FATIGUE STUDY OF A CIRCULAR SAW SHAFT WITH COSMOSWORKS®

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ABSTRACT

In the last few years systematic fatigue studies are carrying out in Faculty of Forest Industry. Fatigue analysis of a 3D-model of circular saw shaft is carried out by finite elements method (FEA) with CosmosWorks® on the base of the fatigue curve (*S*-*N* curve) for carbon steel 45. Different fatigue events are studied – with constant amplitude (stress ratio *R*=-1) and with changeable amplitude. Plots for total life and damage, rainflow 3-D histograms and damage 3-D histograms are obtained.

Key words: fatigue, fatigue life, circular saw, CosmosWorks®, FEA

INTRUDACTION

In the last few years systematic fatigue studies of woodworking machines are carrying out in Faculty of Forest Industry: [1, 5, 7] and especially the thesis [6], where so called method IDD (Integration of Damage Differentials) for fatigue life assessment at any variable loading is applied. This method starts from known fatigue curves, after that gives full liberty of the stress condition: it can be a multiaxial loading, with arbitrary and non-proportional components of oscillograms. Current study correlates with the mentioned studies by question of how to give an account for the local concentrate in the concentrators, from which the fatigue cracks initiate. It is known that the local stresses can be excluded according to Saint-Venant's rule [4], but only at static studies. In the textbook [4] the question for the concentrate stresses is referred to the modern possibilities of the computer engineering designing and calculations. Indeed, in the last years with the computer's expansion, new methods and technologies are applied to study fatigue of components and assemblies. The modern computer technologies for fatigue prevention, Computer-Aided Engineering (CAE) programs use three major methods to determine the total fatigue life: Stress Life (SN), Strain Life (EN) and Linear Elastic Fracture Mechanics (LEFM). Because of its ease of implementation and the large amounts of material data available, the most commonly used method is the „SN“ method. Although providing poor accuracy for low cycle fatigue it is the easiest to implement and offers a good representation of high cycle fatigue.

The primary tool of fatigue module of CAE programs is the finite element analysis (FEA). FEA can predict stress concentration areas, and can help design engineers to predict components fatigue life and to prevent fatigue cracks initiation. FEA is excellent tools for studying fatigue with the S-N-approach, because the input consists of a linear elastic stress field, and FEA enables consideration of the possible interactions of multiple load cases. The approaches of FEA can help designers to improve component safety while reducing overengineered, heavy, and costly designs. The new computer technologies for fatigue prevention give designers greater opportunities to design new products instead of solving of unthinkable problems before now.

The object of this study is fatigue investigation of a circular saw shaft by finite element analysis for engineering analysis with

CAD/CAE systems Solid Works®/Cosmos Works®.

METHODS OF INVESTIGATION

Fatigue investigation with CAE system CosmosWorks® is realized by finite element analysis (FEA). Results of static study of the 3D model created with Solid Works® [10] are used as the basis for defining the fatigue study. The number of cycles required for fatigue failure to occur at a location depends on the material and the stress fluctuations – *S-N* curve. Equivalent stresses (von Mises) are chosen for calculating the equivalent alternating stresses and for extracting the number of cycles from the *S-N* curve (another possibilities which the program offers are stress intensity (*P1-P3*) and max. absolute principal (*P1*)).

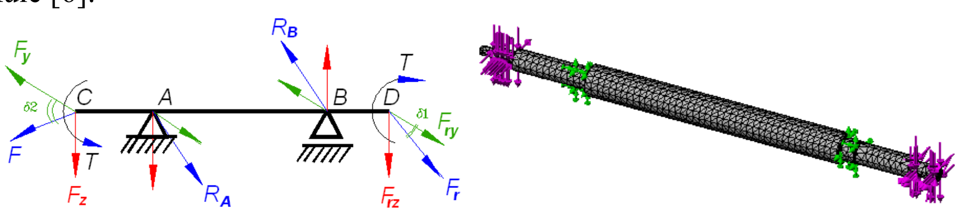
The software handles two different types of fatigue events: constant amplitude and variable amplitude. The Rainflow cycle counting method extracts the composition of a variable amplitude load history. If the amplitudes are more than one, the Miner's Rule is applied – the each amplitude damage is calculated and picks are combined for determining the total, cumulative damage. The result is the total damage factor as a part from 1,0, the part of component failure. Failure due to fatigue occurs when the damage factor reaches 1,0. This theory predicts that the damage caused by a stress cycle is independent of where it occurs in the load history and the rate of damage accumulation is independent of the stress level. This rule is referred as the Linear Damage Rule or Miner's Rule [6].

