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NUMERICAL ANALYSIS OF WAGON LEAF SPRINGS

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Abstract *– This paper deals with the methodology of analysis of the leaf springs of the freight railway wagons by using modern software packages. The methodology is applied in a concrete example of leaf spring for axle load of 200 kN. The procedure of forming the CAD model of the leaf spring using AutoCad and Solid Works is exposed, as well as the development of numerical model in Ansys software package. The results of the static and dynamic analysis of given leaf spring are presented and commented. Comparison with the results of analytical calculation has shown the validity of the developed model. In this way, the proposed methodology can be successfully used in the design of various types of leaf springs in engineering practice.*

Keywords – Leaf Spring Calculation; FEM Analysis; Railway Vehicles; Freight Wagons.

1. INTRODUCTION

The suspension system of the railway vehicles is usually based on the helical or leaf springs. The advantages of helical springs are relatively small dimensions and good elastic properties, so they require less space for installation. In case of their usage, the additional elements for damping of oscillations must be installed in suspension system of railway vehicles. In contrast, leaf springs have both elastic and damping behaviour, while they need something larger space for installation. In any case, both solutions are widely used in suspension systems of railway vehicles, while the leaf springs are the subject of interest in this paper.

Fast design and calculation of the leaf springs of railway vehicles is very significant in engineering practice. In this sense, the advanced and modern software packages provide large possibilities [1–2]. The modern approach comprise the development of numerical models based on finite element method (FEM) that provide performing the static and dynamic analysis of these elements [3–4]. Consequently, this paper deals with one of the approaches in the design and analysis of leaf springs of railway vehicles by using a modern software packages.

2. CONSTRUCTION OF LEAF SPRINGS

The leaf springs are the oldest elastic elements composed of more steel leafs that are connected by spring buckle. During the exploitation, it is deformed, while between leafs there are mutual friction that damping the oscillations. The complete of leaf spring is composed of the main leaf (with eyes), other leafs, spring buckle and wedge. Leafs are made of steel tapes which are bend in certain radius and subjected to the thermal treatment. Every leaf has on its upper side the longitudinal groove and on bottom side the appropriate longitudinal rib, which prevents mutual lateral movement of the leafs. The main leaf has on its ends the eyes for connection with the wagon underframe or bogie frame. The characteristic construction and dimensions of the leaf spring are shown in Fig. 1.

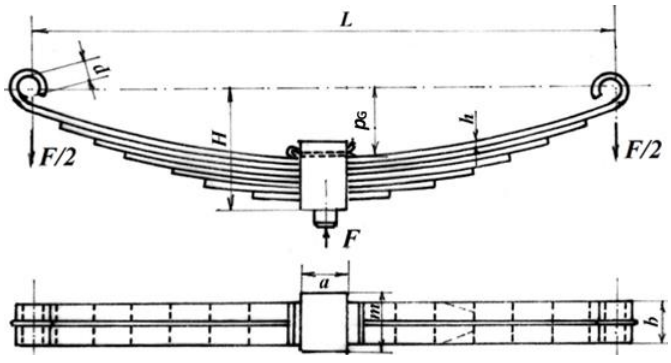

Fig. 1. The characteristic construction and dimensions of the leaf spring [5]

The characteristic dimensions of the leaf spring are (Fig. 1): L – length (distance between ears centers in unloaded condition); d – inner diameter of ear; p_G – camber (distance from the upper side of the main leaf and the line that pas through eyes centers, in the

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middle, in unloaded condition); and H – height of the leaf spring (distance from bottom side of spring buckle and the line that pas through eyes centers, in the middle, in unloaded condition). Under the vertical load, the values of the camber of the leaf spring is decreased, and the difference between the camber in unloaded and loaded condition is the deflection of the leaf spring. During the running of the railway vehicle, value of the camber oscillates around the equilibrium position (the value of the camber under the static load of the leaf spring). The frequency of these oscillations is important for stress state, especially for the fatigue and life of the leaf spring.

