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TECHNIQUE AND SOME STUDY RESULTS OF SHAPE MEMORY ALLOY-BASED DAMPING DEVICE FUNCTIONAL PARAMETERS

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Summary. *A damping device based on the shape memory alloy which was designed and manufactured has been described in the paper. The device consists of two preliminary stretched wires made of pseudoelastic NiTi alloy and two compressed springs, that ensure the wires tension. The pre-stretched wires made of SMA provide the reliability of the system and good damping properties, and the preliminary compressed springs provide the possibility of alternating load and the restoring of the device to its original position after removing the external load. Due to the structural parameters and pseudoelastic effect the device under consideration provides the self-centering force and good damping properties, and can be used for dynamic loads reducing on building and engineering structures. To stabilize the functional properties of SMA wires the device had been loaded for 50 cycles at frequency of 0,5 Hz and displacement amplitude of 5 mm. The technique of experimental study of functional characteristics of damping device on the servohydraulic test machine equipped with the automatic control and measuring data recording system has been developed. Force, the device piston rod displacement and SMA wires strain had been measured during the test. The dissipation specific energy at 0,1 Hz frequency was found to be almost proportional to the displacement amplitude increase of the device piston rod but the loss factor was insensitive to the displacement amplitude change within the range from 3 to 9 mm. These results are important for further calculations and modeling of the behavior of the device under cyclic loading.*

Key words*: damping device, shape memory alloy, pseudoelasticity, dissipation specific energy, loss factor, cyclic loading.*

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Problem statement. Shape memory alloys have been widely used in medicine [1, 2], aviation [3], mechanical engineering [4], construction engineering [5], [6, 7] due to their unique characteristics, namely the super elasticity effect and shape memory effect which are connected with direct and reversal austenitic-martensitic transformation under loading or temperature action.

Due to their superelastic properties appearing under temperature which is over the austenitic transformation completion temperature the shape memory alloys have been widely used for damping devices in construction to reduce the dynamic loading of building structures elements [8, 9], bridges [10, 11], under operational loading or earthquakes conditions.

Science and engineering development has required new higher standards of such essential structures safety, namely of the devices which will be used in them.

A design of damping device based on pseudoelastic shape memory alloy [12] and the calculation procedure of its strength and structural parameters [13] have been proposed by the authors in previous papers. The technique for the device serviceability testing, structural parameters calculations specification and further improvement of damping device should be developed and the device functional characteristics within wide range of frequency and loading amplitude should be studied.

The design of the developed and manufactured damping device, the technique and some results of its functional characteristics study have been described in the article under consideration.

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Analysis of the previous study results. There are some well-known shape memory alloy-based passive damping devices, for example with bunched wires as main functional elements in the systems of passive protection from the dynamic loading of building structures, which use both damping and self-centering possibilities as well. Taking into account the degradation of SMA functional properties under cyclic loading, namely increasing of residual strain under controlling of displacement or stress amplitude and decrease of superelastic stress hysteresis – deformation [14, 15], different methods are used to stabilize their characteristics [16]. In particular, this is so called «stabilization training» due to the previous tensile deformation or previous cyclic loading.

Paper purpose. The aim of the paper under consideration is to develop and test the technique of functional characteristics study of the designed and manufactured damping device equipped with preliminary stretched wires made of pseudoelastic NiTi alloy. The dependencies of hysteresis loop for the device («force» – «piston rod displacement») and SMA wires («force» – «wires strain») are to be obtained taking into account the displacement amplitude. They are very important for the structural parameters calculation specification and damping capacity improvement.

Problem setting. The offered damping device (Figure 1) includes an axis 1 with two side fixing systems 2 on it. Springs 3 and 4 are placed between these systems. The springs are separated by a central locking device 5, the side mounting systems are equipped with fastening sleeves 6 with apertures on which the cone 7 is placed with a conical sleeve 8, between which the 9 SMA wires are fixed.

