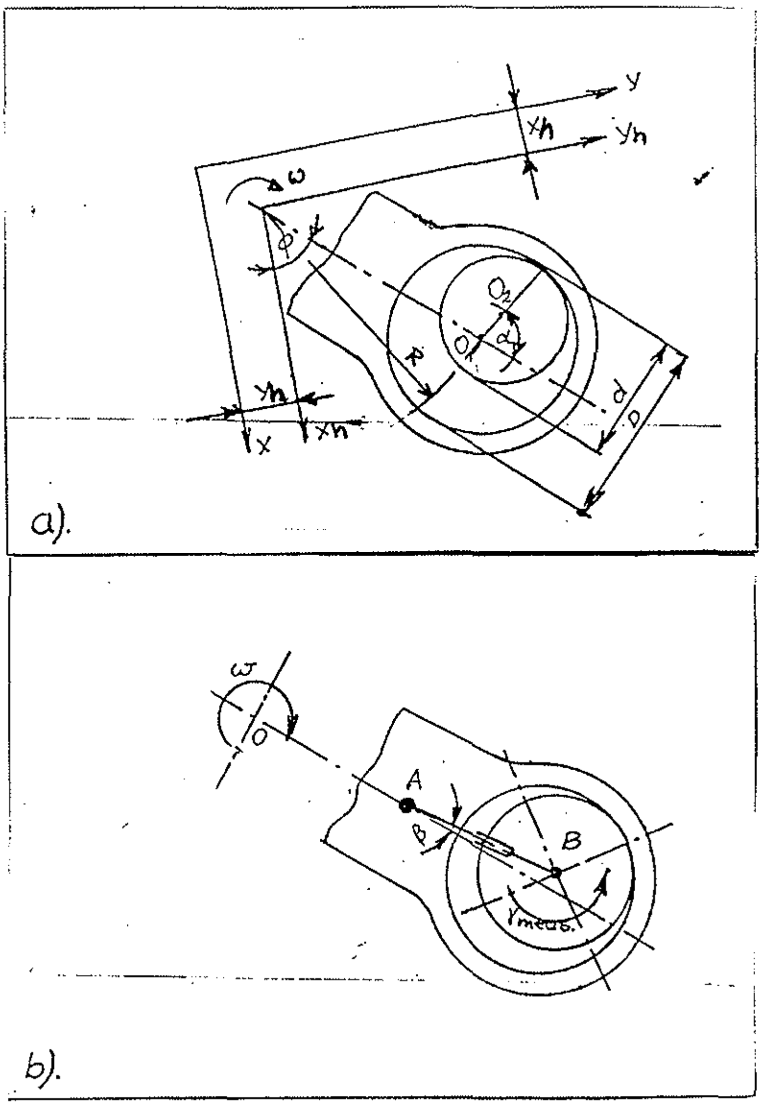

Fig.3 a) Dynamic model of absorber.

b) Scheme of system for measurement of roller displacement.

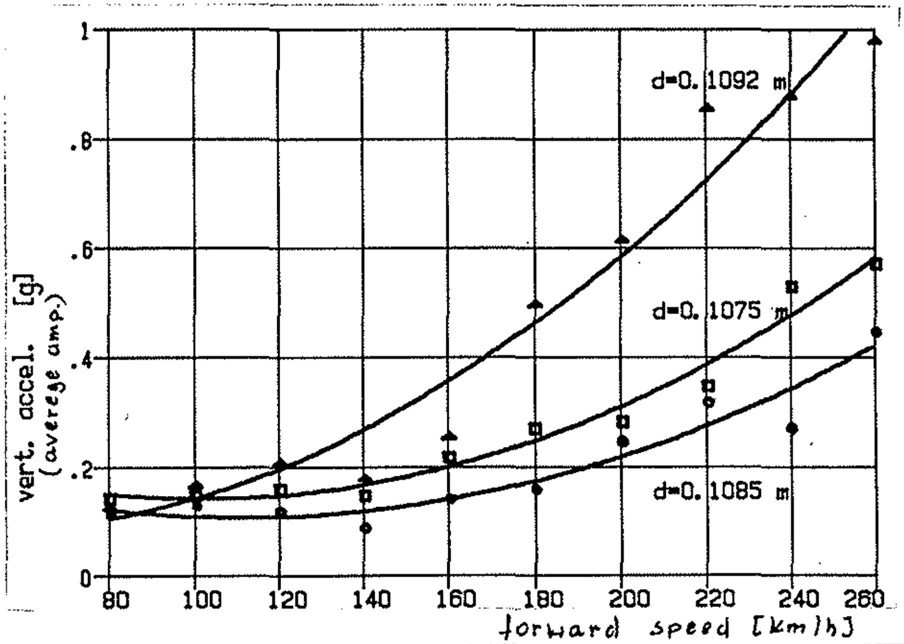

Fig.4 Level of cockpit vertical acceleration (4P) for various roller set vs forward speed.

