Experimental research and simulation of vibration isolation elements mounted within transport boxes

D Voicu¹, R M Stoica¹, R Vilau¹, and L Barothi¹
¹Military Technical Academy “Ferdinand I”, Bucharest, Romania
E-mail: daniela.voicu@mta.ro

Abstract. Military vehicles, destined either for transportation of goods and personnel, or for battle missions, move in most situations on unpaved roads. Average movement speed is limited by suspension performances, which have to ensure a constant contact between vehicle’s wheels and rolling track. Other factors with influence on minimum movement speed on heavy terrains (imposed by specific standards: STANAG - Standardization NATO Agreement) are represented by driver’s physical resistance and behaviour of goods when submitted to shocks and vibrations. For the driver’s comfort there can be used independent suspensions for chairs, but in case of transported goods is more difficult, especially when the cargo is fragile and expensive (communication equipment, radars, IT etc.). Therefore, it is very important to study means to reduce vibrations and shocks, using vibration damping materials. Experimental research conducted within present study aimed to analyse vibration isolation elements made of rubber, which have been mounted inside transport boxes. This solution is important to be interoperable and ensure a simplified version of logistics, with the use of containers or standardized transport boxes. Experimental tests aimed to determine material properties, which have not been provided by the manufacturer, and the results have subsequently been used for modelling-simulation of vibration isolation elements behaviour. Virtual model was validated by experimental research consisting in applying composed axial stresses to the analysed materials.

1. Introduction

Studying alternatives of vibration isolation elements, mounted within transport boxes is important due to widening and variation of transported equipment (telecommunications, radar, IT etc.) and it is necessary to develop by simulation and experimental research means to minimize vibrations amplitude, generated by the interaction between vehicle’s wheels and rolling track [1].

Due to the fact that vibration isolation elements used within present study are for military purpose and the manufacturer did not provide information about material properties, the article began by determining material characteristics with the use of experimental research and continued to simulate and test experimentally three vibration isolation elements, in static conditions [9].

The result underlined efficiency of usage regarding shocks and vibrations damping, which appear while moving on different road categories (road with obstacles, highways etc.).

2. Determining of vibration isolation elements behaviour when submitted to static or slow variation stress
2.1. Theoretical aspects

In figure 1 it is presented axial load diagram and deformation phases of a vibration isolation element which is solid round in cross section plane. Symbols used were: \( F \) – force operating on rubber element, with values between \( 0 \leq F \leq F_{\text{max}} \), \( (F_i) \) – intermediate values, \( h_0, h_i \) – initial height of rubber material and in deformation phase, respectively, characteristic to "i" load pace.

![Figure 1. Axial load diagram and deformation phases of a vibration isolation element made of rubber.](image)

For each load phase it can be determined the element’s area, considering constant volume, \( V_0 \), in which \( x \) takes values between \( x_0 \) - \( x_n \), \( V \):

\[
A = \frac{V_0}{h_0 - x}
\]  

(1)

For minor deformations \( (\varepsilon \leq 15\%) \), based on formula (1), it can be written Hooke’s law, which allows determining static longitudinal modulus of elasticity \( E_s \):

\[
E_s(x) = \left( \frac{k \cdot h_0}{V_0} \right) \cdot (h_0 - x)
\]  

(2)

where: \( k = F/x \) - stiffness coefficient of rubber element, considered constant [5].

2.2. Experimental research – determining of modulus of elasticity

The experimental research consisted in submitting to tests three types of elements with military destination series C554-4, belonging to three different hardness groups, noted ECS 12, ECS 13 and ECS 14. Testing procedure included three measurements for tension, compression, and tension-compression stress.

The force was applied with a sliding table press. For the measurement of actuation values it was used a TEDEA strain gauge with a maximum measurable value of 3000N, and displacement was measured with a W50 linear potentiometric sensor (figure 2). Signals have been acquired with IoTech StrainBook 616u system and there have been subsequently processed with the use of DasyLab software, version 12. Data frequency acquisition was 10 Hz, and the actuating force was applied for a period of 40 seconds.
Maximum deformation level adopted was around 30%. Also, deformation pattern of vibration isolation element is presented in figure 3.

Results obtained during tests conducted on element ECS 14 are presented in figure 4 wherefrom it can also be observed hysteresis phenomenon, due to internal friction of rubber. Variation of modulus of elasticity (according to formula (2)) is represented in figure 5. The curves have been plotted by 2 degree polynomial interpolation of measured data.

With the use of mean values it was determined the modulus of elasticity values according to formula 2. For significant results, in graphical representation depicted in figure 5 the variable adopted was relative deformation expressed as a percentage.

$$\gamma = -2.1637x^2 + 99.135x - 39.284$$

$$\gamma = -2.1903x^2 + 99.102x - 32.566$$

$$\gamma = -2.0032x^2 + 94.168x - 51.338$$

Figure 2. Measurement of static characteristic.