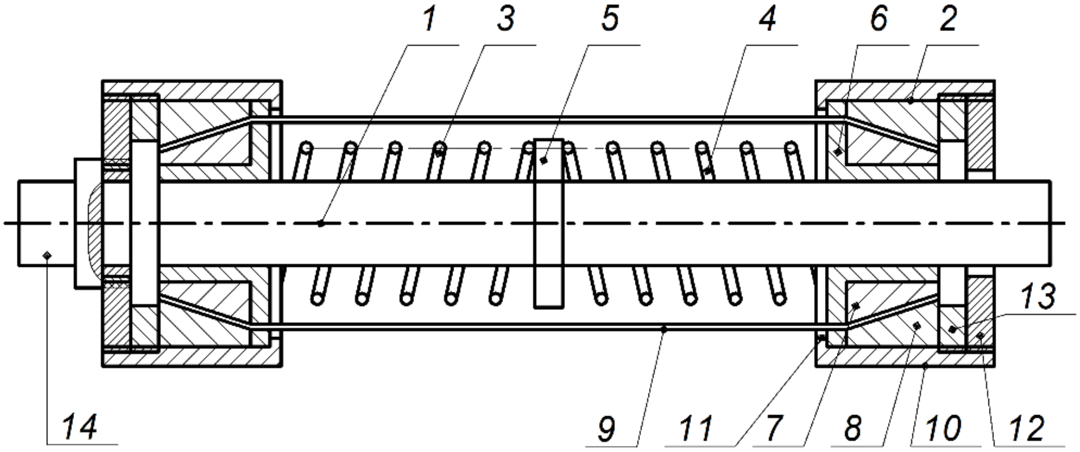


Figure 1. Scheme of the damping device [12]

Each side fixing system is equipped with a cylindrical cage 10 with an inner ring stop 11 on one side and an inner thread 12 on the opposite side, in which the threaded collar 13 is threaded pressing the conical sleeve through the intermediate washer. The threaded collar 13 of the left side fixing system is connected with the connecting rod 14.

The damping device under discussion has been designed and made on the basis of above-mentioned scheme (Figure 1). The basic design parameters of the device are given in Table 1.

A wire of pseudoelastic $Ni_{55,8}Ti_{44,2}$ alloy of 1,5 mm diameter (made by Wuxi Xin Xin glai Steel Trade Co., LTD) was used as a main element of the device.

Each of two fixed SMA wires in device has a gauge length of 343 mm. The tests were conducted at room temperature close to the temperature of austenitic-martensitic transformation finishing (28.1°C). The modulus of elasticity of austenite is E_A = 52.7 GPa, the stress of direct transformation start is σ^{AM} = 338 MPa [17].

Mechanical properties of the SMA wire ∅1,5 mm were estimated at temperature 18°C on FP-100 testing machine using special grips (Figure 2).

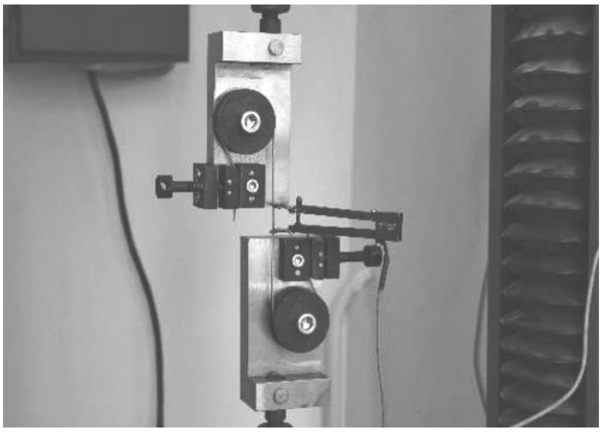


Figure 2. Grips with a wire and an extensometer for measuring longitudinal strain installed in a FP-100 machine