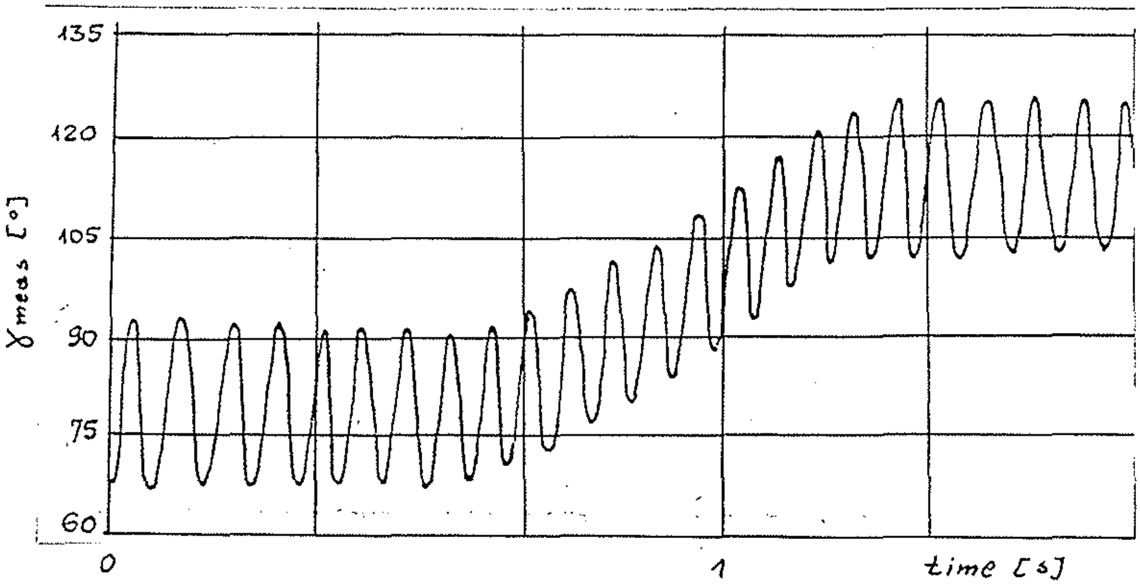

Fig.5 Fragment of record of the roller measured rotation angle $\gamma_{meas.}$, illustrating the slip.