Gerber method (for ductile materials) are chosen from offered by the software 4 possibilities (others: no correction, Goodman method and Soderberg method) for the mean stress correction of each cycle.

APPLICATION FOR FATIGUE STUDY OF A CIRCULAR SAW SHAFT

The fatigue study is carried out with 3D model of a real circular saw shaft, created with SolidWorks® (Fig.1, b), which is described in details in [2]. The model is generated by preliminary calculated shaft with one circular disk (*D*=180 mm) for undercutting of wooden materials boards with foil or plastic coating [3].

The static study is carried out with CosmosWorks® by FEA. The restrains (fixed) and the follow moment and forces are set according to Fig. 1, a: torque *T*=5,59 N.m; total cutting force (included feeding force and disk and flanges weight) *F*=60 N ($\delta_2=28^0$); force from belts stretching *Fr*=630 N ($\delta_1=60^0$) [3]. The created mesh of finite elements has been described in [3]. From the Cosmos materials library steel AISI 1035 is chosen with characteristics closest to the Bulgarian carbon steel 45 according BDS 2592:1971: tensile strength 585 MN.m^{-2}; yield strength 282 MN.m^{-2} elastic modulus 2,05.10^{11} N.m^{-2}, shear modulus 7,9.10^{10} N.m^{-2}; Poisson's ratio 0,29. *S-N* curve for this material is presented on Fig. 2. Resulted equivalent stress (von Mises) distribution in the shaft model is presented on Fig. 3.



a b

Fig. 1. Loading scheme of the shaft (a) and 3D model (b)

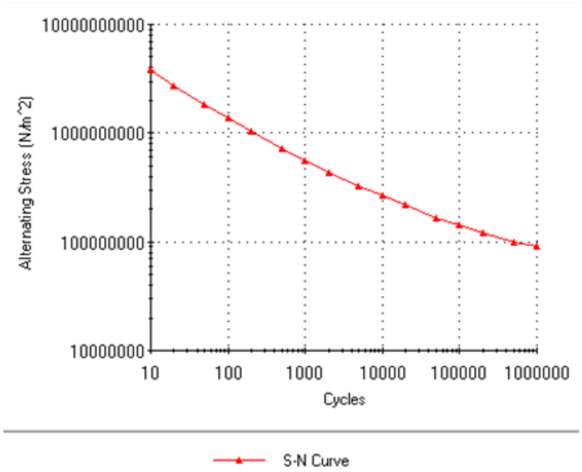


Fig. 2. *S-N* curve of AISI 1035

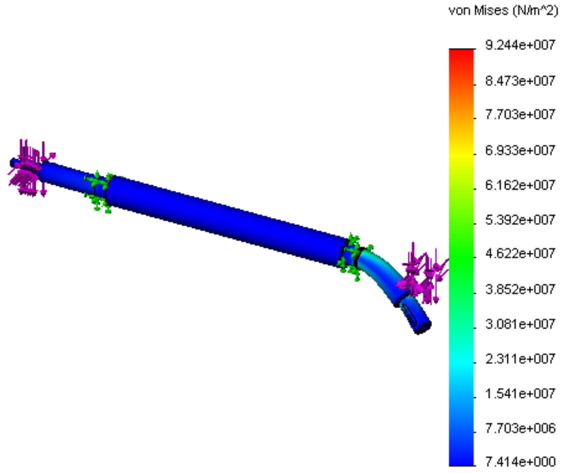
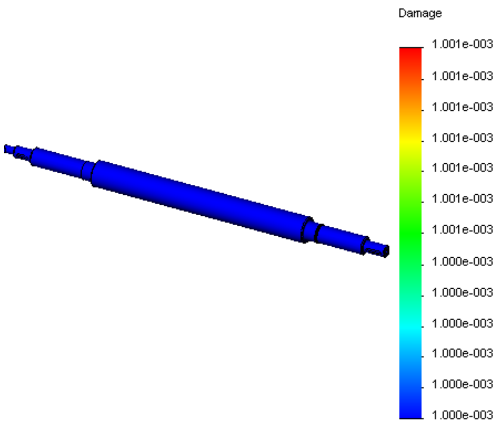