Figure 3. Measurements during compression (a) and tension (b) tests.

Figure 4. Measurement results in case of tension-compression of element ECS 14.
In figure 6 it is presented for all three vibration isolation elements, the variation pattern of modulus of elasticity depending on relative axial deformation of rubber.

2.3. Static axial-transversal stress of vibration isolation elements made of rubber

2.3.1. Theoretical aspects
Transport boxes are equipped with an inner frame (rack) which allows a safe fixing of equipment. Between exterior frame and inner box there are usually placed 8 vibration isolation elements, as depicted in figure 7.
During transport, the box is submitted to acceleration on three directions: longitudinal, transversal and vertical. Because only vertical direction is imposed in case of positioning the boxes within motor vehicles, all stresses in horizontal plane, on transversal and longitudinal direction, must be considered equal.

There are three separate situations, depending on the time variation of acceleration:
A. Static stress, corresponding to constant acceleration;
B. Vibration induces stress, corresponding to harmonic variation of acceleration;
C. Shock induced stress, corresponding to an impulse type variation of acceleration.

Within present article it was analysed behaviour of vibration isolation elements made of rubber in situation A, for constant acceleration. This functional phase corresponds to requests from aerial transport, for testing conditions which asserts acceleration values of \(8g\ldots10g\) \((g=9.81\ \text{m/s}^2)\) on all directions.

When inner frame is displaced after vertical direction, vibration isolation elements mounted on the side corresponding to movement orientation will be compressed, resulting in axial and transversal deformations of materials; all other isolation materials will be submitted to axial tension stresses and transversal deformations.

2.3.2. Modelling and simulation of static axial-transversal stress
With the use of Catia V5 software, it was modelled and simulated the transport box [7] by placing a rack at the interior, which was connected with the use of vibration isolation elements made or rubber [6].

Behaviour of vibration isolation elements was simulated by applying successive forces on all three directions and determining the inner frame displacement on the corresponding axis.

The force applied on Ox axis was 5600N.

As a result, due to elastic deformation of vibration isolation elements, the inner frame had a 22.724 mm displacement, figure 8a).

Similarly, the process repeated on cross section axis, namely Oy, by applying an equal force of 5600 N. It was observed a displacement of 22.928 mm. The simulation result is depicted in figure 8b).

In both simulation cases previously described, vibration isolation materials were submitted to axial stress due to a continuous changing distance between the rigid points of metallic structure, but also shear stress (in cross section) due to a displacement of axis between the inner and exterior casings.

By applying a 1800 N [8] force on longitudinal direction (Oz axis), it resulted a displacement of 26.804 mm. Therefore, the initial conclusion was that vibration isolation elements were only submitted to shear stresses, but just in case of small displacements. In this situation, the relative misalignment between the two casing’s axes can be ignored (figure 9).
In case of higher displacements, due to applying increased forces, vibration isolation elements were additionally submitted to tension. Therefore, it can be stated that there are mixed stresses on axial-transversal directions.

All simulations previously presented were performed by using data from ECS 14 rubber; similarly, there were realised simulations for all the other types of vibration isolation elements. Simulation part was realised considering simplified hypothesis. For example, modulus of elasticity was constant. In order to validate the models, there was subsequently performed experimental research for measuring displacement of inner casing due to a force applied on all three directions.

2.3.3. Experimental research
Experimental research aims to determine behaviour of vibration isolation elements [4] mounted within the transport box, in case of imprinting a force to the inner casing, on one of main direction of symmetry. The process consisted in applying a progressive force and measuring both the actuating value and displacement of inner box relative to exterior frame.
The applied force was measured with an S shaped 10 kN strain gauge, manufactured by TEDEA (Vishay branch office), and displacement of casings was measured with a W50 potentiometric sensor manufactured by MicroStrain company [6]. Position mounting of both sensors is presented in figure 10.

Signals of sensors were applied at entry point of a signal conditioning system and data acquisition, type IoTech StrainBook 616, managed with the use of DasyLab software, version 12.

The force was applied manually until it was reached the limit allowed by the vacant space between casings, determining a high stress on vibration isolation elements; the intensity of extreme load supported by the rubber can be observed in figure 11 considering that the force was applied in vertical direction.

**Figure 12.** Deformation of vibration isolation element in case of applying a longitudinal force.

In case of applying a force on longitudinal direction of inner frame, it was observed that shear force was the main stress due to the fact that axes of both casing remain parallel during displacement. Therefore, elastic material becomes S shaped, as depicted in figure 12.

**Figure 13.** Graphic display of data processing.

Measured data were processed by plotting on the same graph curves and polynomial interpolation of curves. By obtaining coefficients of polynomial regression, it allowed to extract mean of measured data and plot the resulting curve. Results can be observed from figure 13, where there are presented two of the tests.

