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NUMERICAL TESTS OF THE DOUBLE SPRING WITH HANGERS

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Abstract

Subject of the work include selected numerical models of the test stand intended for testing a prototype double multi-leaf spring of bi-linear nature. Basic design assumptions of the stand were as follows: provide laboratory tests of multi-leaf (single and double) springs designed for dependent suspensions of passenger cars of permissible weight up to 3,5 tones. The stand should allow for testing basic spring and strength characteristics in the quasi-static conditions and dynamic conditions with the impact of the force impulse or a set variable load characterized by a particular force amplitude (displacement) and frequency of its variations. Considered stand models include the tested spring, base, support and the hanger. This paper presents two types of FEM models of the spring element (beam and 3D). In the first element, components of the spring-hanger system were mapped by means of beam elements, in the second one by means of definite solid elements. The spring was loaded with a vertical force from 0 to 10000 N. A non-linear analysis of the bi-linear spring was carried out including clearance as well as the elastic analysis of the stand. The results of the numerical tests are presented in a form of tabular specifications, diagrams of displacements, and reduced stresses of selected components of the stand.

Keywords*: double multi-leaf spring, suspension of a motor truck, stand test, vertical load, 1D and 3D FE models*

1. Introduction

A wide scope of tests on the action properness and structure usable properties are necessary during design and diagnostics process of wheeled vehicle suspensions. Complete components and elements of the wheeled vehicle suspensions are tested repeatedly experimentally and numerically for strength [3, 11, 13, 14]. Tests performed on proper testing stands and computer simulations are particularly useful in the validation processes. They are used for comparative evaluations when they using different materials, alternative construction solutions or in order to identify reasons of damages or defective conditions [1, 2, 4-9].

This paper presents selected aspects of FEM analyses of the suspension system consisting of a double multi-leaf spring [10, 15] and the hanger. Various FEM models of a tested system and selected analysis results were discussed. In 3D models, a complete experimental stand for testing a prototype multi-leaf spring of bi-linear nature was mapped. The tested spring [1, 4-9] consists of four leafs of the main spring and two leafs of the auxiliary spring (Fig. 1). Such structure is characterized by the increase of the spring stiffness as the load increases. In the initial scope of the load, only the main spring works (Fig. 1). During the load process, the gap between leafs of the main spring, and leafs of the auxiliary spring is getting smaller (Fig. 1). When the clearance between the mentioned spring components disappears and there is a full contact between the leafs, the auxiliary spring starts to work and it results in the increase of the vehicle suspension stiffness.

2. Study of the effect of a hanger inclination on selected characteristics of the spring

A multi-leaf double spring, consisting of the four-leaf main spring, two-leaf auxiliary spring and the hanger, makes the subject of the tests. One end of the main leaf was fixed to the bracket by means of a joint in non-displaceable position, while the second one could move and rotate. A diagram of the spring installation and the hanger position is presented on Fig. 1. The numerical tests were executed at two stages, for various calculation variants, assuming a constant hanger length of 90 mm. The hanger was initially placed in the vertical position and in the next numerical tests; it was tilted from the vertical plane by 5 mm and 15 mm respectively. Each time the following calculation variants were considered:

- Variant 1 – corresponds to the static diagram of the spring without the hanger,
- Variant 2 – the spring with the hanger in the vertical position,
- Variant 3 – the spring with the hanger tilted to the left side – lower point displaced by 5 mm, (Fig. 1),
- Variant 4 – the spring with the hanger titled to the left side – lower point displaced by 15 mm, (Fig. 1).

At the first stage, the basic spring-hanger system was analysed using the most simple beam models [6] allowing for the execution of multi-variant tests with relatively low effort. In the above model, the leafs were mapped keeping their curvature in the middle plane and with simplified cross-sections in a rectangular form. The gaps between the leafs of main spring and the auxiliary spring were mapped by means of the GAP type contact elements. The beam elements of replacement rectangular cross-section were also used for mapping the hanger model. The spring load model in a form of the vertical of the concentrated force, applied to the spring symmetry plane (Fig. 1), of the maximum value of P = 10 KN, was assumed. The load was increased from zero to the maximum value in ach calculation variant.