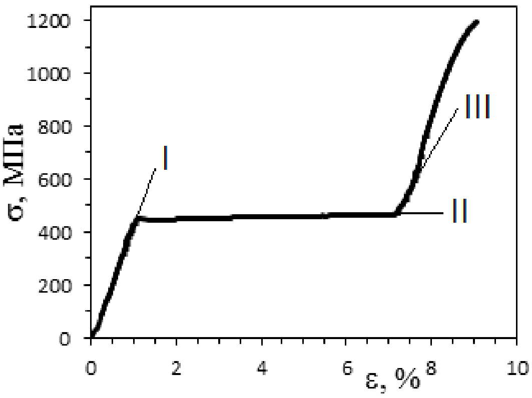


Figure 3. Stress–strain diagrams of wire; I – austenitic, II – austenitic-martensitic, and III martensitic phase.

The wire was loaded with holder displacement velocity 3 mm per sec according to the requirements [18].

Table 1

Structural parameters of damping device

Parametrs of spring of self-centering group					Parameters of SMA wire	
Wire diameter, mm	Length, mm	Number of active coils	Rigidity, N/mm	Maximal loading, N	Length L_w, mm	Diamater d_w, mm
6.30	70	5.8	217.68	3513.40	343	1.5

Technique of experimental study. The functional properties of damping device (Figure 4) were studied on servohydraulic STM-100 testing machine [19] with automated control and data acquisition system. Fatigue tests were carried out under stress–controlled mode.

Figure 4. Photo of damping device mounted in the clamps of the testing machine STM 100

The applied force, piston rod displacement, SMA wires longitudinal strain of the gauge length of 12 mm had been recorded continuously during the test. Longitudinal strain was measured by Bi-06-308 extensometer produced by Bangalore Integrated System Solutions (BISS); maximum error did not exceed 0.1%. The piston rod displacement was determined by inductive Bi-02-313 sensor with an error not more than 0.1%. The length of each of two wires was equal to 343 mm.

Uniaxial tension-compression tests were carried out at room temperature in the air under displacement controlled mode. of the damping device axis with asymmetry coefficient of a displacement cycle $R_S = -1$. The characteristics of the damping device were studied within the frequency range of 0,005 – 5 Hz and displacement range of 3–10 mm. Table 2 describes the tests parameters of each set of experiments, namely frequency and loading amplitude and also the average strain of SMA wires made of pseudoelastic SMA which was calculated as the product of strain amplitude and the correspondent frequency.

Table 2

Set of parameters used in each test series, $R_S = -1$

Test Frequency (Hz)	Test Amplitude (peak to peak) S_a, mm/Wire average Strain-Rate ($\dot{\varepsilon}$,%/c)					
	3	4	5	6	8	9
0,001	1,104E-03	1,64E-03	2,22E-03	2,84E-03	4,61E-03	5,65E-03
0,005	2,09E-02	2,09E-02	2,09E-02	2,09E-02	2,09E-02	2,09E-02
0,01	7,38E-03	1,12E-02	1,64E-02	2,16E-02	3,36E-02	4,02E-02
0,1	0,0783	0,110	0,148	0,193	0,309	0,362
0,5	0,397	0,551	0,727	0,933	1,475	1,721
1	0,788	1,154	1,553	1,961	2,887	3,397
2	1,63	2,33	3,10	3,91	5,71	–
3	2,47	3,50	4,60	5,96	9,44	–

Having been mounted on the testing machine the damping device had been loaded by the fixing elements straining the wires made of shape memory alloys up to 2.5%. This process was controlled by the strain-measuring device (extensometer) to measure the device bodies 10 displacement (Figure 4). After that the springs had been compressed by means of an adjusting nut to the level when the preassigned deformation reached 2.5% under completely unloaded device conditions.

To stabilize the functional properties of the wires made of shape memory alloys the damping device had been loaded during 50 cycles with frequency 0.5 Hz and displacement amplitude S_a = 5 mm. Under cyclic stress conditions due to the one-sided storage of deformation the decrease of preassigned deformation has taken place.

