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ENERGY DISSIPATION OF AN ELASTOMERIC FRICTION DAMPER IN SUB-ZERO TEMPERATURES

Key word

Damper, elastomer, friction, research, temperature.

Abstract

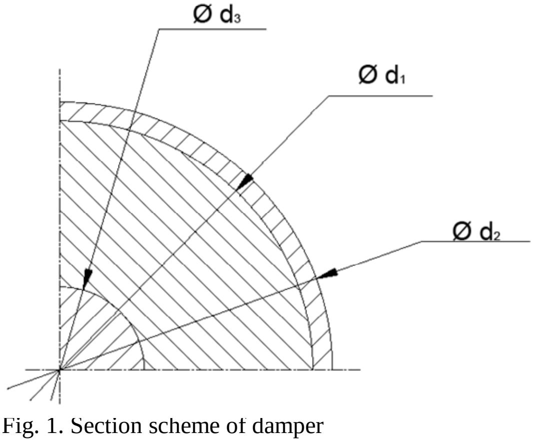
The impact of sub-zero temperatures on energy dissipation levels is very essential in Polish climatic conditions. Experimental research results (made on shimmy self-oscillation damper used in a landing gear of a small plane) show that energy dissipation level of an elastomeric friction damper (in opposition to hydraulic) is decreasing with dropping temperature. This situation is a result of significant differences in thermal expansion of materials, especially the specific elastomer feature – large thermal expansion (elastomer have thermal expansion about 50 times larger than steel). Simulation of damper work, using Finite Element Method, confirmed those dependencies. An estimation of the friction coefficient has been made between the elastomer and aluminium surface. It has been ascertained that those values are relatively small, from 0.13 initial moment declining to 0.085 then rising to 0.256.

Introduction

Significant changing of energy dissipation levels is a very important problem during the operation of a vibration damper (shock absorber) in the highly changing temperature condition of Polish climate. Hydraulic dampers have a high gain of energy dissipation levels in temperatures below 0 degrees Centigrade, and it is cause by the increase of the viscosity of fluid caused by dropping temperature. Elastomeric friction dampers may be the alternative, because they have a smaller sensitivity for changing working temperature. This article represents an assessment of temperature impact on elastomeric friction dampers used to damping shimmy oscillation that occurs in landing the gear of a small plane.

1. Energy dissipation level research of damper

The tests were made on damper applied on a Cessna areoplane – shimmy type, serial number P/N-SE-1069-2, and patent number 6,290,038, produced by LORD. The damper consists of a tubular aluminium case, an elastomeric friction part, and piston rod. The elastomer is rigidly fixed to the piston rod.



d_1 – elastomer diameter

d_2 – case diameter

d_3 – piston rod diameter

Fig. 1. Section scheme of damper

The research was done in the Institute of Machine Design Fundamentals (Warsaw University of Technology) in the Department of Mechanics Laboratory and also in the Institute of Fundamental Technological Research (Polish Academy of Sciences) in the Division of Experimental Mechanics. Figure 1 represents a record of the damper work cycle at 10 Hz frequency (typical range of damper work) at a temperature of -15°C. Figure 3 shows, for comparison, the same cycle at 25°C.