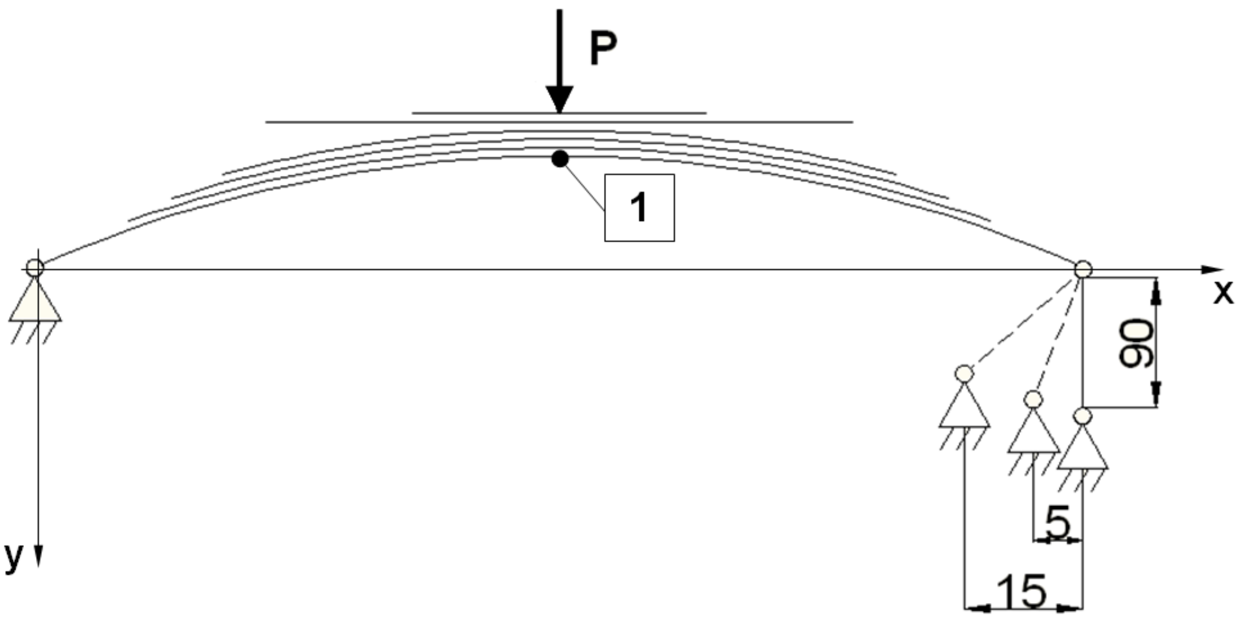

Fig. 1. Scheme of the double spring with the hanger: node No. 1 in 1D FE beam model

Numerical analyses were performed within a scope of non-linear statics [12], due to a geometrical variability of considered diagram resulting from considering the gaps between the leafs of the main and the auxiliary springs. The analysis of the influence of the hanger and its position on the spring was carried out. The results of the numerical spring tests at various initial positions of the hanger in the unloaded condition were presented. Selected results of displacements in the function of the load increase are presented in Table 1 and on Fig. 2.

Tab. 1. Selected results of the node No. 1 vertical displacements in the beam model, for different variants of FE analyses (Fig. 1)

Force P [N]	**Vertical displacements of node No. 1 [mm]**			
	Variant 1	**Variant 2**	**Variant 3**	**Variant 4**
2000	41.7	41.7	42.99	45.1
4000	82.0	82.0	84.19	88.1
6000	105.1	105.1	107,4	111.8
8000	123.1	123.1	126.1	131.9
10000	141.9	141.9	145.5	152.6

Fig. 2 presents the results of calculations for particular variants of the analysis in the form of diagrams illustrating the dependence of the force and displacement, in the spring symmetry section (node 1 on figures 1 and 3). While Fig. 3 shows deformation of the leafs and the spring displacement map for variant 3.