3. LOAD CASES FOR LEAF SPRING CALCULATION

On the basis of additional parameters for every concrete case, such as mass of the empty wagon, mass of the wheelset, number of axles, number of leaf springs, etc., by a certain methodology, three characteristic load cases can be defined. For leaf spring for axle load of 200 kN considered in this paper, the specific load cases are calculated in [5], and those are:

- Load case 1: The load of the leaf spring under empty wagon (F_k=17.8 kN),
- Load case 2: The load of the leaf spring under fully loaded wagon (F_t=91.55 kN),
- Load case 3: The load of the leaf spring under fully loaded wagon in the dynamic regime (F_{max}=119 kN).

Beside this, the geometry of the considered leaf spring is defined in [5]. The required stiffness, dimensions, number of leafs, stresses and safety factor, are determined. The defined geometry and the previous load cases are used for demonstration of procedure of analytical calculation of the leaf spring, as shown in the next chapters.

4. FORMING OF CAD AND FEM MODEL

The first step is modelling the main leaf in 2D surrounding, for which AutoCAD is the most favourable, and it is used in this case. In this way, the sketch for importing into 3D software is formed, as shown in Fig. 2. It is important to take into account the importance of proper geometry measures for the unloaded leaf spring as well as location of the coordinate system.

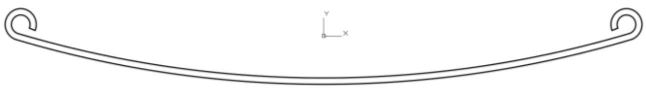

Fig. 2. The sketch of main leaf formed in AutoCAD

In next phase, formed dwg or dxf file with sketch is imported in software for 3D modelling - in this case SolidWorks is used. After this, it is very simple to obtain 3D geometry of main leaf, as shown in Fig. 3.

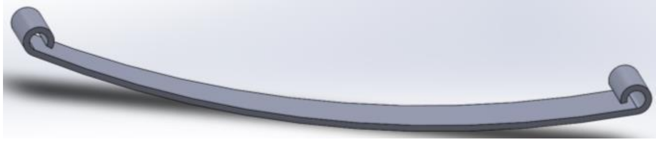

Fig. 3. The 3D geometry of main leaf formed in SolidWorks

The main leaf modelled in this way is basis for modelling the first next leaf, first as sketch in AutoCAD and after that as 3D model in SolidWorks (after importing the sketch). Therefore, this procedure is repeated as many times as there are leafs of the leaf spring. The CAD model is ended after the last leaf is modelled. The finally formed CAD model of the considered leaf spring is shown in Fig. 4.

Fig. 4. The finally formed CAD model of the considered leaf spring in SolidWorks

The basis for forming the FEM model is previously formed CAD geometry which is imported in Ansys in form of IGES or STEP file. The values of parameters of the leaf spring material (spring steel 51Si7) are introduced: E=20000 kN/cm^2 – Modulus of elasticity, R_e=110 kN/cm^2 – Yield strength, R_M=130 kN/cm^2 – Ultimate strength and σ_D=70 kN/cm^2 – Endurance limit. In the next phase, supports are adjusted, as shown in Figs. 5-7.

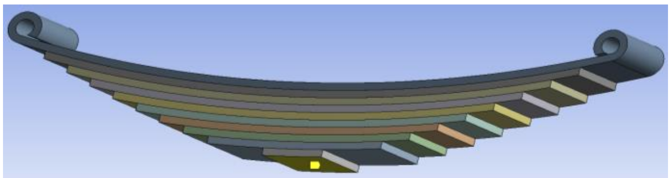

Fig. 5. Support 1. – only vertical translation allowed

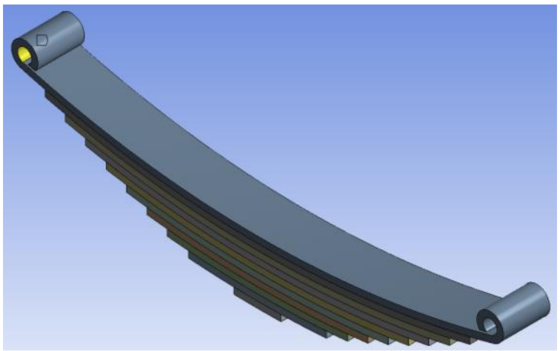

Fig. 6. Support 2. – rotation and horizontal translation allowed

The finally generated FEM model is composed of 28158 finite elements and 109598 joints (Fig. 8). It is important to note that connections between leafs are defined with command "no separation".