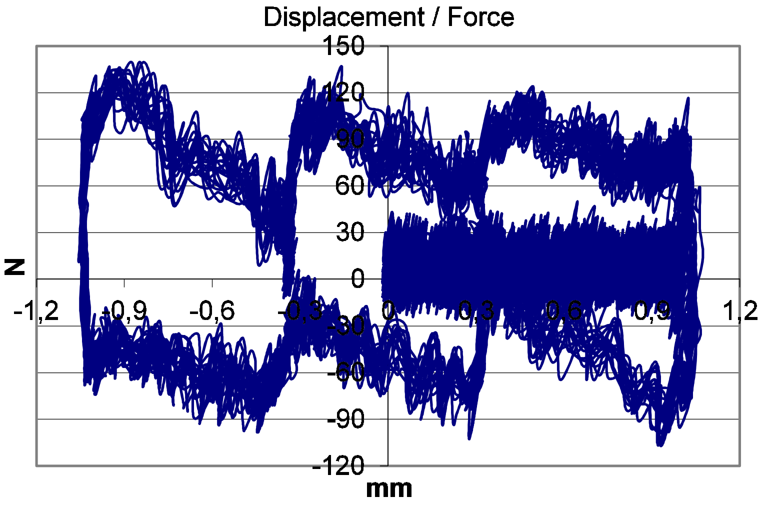


Fig. 2. Damper work cycle in -15°C temperature

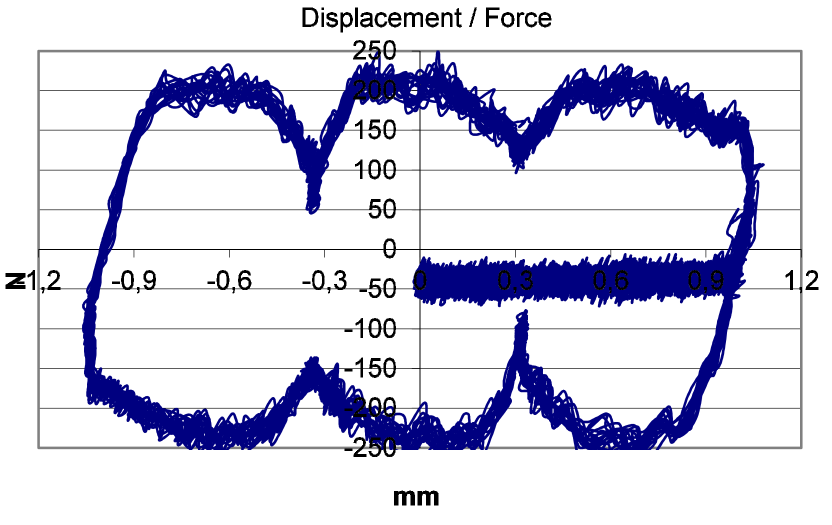


Fig. 3. Damper work cycle in 25°C temperature

The measure of dissipation energy is the area inside one cycle, and to assess this, a level amended program from work [1] was used. Dissipation energy amounted to 0.795 Nm in the plus temperature cycle, and below zero it was 0.305 Nm, which is 60% lower. It is noticeable that the elastomeric friction damper has a lower dissipation energy level below 0°C in opposition to the hydraulic damper. A lot of research conducted by the authors confirms that it is a very powerful dependence (the disparity of dissipation levels compound with increasing frequency). It was noticed that one cycle dissipation energy insignificantly grows with escalating frequency, and the dissipation energy in relation to time quickly increases with increasing frequency.

2. Temperature sensitivity analysis of elastomeric friction damper

The main cause of energy dissipation is friction between the elastomeric element and the inside surface of the casing of the elastomeric friction damper made of aluminium. Energy dissipation levels are dependent on contact pressure between those elements. Changes of dimensions, which have an impact on pressure, are caused by thermal expansion of materials.

Differences in coefficients of thermal expansion are very large. There are some average values, which are used in textbooks for example:

[2] steel – $12 \cdot 10^{-6} \frac{1}{K}$, aluminium – $22 \cdot 10^{-6} \frac{1}{K}$, elastomer – $600 \cdot 10^{-6} \frac{1}{K}$.

If we take the simple model casing, the axisymmetric elastomer and steel elements will be subject to temperature changes; therefore, we can calculate longitudinal strain using this formula:

$\varepsilon_{x1} = \alpha_1 \Delta T$ and $\varepsilon_{x2} = \alpha_2 \Delta T$, and for transverse strain:

$\varepsilon_{x1} = -\alpha_1 \nu \Delta T$ and $\varepsilon_{x2} = -\alpha_2 \nu \Delta T$.

Changes of transverse dimension can be calculate using the following formulas:

$$W_1 = -\frac{1}{2} \varepsilon \nu_1 \alpha_1 \Delta T d_1 \quad \text{and} \quad W_2 = -\frac{1}{2} \varepsilon \nu_2 \alpha_2 \Delta T d.$$

The difference of the above values is a measure of interference, and it can be compute with the following formula:

$$U \equiv (W_1 - W_2) = \frac{1}{2} \Delta T (\nu_1 \alpha_1 d_1 - \nu_2 \alpha_2 d_2).$$

If U takes the zero value, the whole system will be unaffected by changing temperature as follows:

$$\nu_1 \alpha_1 d_1 = \nu_2 \alpha_2 d_2.$$

Then calculation of case diameter is

$$d_2 = \frac{\nu_1 \alpha_1}{\nu_2 \alpha_2} d_1,$$

If numerical values are used

$$d_2 = \frac{0.499 \cdot 600 \cdot 10^{-6}}{0.34 \cdot 22 \cdot 10^{-6}} d_1 \cong 40 d_1 \tag{1}$$

It means that the damper casing must be 40 times wider than the elastomer element, and this is impossible to achieve because damper will be too heavy. In the case when we take all damper elements (Fig. 1), we can use the following formulas:

$$\mathrm{E}_{x1} = \alpha_1 \Delta T\,; \quad \mathrm{E}_{x2} = \alpha_2 \Delta T\,; \quad \mathrm{E}_{x3} = \alpha_3 \Delta T.$$

The very small strain, caused by rigid fix of elements 1 and 3, in transverse dimension evaluation was omitted. So the following formulas will be used:

$$W_1 = -\frac{1}{2} \nu_1 \alpha_1 \Delta T d_1,\ W_2 = -\frac{1}{2} \nu_2 \alpha_2 \Delta T d_2,\ W_3 = -\frac{1}{2} \nu_3 \alpha_3 \Delta T d_3$$

Interference U is calculate from

$$U = -(W_1 + W_3) - W_2 = \frac{1}{2} \Delta T (\nu_1 \alpha_1 d_1 + \nu_3 \alpha_3 d_3 - \nu_2 \alpha_2 d_2) \tag{2}$$