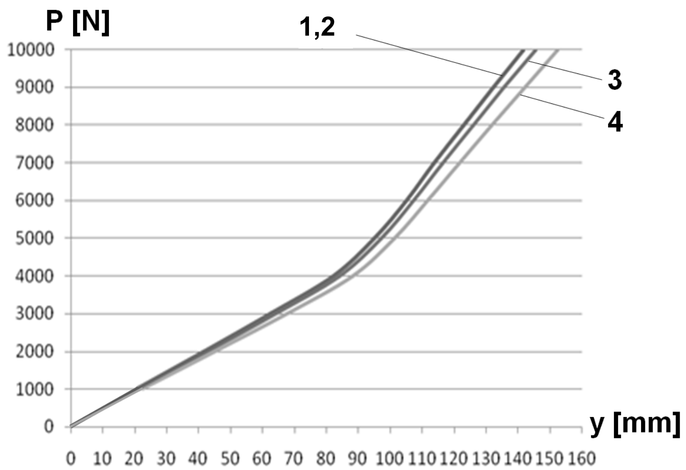

Fig. 2. Diagram of the force P – node No. 1 vertical displacement relation (according to Fig. 1, 3) in Variants 1-4

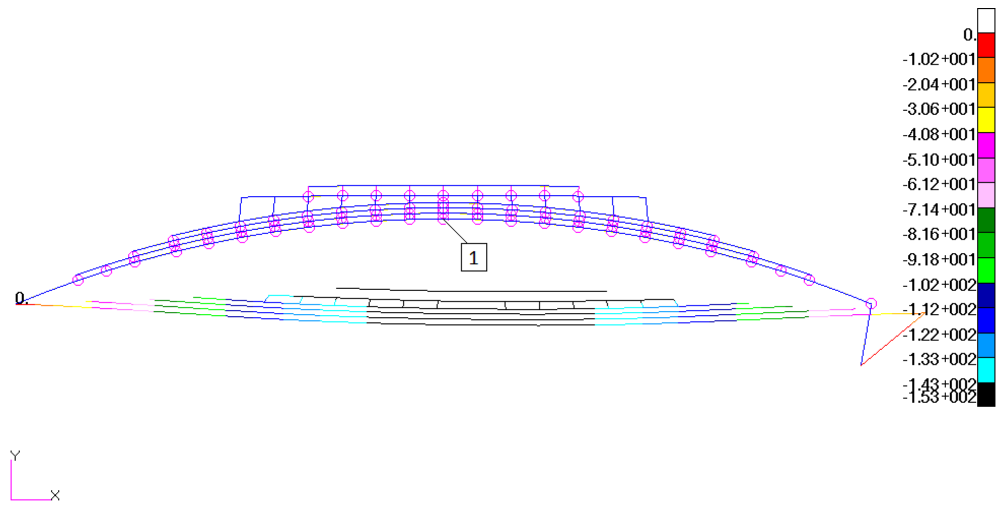

Fig. 3. Deformation of the double spring under load with the maximum vertical force P; displacement for node No. 1 – $V_{y\,max} = -153$ mm

The values of the maximum displacements for variants 1 and 2 (without the hanger and for the spring with a vertical hanger position) are slightly different, therefore corresponding curves on the diagram (Fig. 2) overlap. In case of such model configuration, limitations of the movement of the longest spring leaf are identical as in case of applying the joint-sliding support in the model without the hanger (variant 1). The biggest displacements were obtained for the variant 3, where the lower end of the hanger was tilted to the left side by 15 mm. The lowest displacement was obtained for the spring without the hanger and for the spring with the hanger placed in the vertical position. The values of the vertical displacements differ in individual variants of the analysis by up to 8%.