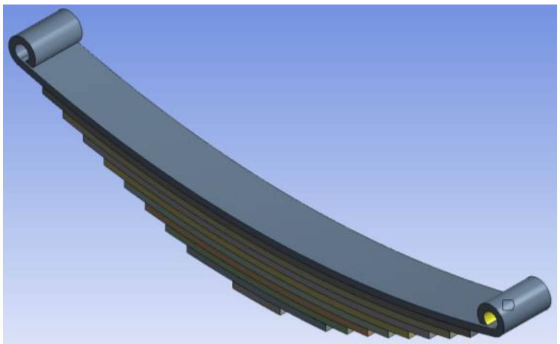

Fig. 7. Support 3. – rotation and horizontal translation allowed

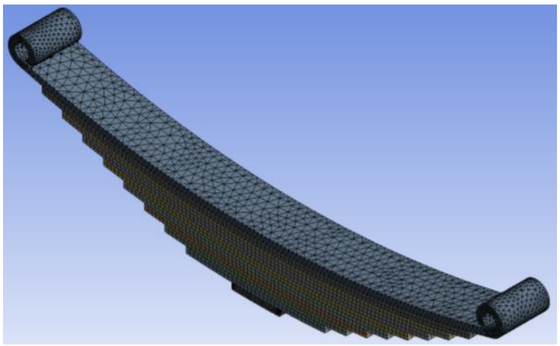

Fig. 8. The finally formed FEM model of the considered leaf spring in Ansys

At the end, previously defined three load cases are adjusted. The applied force for third load case is shown in Fig. 9.

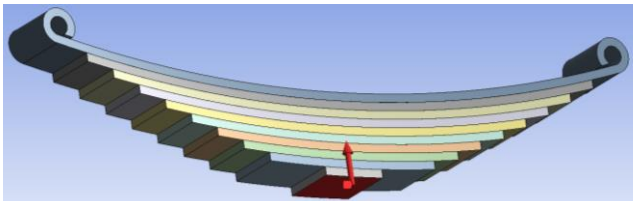

Fig. 9. The applied force for third load case

5. RESULTS OF FEM CALCULATION

The obtained results for given load cases are shown in Figs. 10-15.

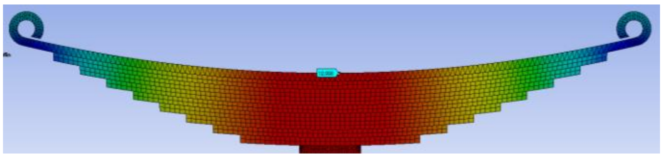

Fig. 10. The deflection for load case 1 (1.1 cm)

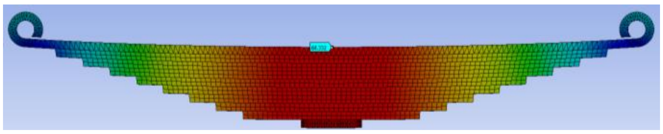

Fig. 11. The deflection for load case 2 (6.4 cm)

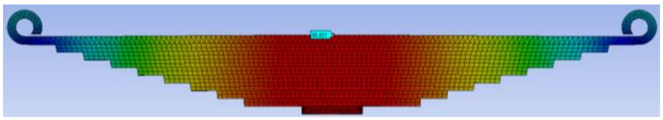

Fig. 12. The deflection for load case 3 (8.4 cm)