There have been performed all phases mentioned above for all three vibration isolation elements, in each case considering three directions where the force was applied. In figure 14 are presented results in case of element ECS 14. From the analysis of force variation on longitudinal direction of casing,
when vibration isolation elements are more submitted to shear stress, the inner frame displacement is proportional with the force, thus resulting a linear variation.

![Figure 14. Measurement results in case of element ECS 14.](image)

By applying the force on vertical direction, there can be observed three characteristic areas.

In case of small deformations of vibration isolation elements [2, 3], characteristic to an inner frame displacement of 10…15 mm, the rubber had an increased stiffness, determining a rapid development of required force. This area is followed by a second section with a significant decrease of stiffness and the third segment, characteristic to more than 25 mm, stiffness increases once again.

This behaviour can be explained by the succession between tension-compression stress and shear stress, based on displacement of inner casing relative to exterior box.

Modelling-simulation analysis and experimental research regarding behaviour of vibration isolation elements which are mounted in transport boxes for sensitive equipment were conducted considering a constant acceleration, according to requirements of military standard STANAG 4370. By applying a force to the inner box where rubber elements are mounted, it is determined a frame displacement as well as deformation of vibration isolation elements.

In table 1 there are presented comparative data obtained from simulation and experimental tests.

| Element type | Force axis | Applied force, N | Applied force, mm | Difference, % |
|--------------|------------|-----------------|-------------------|--------------|
|              |            | Simulation     | Experimental     |              |
| ECS 12       | Vertical   | Oy 700         | 24.597           | 18.1         | 26.41   |
|              | Lateral    | Ox 700         | 24.628           | 24.3         | 1.33    |
|              | Longitudinal | Oz 400       | 25.708           | 25.0         | 2.74    |
| ECS 13       | Vertical   | Oy 1200        | 24.34            | 18.8         | 22.76   |
|              | Lateral    | Ox 1200        | 24.487           | 23.9         | 2.4     |
|              | Longitudinal | Oz 700       | 26.01            | 25.3         | 2.73    |
| ECS 14       | Vertical   | Oy 1400        | 22.724           | 19.5         | 14.19   |
|              | Lateral    | Ox 1400        | 22.928           | 30.1         | 23.83   |
|              | Longitudinal | Oz 900       | 26.804           | 26.5         | 1.13    |
3. Conclusions

From the modulus of elasticity variation analysis, based on specific deformation, results several conclusions of what can be mentioned:

a. Behaviour of vibration isolation elements is non-linear, both in case of compression and tension.

b. For small deformations, modulus of elasticity value is higher than for great deformations.

c. For all vibration isolation elements, modulus of elasticity is higher with 10%....16% in case of tension than in case of compression.

d. The analysis of all three vibration damping elements, made of different materials, underlined an increase of modulus of elasticity value with stiffness, in case of the entire range of deformations.

Depending on the axis, by applying a certain force value, there have been observed higher differences of inner box displacement, between simulation and experimental results.

Considering all graphs obtained from processing the experimental data and analysing differences presented in table 1, it can be concluded that results were caused by the process of applying force during simulation and experimental tests (simulation consisted in instantaneous imprinting of force and experimental tests were defined of a progressive force). Thus, there are emphasized anisotropy properties of rubber materials and very different dynamic behaviour than in quasi-static conditions.

During tests, the inner box was submitted to constant force, characteristic to a constant acceleration transmitted while transport and the values used for simulation and experimental research were $6g...8g$ ($g=9.81 \text{ m/s}^2$), which are not found in case of road transport (it is acceptable a maximum quasi-constant acceleration of $1g$). Nevertheless, military standards require tests with higher values of constant acceleration in order to cover situations of aerial transport.

4. References

[1] Copae I, Cazacu C, Lespezeanu I Dinamica autovehiculelor Editura Ericon pp 380 2006 ISBN (10) 973-87047-7-4

[2] John D F Viscoelastic Properties of Polymers 3th edition ISBN 0-471-04894-1

[3] Meyers M A, Chawla K K Mechanical Behaviour of Materials Cambridge University Press 2009 ISBN-13 978-0-511-45557-5

[4] Norman E D Mechanical Behavior of Materials Engineering Methods for Deformation, fracture and fatigue, 4th edition ISBN 10:0-273-76455-1

[5] Polidor B Sisteme elastice de rezemare pentru masini si utilaje Editura Tehnica Bucuresti 1990

[6] Ran Z, Liping Y, Baiguo L and Jing X Measurement of Truck Transport Vibration Levels in China as a Function of Road Conditions, Truck Speed and Load Level, Packaging Technology and Science pp 949-957 2015

[7] Richard G B, Nisbett J K Diseno en ingenieria mecanica de Shigley 8th edition McGraw-Hill Interamericana editores ISBN-10:970-10-6404-6

[8] Robert L N Diseno de maquinaria Sintesis y analisis de maquinas y mecanismo 4th edition Mexic ISBN 978-970-10-6884-7

[9] Stanag 4370 – AECTP 400 Method 401