3. Numerical analysis of the double spring with hanger on a prototype test stand

The 3D FEM spring model and a specially designed testing stand [10] were used at the following stage of this paper. The considered spring made the subject of the elaborations [2, 6], where the authors used the numerical methods in the analysis of the springy characteristics, double spring strength [6], and they discussed the results of the dynamic load tests performed on the bi-linear spring in the testing stand, using the pneumatic hammer and recording the results by means of a fast video camera [2]. They refer to the system without the hanger (Fig. 4a). While presented numerical analysis of the spring testing stand model makes a continuation of these papers. In the future, the results of the analysis will be used for multi-variant laboratory tests on a double spring with a hanger (Fig. 1) on the strength machine presented on Fig. 4a [10].

In the presented stand model (Fig. 4b), the spring was connected with the stand base (3) by means of two hangers (4) and two supports (5). It was assumed that the base (3) would be made of a standardized C160 C-section of the length adjusted to dimensions of the tested spring. Moreover, it was assumed that the hanger connecting the support and the spring would be initially titled, in the unloaded condition, from the vertical by an angle of 20 degrees.

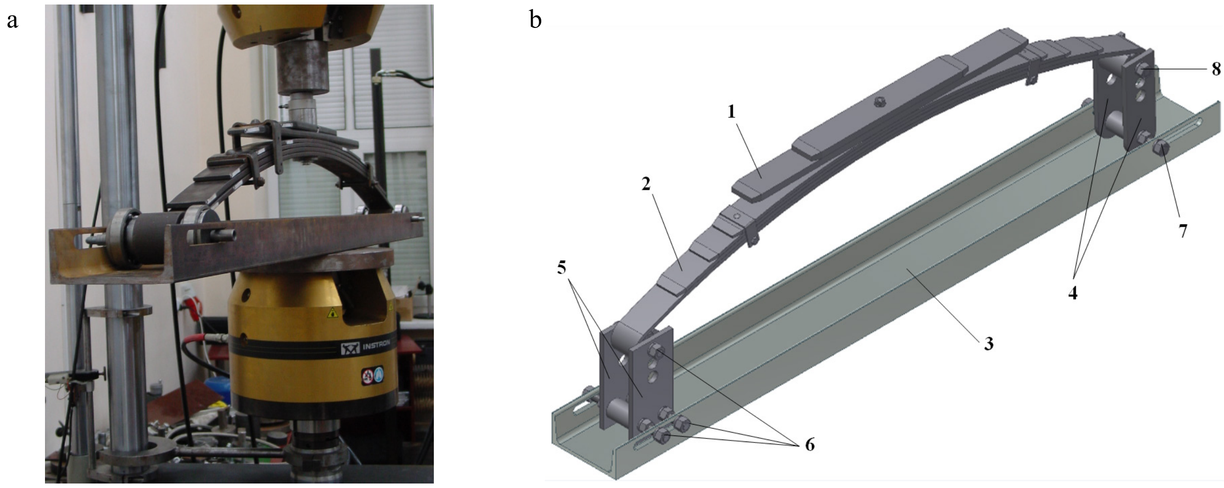

Fig. 4. Research stand for elastic characteristics test of the spring: a) during laboratory test of the spring in Variant 1 [3] at the strength machine, b) the prototype stand for test of spring with a hanger – Variants 2, 3, 4 [10, 15]

The support (5) was fixed to the support by means of two screws (6) and it prevents from displacement and rotation of these two elements (Fig. 4b). From the other side, the support was connected to the spring by means of one screw. Therefore, the spring can freely rotate relative to the supports. The hanger (4) was fixed to the base by a screw (7) and to the spring by a screw (8). Such solution allows for the hanger rotation, relative to the base during spring loading and deformation. In case of such support, the spring can rotate relative to the hangers. When loading the spring, the upper screw rotates relative to the lower one on the radius, which equals the distance from the lower axis to the upper screw. Thanks to that, the right end of the spring moves not only in the horizontal direction but also in the vertical direction relative to a set position of the left end.

In the 3D model, a spatial system of the stand components was mapped by means of solid definite elements [15]. The spring mappings discussed in the previous papers [2, 6-8] were used in the FEM models of the stand. It was decided to use discrete models built because of definite 3D models, as simplifications related to the use in 1D discrete models of the beam elements determine some inconvenience and limitations in the analysis of the results; for example, a precise mapping of the results in the omitted system components and structural details is not possible. The 3D version of the FEM model presented on Fig. 5 consists of the following components: the tested spring, the support, two connectors and two hangers. The spring was mapped in a form of solids by means of HEX8 type elements (Fig. 5).