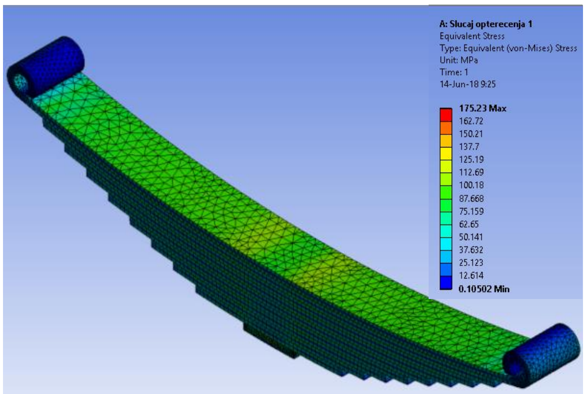

Fig. 13. The equivalent stress for load case 1

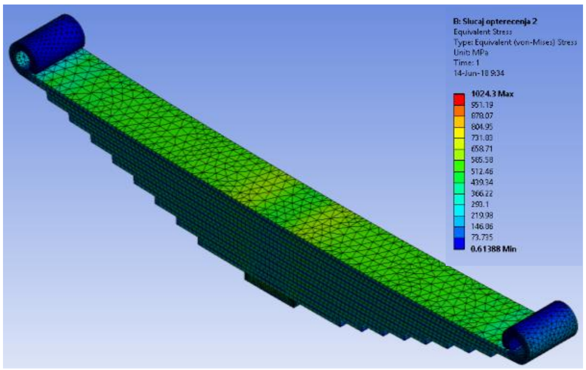

Fig. 14. The equivalent stress for load case 2

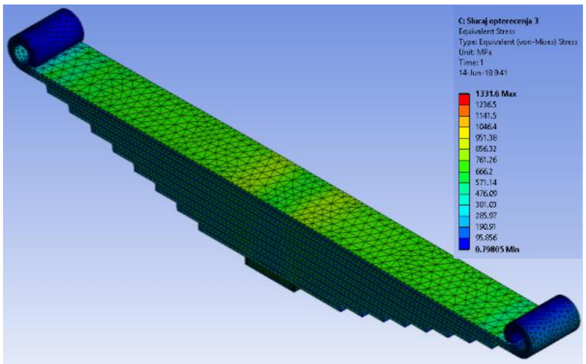

Fig. 15. The equivalent stress for load case 3

The obtained stress-strain state is more convenient to analyse over the static safety factor which is automatically obtained in Ansys. The static safety factor is defined by the ratio between yield strength and von Mises Stress (Fig. 16):

$$s_{st} = \frac{R_e}{\sigma_e} \geq 1 \tag{1}$$

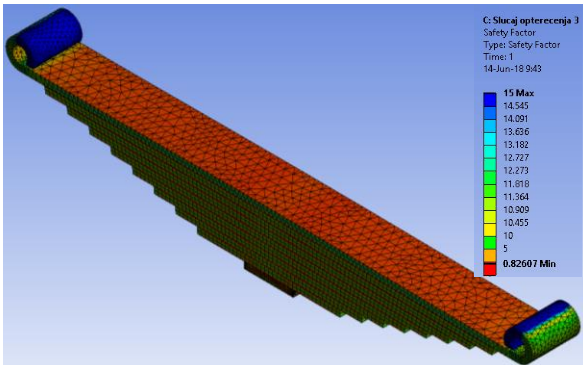

Fig. 16. The static safety factor for load case 3

Additionally, dynamic analysis of the considered leaf spring is performed. According to the Soderberg criterion, the dynamic safety factor is defined by the expression:

$$s_{din,sod} = \frac{R_e}{\sigma_{SR} + \sigma_a \cdot K_f \cdot \left(\frac{R_e}{\sigma_D}\right)} \quad (2)$$

where: $\sigma_{SR}=(\sigma_{max}+\sigma_{min})/2$ – authoritative medium stress, $\sigma_a=(\sigma_{max}-\sigma_{min})/2$ – authoritative amplitude stress, $K_f=1$ – coefficient of stress concentration.