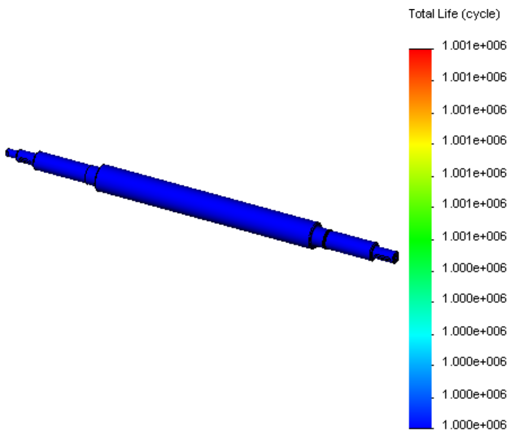
Fig. 3. Equivalent stresses

Four independent fatigue studies are carried out (no interaction and fatigue strength reduction factor K_f =1) – one constant amplitude event and tree variable amplitude events are defined:

1. Constant amplitude event – symmetric cycle with stress ratio *R*=-1 and cycles number 1000 is studied. The results are graphically represented on Fig. 4, a and b. The life plot (Fig. 4, b) shows that failure due to fatigue is likely to occur at the shaft shoulder next to the V-belt pulley, node №1 (*x*=387 mm; *y*=9,1 mm; *z*=-5,2 mm), after 1.10^6 cycles. The results for the damage factor (Fig. 4, a) indicate that the specified event consumes about 0.1% of the life of the shaft model. The minimum factor of safety is 5,619e+028 and biaxiality indicator is 0,0 – the stressed state is one-axial.



a



b

Fig. 4. Damage factor (a) and total life (b) for constant amplitude event

2. Variable amplitude events: Three load history curves, offered from the software, are investigated. The following parameters are set: 25 bins for decomposition of the variable amplitude record; filter load cycles below given % of maximum range – 0 (this means that every cycle will be counted no matter how small its alternating stress is); infinite life – 1.10^7.

2.1. Load history curve „SAE Bracket" – Fig. 5. This curve is closest by type to the presumed curve, reflected alternating stresses of a circular saw shaft according to [5]. The results are represented in Fig. 6 a, to d.

It is obviously from Fig. 6 a, that the maximum damage is 256,4: failure due to fatigue is likely to occur after 1/256,4=0,0039 repeats of this load at node №234 (x=320 mm; y=13,8 mm; z=-8 mm) of the circular saw shaft. The maximum total life is 3369 repeats (Fig. 6, b). Rainflow matrix chart (Fig. 6, c) and damage matrix (Fig.6, d) are obtained and displayed for node with worst damage location – node №234, localized in front of shaft shoulder, where the bearing on the side of V-belt pulley is assembled.