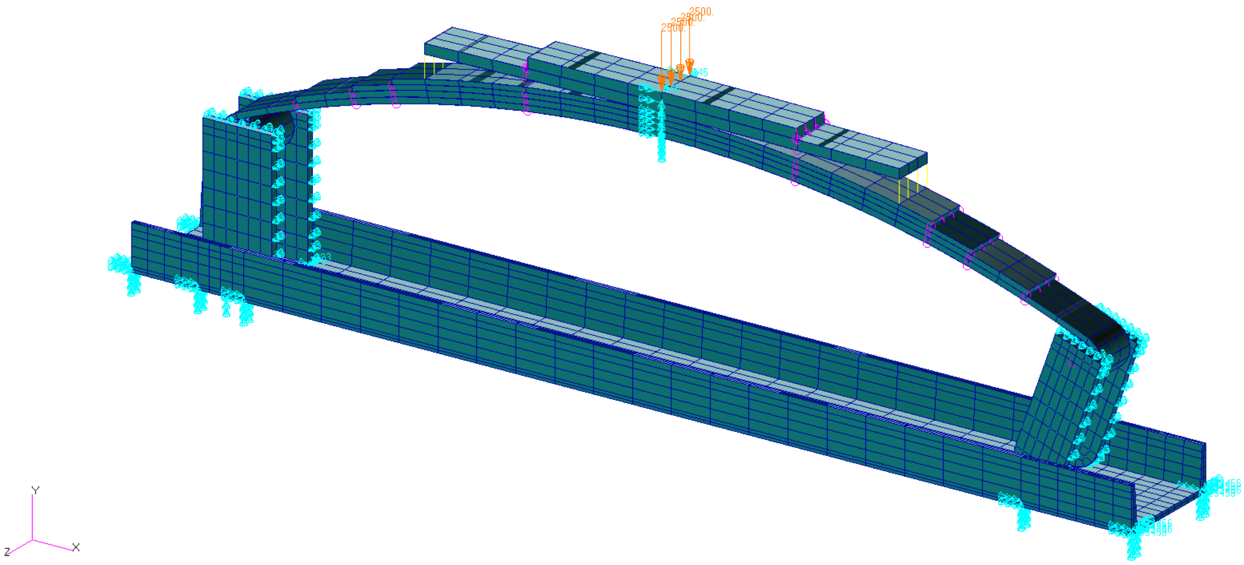

Fig. 5. 3D FE model of the complete research stand for spring testing [15]

A simplification in a form of omission of holes in the support, hanger elements and the stand base, in places where the screws are located (Fig. 5), was applied in FEM models. Thanks to that, there was no need to model, in these areas, the contact between the screws and the fixing elements. Connections of the supports and the hangers with the main spring leaf and the stand base were modelled by means of MPC elements with properly related degrees of freedom of combined components (internal tie models) and beam elements of replacement stiffness. They map the screws and allow for the rotation of connected elements relative to proper axes. The numerical models of the stand were prepared by the Inventor software and MSC Patran pre-processor. Proper external ties were introduced in order to map a real support of a complete stand (Fig. 5). The base was immobilized by introducing ties on translation directions of the freedom degrees along the OY axis in the nodes of its lower part. Similar ties were included in the hanger and support models, receiving all translation degrees of freedom from the lower edges of these stand components. The model of the complete stand (Fig. 5) was exposed to the load of four concentrated forces of the value of 2.5 kN each, applied in the plane of the vertical spring symmetry. The resultant force of the loading set, amounting to 10 kN, corresponds to the maximum value of the load applied in the spring stiffness tests on the experimental stand shown on Fig. 4a [3]. Numerical calculations within a scope of non-linear statics [6] were made using the MSC Nastran software. Examples of the calculation results in a form of displacements and reduced stresses were presented on Fig. 6. The maximum values of resultant displacements in this variant of the stand model were obtained in the spring and they amount to 170 mm (Fig. 6a).