The dynamic calculation is performed for the case of uniaxial fatigue. It was adopted that the lower value of the load is 10% of the upper – maximum value. This is established on the basis of the results of the obtained equivalent stresses. So, the force varies from the load of the leaf spring for loaded wagon F_t, to maximum load F_{max}. Some of the obtained results of the lifetime and dynamic safety factor for the most critical load case are shown in Figs. 17 and 18.

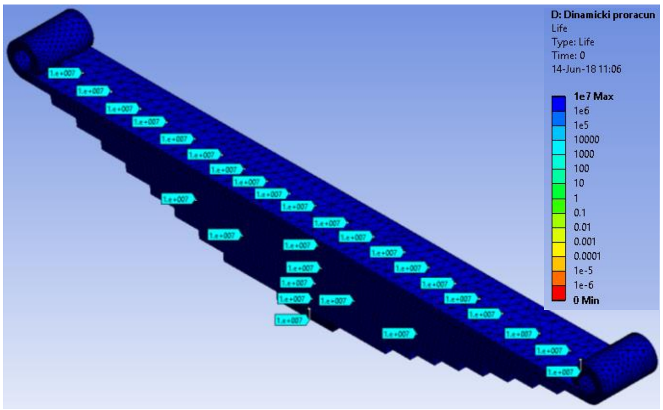

Fig. 17. The lifetime of the leaf spring

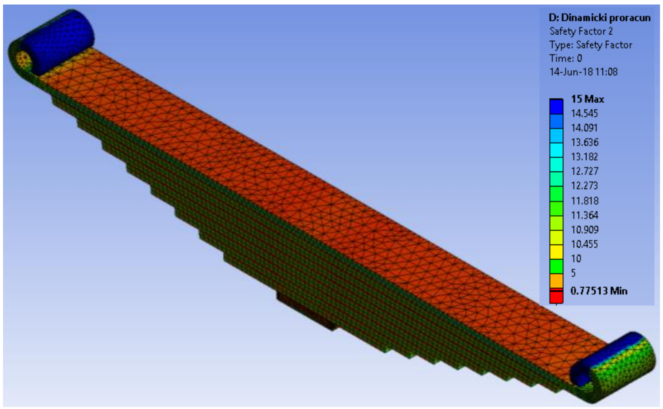

Fig. 18. The dynamic safety factor of the leaf spring

The obtained results have shown that the considered leaf spring is in the zone of permanent dynamic endurance, i.e. that it meets the necessary criteria from the aspect of dynamic strength.

In the final stage, the results obtained by the numerical calculation are compared with the results of analytical calculation (exposed in literature [5]). The comparative diagram of the deflection of considered leaf spring, obtained by the FEM and analytical way, is shown in Fig. 19.

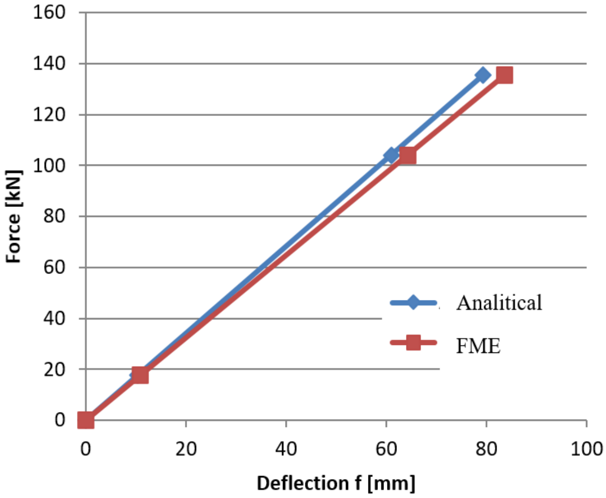

Fig. 19. The comparative diagram of leaf spring deflection obtained by the FEM and analytical way

6. CONCLUSION

This paper deals with the methodology of analysis of the leaf springs of the freight railway wagons by using modern software packages. In the example of considered leaf spring, deviations between numerical and analytical results are in the range of 5 %. This confirms validity of the proposed methodology of analytical calculation which can be applied in the design of various types of leaf springs in engineering practice.

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