After the wires training the springs had been compressed by means of an adjusting nut to the level which provide restoring of initial pre-strain at completely unloaded device to the value of 2.5%.

During the experiment the device under consideration had been loaded in the mode of displacement control at symmetrical cycle R_S = – 1 increasing the displacement amplitude in each cycle. In this case the constant loading frequency was provided. Loading history during the experiment at frequency of 0.1 Hz is given on Figure 5.

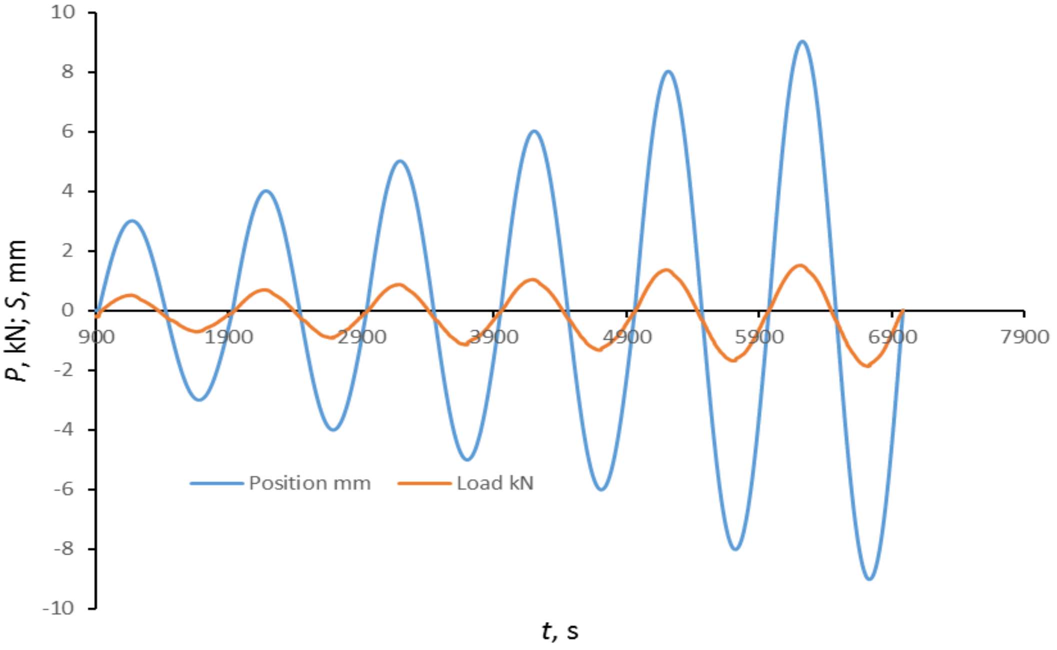
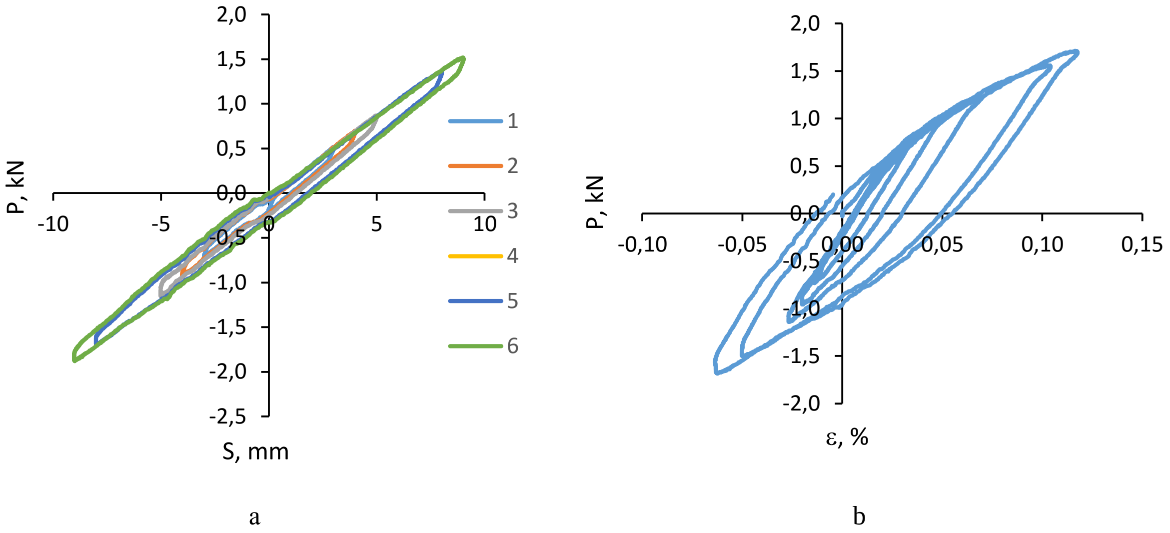