2.2. Load history curve *„SAE Transmission“* – Fig. 7. The results are presented in Fig. 8.

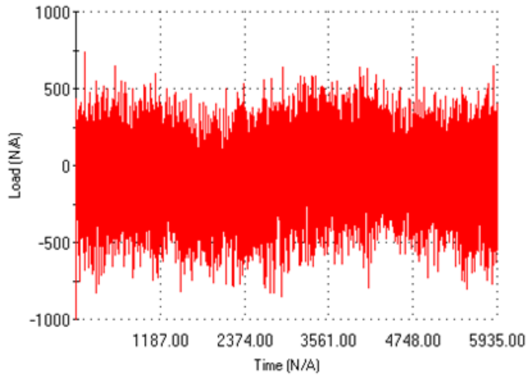


Fig. 5. Load history curve „SAE Bracket“

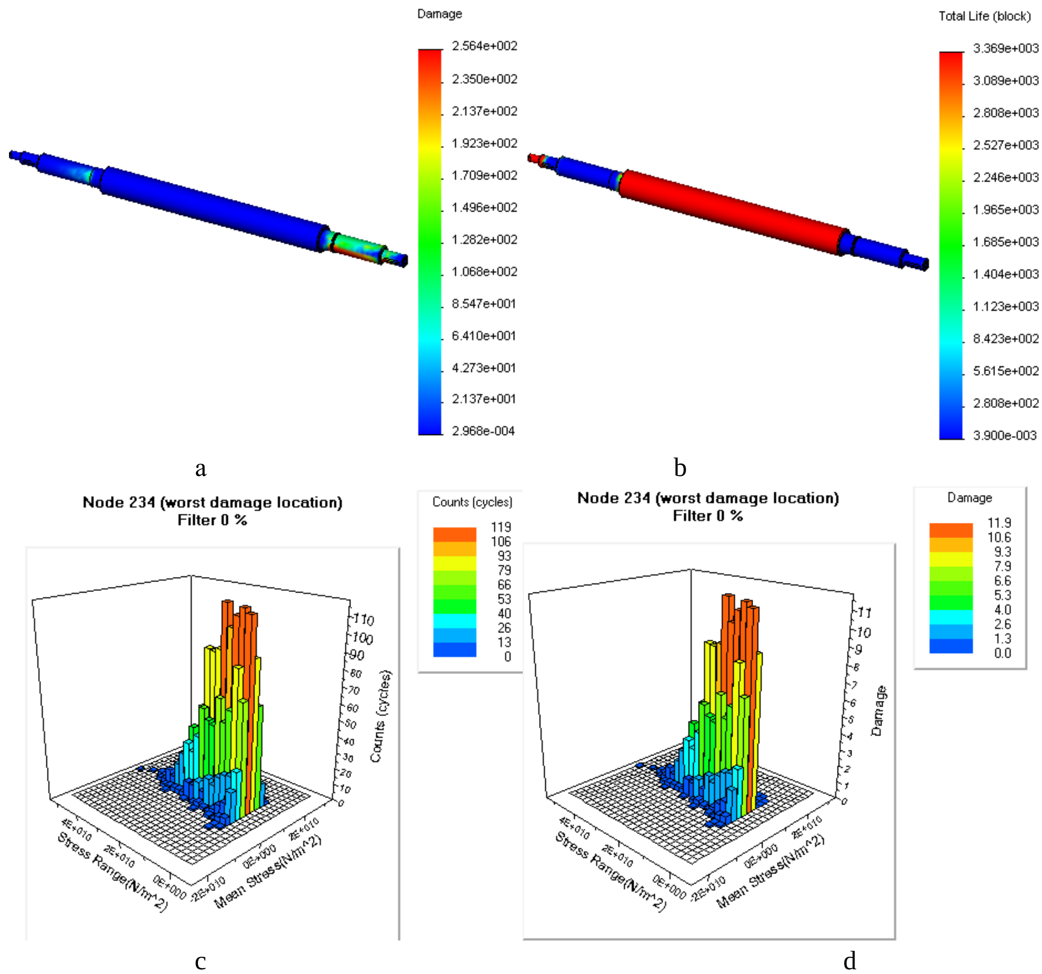


Fig. 6. Damage factor (a), total life (b), Rainflow matrix chart (c) and damage matrix (d) for „SAE Bracket“