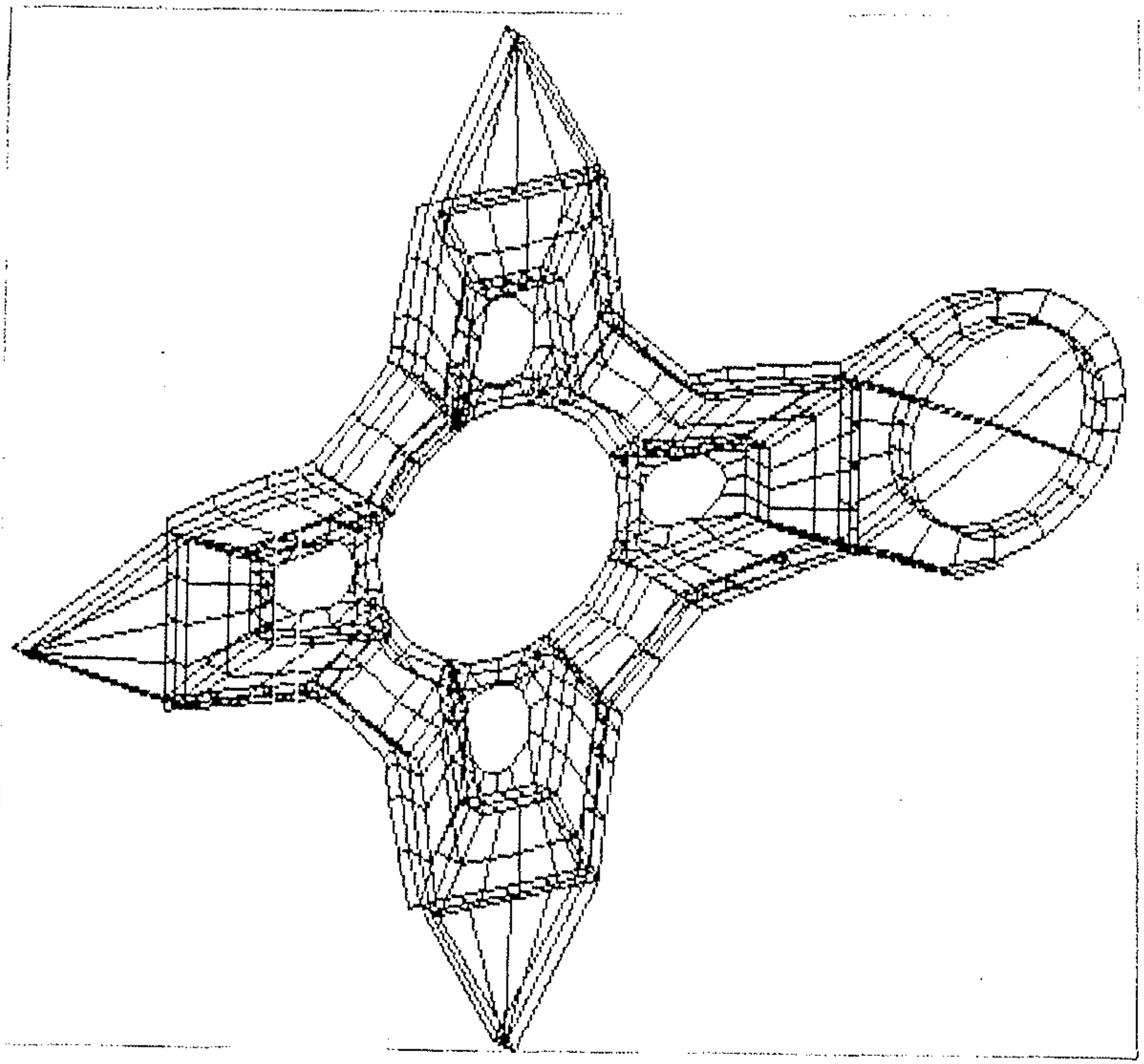

Fig. 6. Vibration absorber model used for stress calculation.

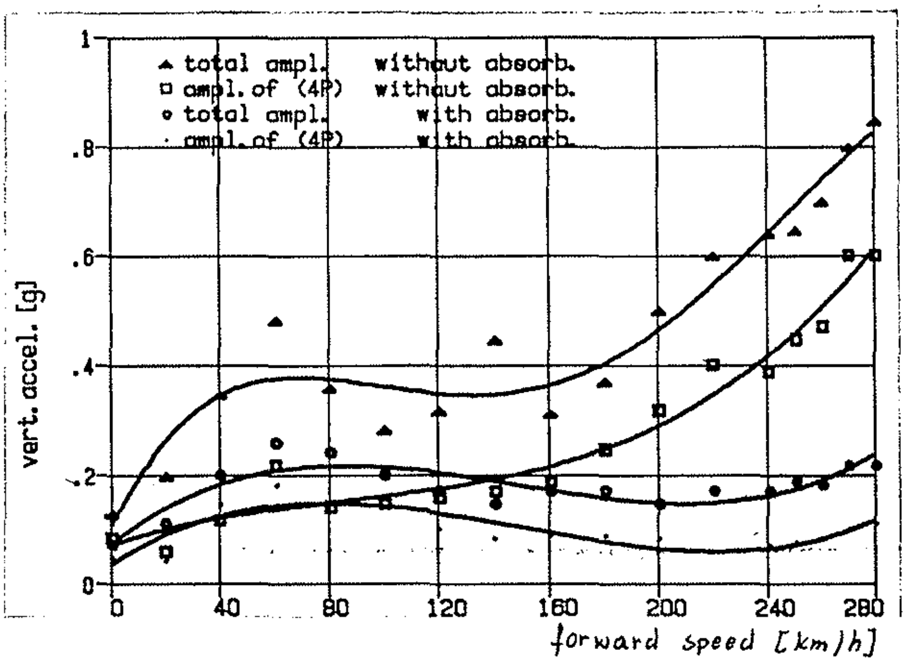

Fig.7 Amplitudes of vertical cockpit acceleration with and without absorber vs forward speed.