Taking a condition of zero value

$$\nu_1 \alpha_1 d_1 + \nu_3 \alpha_3 d_3 - \nu_2 \alpha_2 d_2 = 0,$$

$$d_2 = \frac{\nu_1 \alpha_1 d_1 + \nu_3 \alpha_3 d_3}{\nu_2 \alpha_2} = \frac{\nu_3 \alpha_3 d_3}{\nu_2 \alpha_2} + \frac{\nu_1 \alpha_1}{\nu_2 \alpha_2} d_1,$$

$$d_2 = \frac{0.3 \cdot 12 \cdot 10^{-6}}{0.34 \cdot 22 \cdot 10^{-6}} d_3 + \frac{0.499 \cdot 600 \cdot 10^{-6}}{0.34 \cdot 22 \cdot 10^{-6}} d_1, \text{ so } d_2 = 0.48 d_3 + 40 d_1.$$

The condition of zero value can be achieved by changing of dimensions – increasing d_3 diameter (inside steel shaft – piston rod) or leaving d_3 diameter (elastomer element) without modification. It is possible to fulfil these conditions with a change of casing material from aluminium or steel to plastic with a larger coefficient of thermal expansion. The analysis has a qualitative nature, and precise calculations require considering many nonlinear phenomena. It can be computed by numerical analysis.

3. Simulation using Finite Element Method

The Finite Element Method was used to analyse the elastomeric friction damper work cycle using the ABAQUS program. All nonlinear phenomena were taken into account, i.e. the contact problem with friction, the large deformation of the elastomer, and they were described by a reduced sixth order polynomial model. The model was made from cubic elements, and the calculation was made with retention of all Gauss points, without reduced integration. The damper was made as an interference fit. The external elastomer diameter is larger than the internal case diameter at first. The first stage is the simulation of making an interference fix (thermal or mechanical). Then stages of temperature changes and work cycles can be repeatedly made. This task requires the delineation of the thermo-mechanical problem with the possibility of changing temperature and tension. The elastomer was described by a reduced polynomial model, according to test result shown above, with the coefficient changing as a function of temperature function as in [3], a density of $200\frac{kg}{m^3}$, and damping proportional to the inert matrix with coefficient near 0 at 25^o C and increasing to a value of 1000 at -30^o C. Aluminium and steel was described as elastic materials. A simulation of pressing the roller fixed to the elastomer element was made, with an insert to zero point (work start). It is possible to assemble the damper by hand, and we presuppose that the damper was made that way, so we can acknowledge the obtained results as real values. The coefficient of friction was assessed by a comparison of obtained pressure values (average values on the surface) with figures from experimental research. The coefficient of friction was 0.13 at the start (speed 0), and decreased at low speeds. The minimum occurred at 0.008 m/s and had a value of 0.085. Next, the coefficient of friction increased, and at maximum speed (in the analysis was 0.2 m/s), it had a value of 0.256.

These coefficient of friction values will be used in further calculations. Executed examples confirmed the nature of the phenomenon noticed during experimental research, i.e. dissipation energy significantly recedes with lower working temperatures. This phenomenon can be considerably reduced by changing elements dimensions, according to analysis from Section 2, and it was validated by subsequent calculated examples.

In conclusion, it can be said that an elastomeric friction damper is a possible alternative to the hydraulic damper in appliances working in an environment with changing temperatures. It is possible to achieve more

regularity of the energy dissipation level in an environment with a high fluctuation of temperature. Using of this type damper can be especially advantageous in winter work conditions (sub-zero temperature).

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Rozpraszanie energii w tłumiku elastomerowo-ciernym w warunkach ujemnych temperatur

Słowa kluczowe

Tłumik, elastomer, tarcie, badania, temperatura.

Streszczenie

Problem wpływu ujemnych temperatur na zmienność poziomu rozpraszania energii w polskich warunkach klimatycznych ma ważne znaczenie. Przedstawione w pracy wyniki badań doświadczalnych (wykonane na przykładzie tłumika drgań samowzbudnych typu shimmy w podwoziu małego samolotu) pokazują, że tłumiki elastomerowo-cierne (w przeciwieństwie do hydraulicznych) charakteryzują się obniżaniem poziomu rozpraszania energii z spadkiem temperatury. Przyczyny takiej sytuacji wynikają ze znacznych różnic rozszerzalności cieplnej materiałów, w szczególności specyficznych cech elastomerów, istotna jest duża (około pięćdziesięciokrotnie większa od stali) rozszerzalność cieplna elastomerów. Symulacja działania tłumika wykonana Metodą Elementów Skoń-

czonych potwierdziła te zależności. Wykonano również oszacowanie wartości współczynnika tarcia pomiędzy elastomerem a ścianą wykonaną z aluminium – stwierdzono, że są to względnie małe wartości od 0,13 w chwili początkowej spadające do wartości 0,085 i następnie rosnące z prędkością do 0,256.