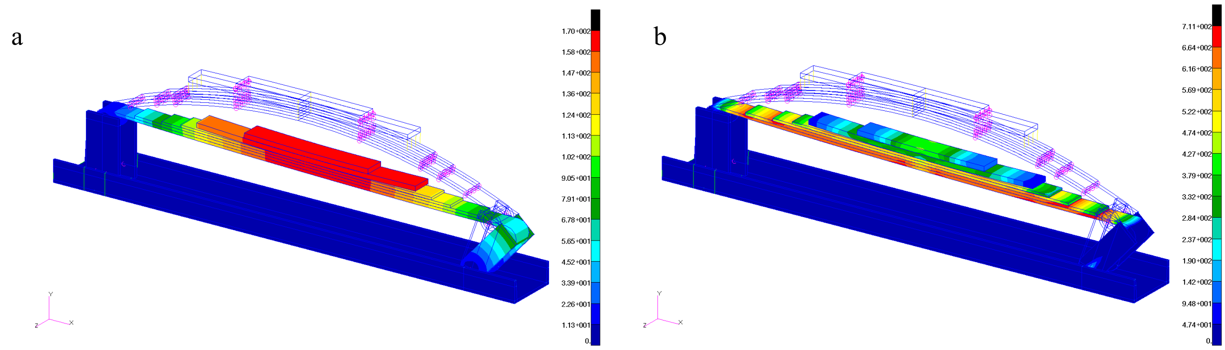

Fig. 6. Selected results of numerical analyses of the complete stand for spring testing; a) resultant displacement map; Vc_{max} = 170 mm, b) map with reduced HMH stresses; σ_{max} = 711 MPa [15]

While the maps of reduced stresses obtained for the hangers and the base of a complete stand were presented on Fig 7. The maximum tensions in the hangers (Fig. 7a) occur in a place of connection of that element with the base and they amount to 192 MPa. The maximum stresses in the C-section of the stand base (Fig. 7b) occur in a place of connection of that component with the hanger and they amount to 32.8 MPa.

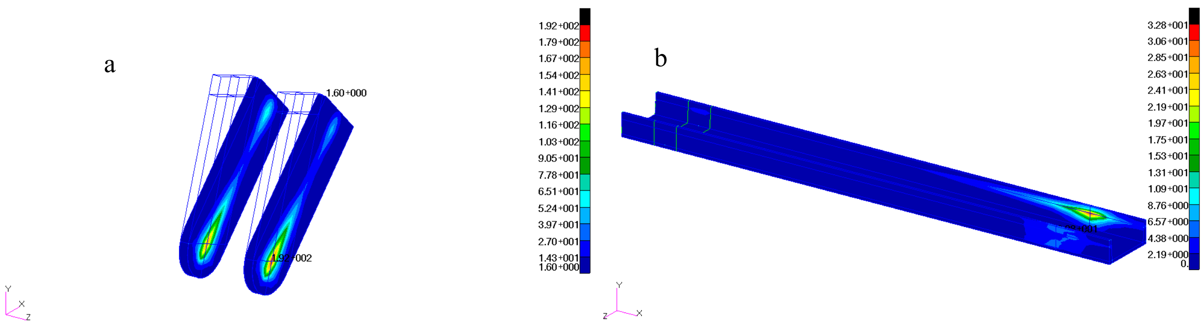

Fig. 7. Map of reduced HMH stresses for selected components of the laboratory stand; a) hangers, b) base of the stand – the C-profile

Table 2 shows the maximum values of reduced H-M-H stresses for the testing stand components. It was found that the stress values in the base and the supports do not exceed 35 MPa, despite the simplifications applied in the fixing areas, that is replacing the screw connections with the ”node-to-node” type MPC models. The maximum stresses in the hangers make less than 30% of stresses defined in the most tensioned leafs of the spring.