Figure 5. Time dependency of force and device displacement at frequency 0.1 Hz

Results of the study. Hysteresis loops in the coordinates of applied force – device displacement (a) and applied force – wire strain made of shape memory alloy (b) are shown on Figure 6. It should be mentioned, that the strict dependence of hysteresis loop shape on the amplitude of piston rod displacement is observed. By using hysteresis loops one can quantitatively calculate the functional characteristics of the damping device such as energy dissipated within the complete cycle of the loaded device and loss coefficient. The coefficient is the efficient parameter for assessment of the damping device capability and defined as damping capability (capacity) per radian of cycle.



a

b

Figure 6. Change of damping device hysteresis loop shape for various amplitude of displacement – a, and wire strain – b. Different colors correspond to displacement amplitude of active part of device at 3, 4, 5, 6, 8 and 9 mm under 0,1 Hz

Analyzing the hysteresis curves (Figure 6a) it could be assumed that the damper device provides the self-centering force under loading frequency of 0.1 Hz due to its design parameters and pseudoelasticity. More detailed study of functional characteristics of the damping device by frequency and amplitude parameters of loading specified in the Table 2 is going to be conducted.

The results of investigation by the above-described scheme are given on Figure 6 where strict dependence of hysteresis loop shape on the loading frequency is observed. This process can be described quantitatively by characteristic parameters such as energy dissipated within the complete cycle of the loaded device and loss coefficient which is the efficient parameter of the damping device capability assessment defined as specific damping capability (capacity) per radian cycle.

Loss factor was calculated by formula [16]

$$\eta = \frac{\Delta W}{2\pi W}, \qquad (1)$$

where $\Delta W -$ specific dissipated energy; $W-$ strain work measured at the maximum displacement amplitude of the cycle.

Dependences of specific dissipated energy and loss factor calculated by formula (1) on the displacement amplitude at loading frequency 0.1 Hz are given on Figure 7 and 8. In general, within the frequency range under study the increased dissipation specific energy was observed at the increased displacement amplitude of the device piston rod (Figure 7). Unlike the dissipation energy, the loss coefficient is slightly decreasing at the increased displacement amplitude (Figure 8).

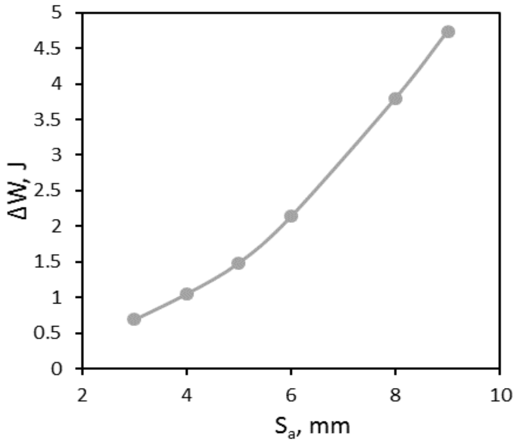


Figure 7. Dependence of dissipation energy on the displacement amplitude at frequency 0.1 Hz