Tab. 2. List of maximum HMH stress values obtained in tests of the complete laboratory spring stand

Components of the research stand	**Base**	**Hangers**	**Brackets**	**Spring**
Maximum HMH stress [MPa]	32.8	192.0	31.0	711.0

Fig. 8 presents a rotation of the hangers relative to the initial position and their complete displacements in a form of a colour map. The maximum value of the complete displacement amounts to 77.2 mm. On the basis of the values of the coordinates of the nodes located on the axes of the upper and the lower screws, before and after the analysis, an angle α of the hanger rotation relative to the axis of the lower screw amounts to about 26°.

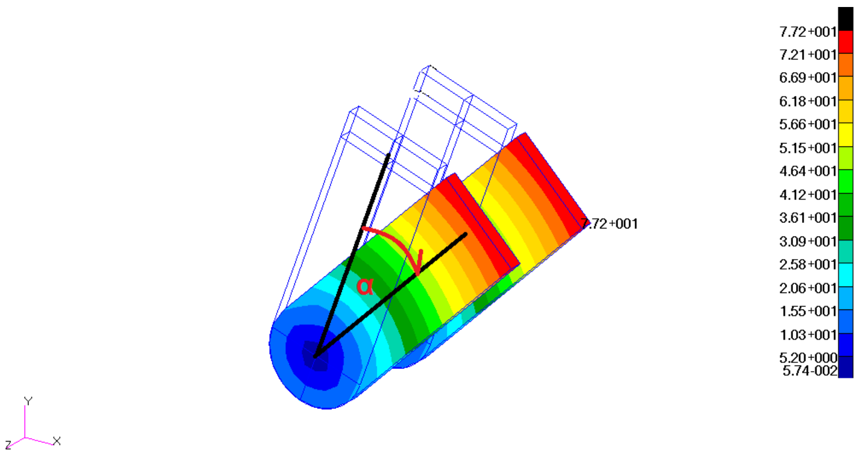

Fig. 8. Resultant displacement map of the hangers with the selected angle of rotation

The table 3 specifies selected values of the maximum displacements and the rotation angle of the components of a complete stand in the 3D version. The stand component displacements, total displacements of the hangers were compared as well as their angle of rotation at the maximum model load with the force of 10 kN. The highest resultant displacements were obtained in the right part of the spring cooperating with the hangers. It results from the fact that the right end of the lower spring leaf connected with the hangers in a movable way by means of the upper screw, during the rotation of the hangers, moves flat in the plane X – Y of the model (Fig. 5, 8). The highest total displacements in the hangers, rotating relative to the axis of the lower screw, were obtained in the corners that are the most distant to the axis of rotation.

Tab. 3. Results of maximum displacement and angle of rotation determined in 3D FE model of the research stand components

Selected parameter	Maximum value
Resultant displacement of the spring supported at test stand	170 mm
Vertical displacement of the spring – node No. 1	167 mm
Resultant displacement of hangers	77.2 mm
Rotation angle of hangers	25.7°

Summary

The use of numerical methods supports the execution of the stand tests and it often allows for limiting their scope (in case of multi-variant tests). The computer methods and simulation tests allow for reducing the costs, for example related to preparation of a proper testing stand or to the purchase of proper measurement equipment. Because of the FEM analysis, we receive information about all dependent variables considered in the calculations. Even the simplest beam models that do not require too much time to model them, allow for obtaining satisfying results. However, we should not forget that simplifications used in them determine some inconveniences and limitations in the analysis of the results. This paper includes the results of the numerical tests performed on the multi-leaf spring with the hanger mapped in 1D and 3D models of various complexity. The results within a scope of the maximum displacements in the represented models differ by about 10%. Many structural details related to simplifications, resulting from the modelling rules assumed in case of 1D models, cannot be mapped in the simplest models. Therefore, a complete 3D stand model, designed for testing the bi-linear spring with a hanger, was developed and tested. Such model will be used for the analysis of the vehicle suspension dynamics. The simulation results will be also used for building the laboratory stand for the spring testing within a scope of quasi-static and impulse loads.

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