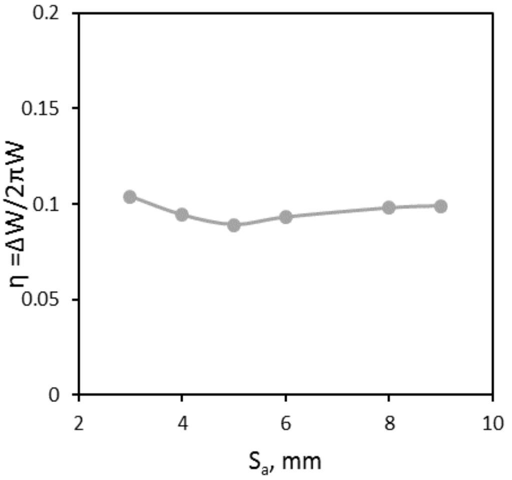


Figure 8. Dependence of loss coefficient on the displacement amplitude at frequency 0.1 Hz

Conclusion. A damping device equipped with preliminary stretched wires made of pseudoelastic NiTi alloy carrying both compressive and tensile loading has been designed and manufactured. A technique of functional characteristics study of the damping device has been developed. The hysteresis curves of the device and the SMA wires at frequency of 0.1 Hz have been obtained. This curves are important for further calculations of the functional characteristics of the damping device. The dissipation specific energy was found to be almost proportional to the increased displacement amplitude of the device piston rod though the loss coefficient was almost insensitive to the displacement amplitude change within the range from 3 to 9 mm.

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УДК 539.3

МЕТОДИКА І ДЕЯКІ РЕЗУЛЬТАТИ ДОСЛІДЖЕННЯ ФУНКЦІОНАЛЬНИХ ПАРАМЕТРІВ ДЕМПФУВАЛЬНОГО ПРИСТРОЮ ІЗ СПФ

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Резюме. *Описано спроектований і виготовлений демпфувальний пристрій на основі використання сплаву із пам'яттю форми. Пристрій складається із попередньо розтягнутих дротів із сплаву, оснащений попередньо розтягнутими дротинами із псевдопружного NiTi сплаву та двох стиснутих пружин, які забезпечують розтяг дротів. Попередньо розтягнуті дроти із сплаву з СПФ забезпечують ефективні демпфувальні властивості пристрою, а попередньо стиснуті пружини – можливість знакозмінного навантаження і відновлення пристрою до початкового положення після зняття зовнішнього навантаження. Завдяки своїм конструктивним параметрам та ефекту псевдопружності даний пристрій забезпечує вільно центровану силу і добрі гасильні властивості, та може бути використаний для зменшення динамічних навантажень на будівельні споруди та інженерні конструкції. Для стабілізації функціональних властивостей дротин із СПФ, пристрій навантажували упродовж 50 циклів з частотою 0,5 Гц і амплітудою переміщення* S_a *= 5 мм. Розроблена і апробована методика експериментального дослідження функціональних характеристик демпфувального пристрою на базі сервогідравлічної випробувальної машини, оснащеної системою автоматизованого управління і запису вимірювальних даних. Під час випробувань записували значення сили, переміщення робочого штоку пристрою і деформацію дротин із СПФ. Виявлено, що питома енергія дисипації за частоти навантаження 0,1 Гц майже пропорційна збільшенню амплітуди переміщення штоку пристрою, проте коефіцієнт втрат малочутливий до зміни амплітуди переміщення в діапазоні 3 мм…9 мм. Дані результати є важливими для подальших розрахунків і моделювання поведінки пристрою під дією циклічного навантаження.*

Ключові слова: *демпфувальний пристрій, сплав з пам'яттю форми, псевдопружність, питома енергія дисипації, коефіцієнт втрат, циклічне навантаження.*

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