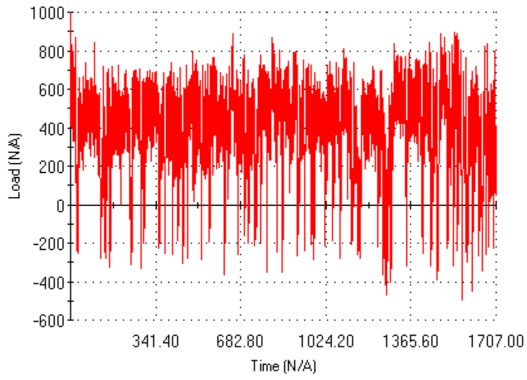


Fig. 7. Load history curve „SAE Transmission“

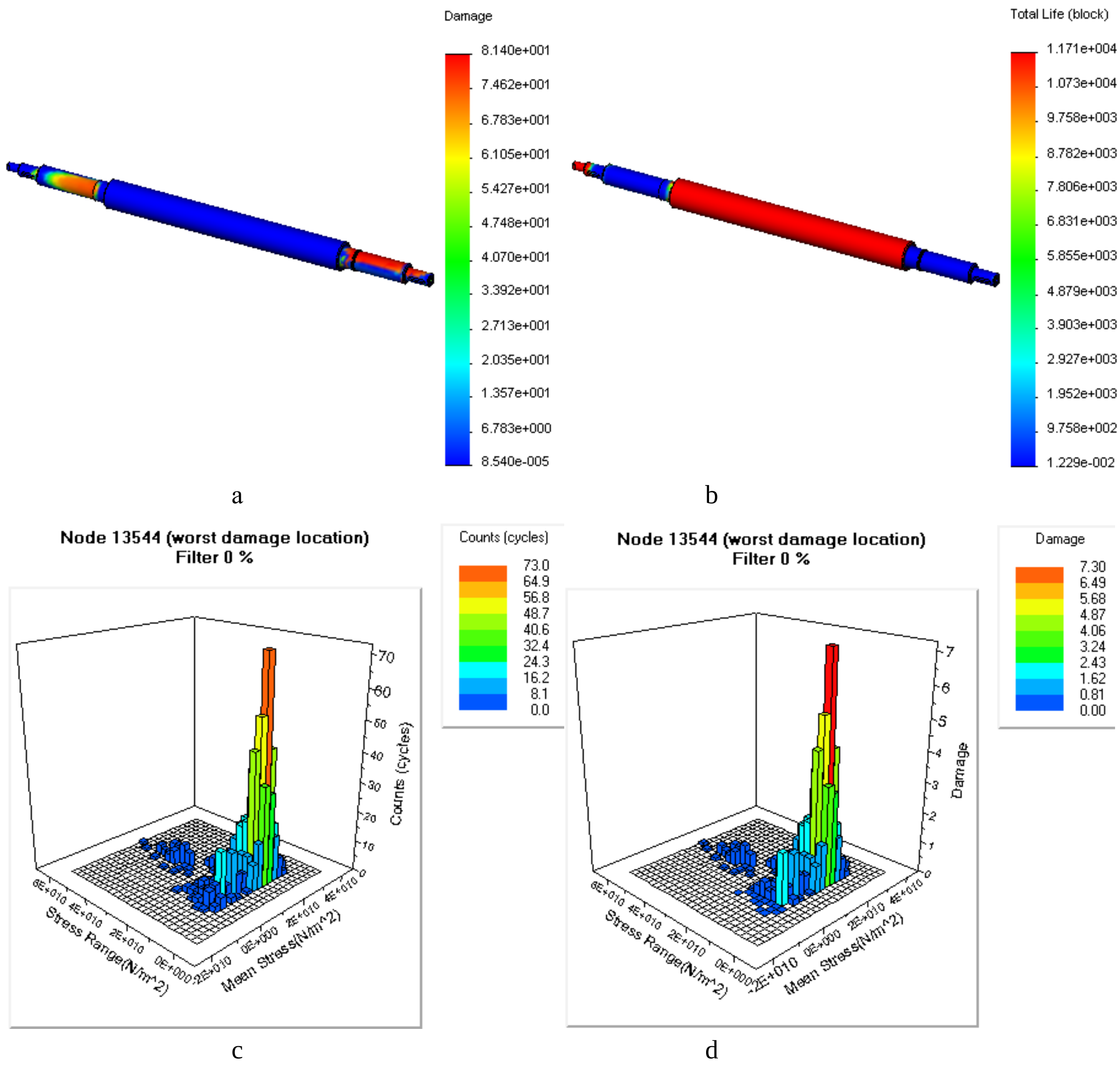


Fig. 8. Damage factor (a), total life (b), Rainflow matrix chart (c) and damage matrix (d) for curve „SAE Transmission“

Damage plot (Fig. 8, a) shows that the maximum damage is 81,40 at node №13544 (x=322,5 mm; y=12,5mm; z=-6,2 mm) and fatigue failure can occur after 1/81,40 = 0,0123 repeats of this load history curve. This result is evident on the Fig. 8, b. The maximum total life is 11 710 repeats. The Rainflow matrix chart (Fig. 8, c) and damage matrix (Fig. 8, d) are presented for the node with worst damage – №13544, localized into shaft shoulder, where the bearing on the side of V-belt pulley is assembled.

2.3. Load history curve"SAE Suspension" – Fig.9. The maximum damage is 123,3 and fatigue failure can occur after 1/123,3=0,0081 repeats at node №101 (x=323 mm; y= -10.4 mm; z= -6 mm), the maximum total life is 8019 repeats. 3D-histograms of rainflow matrix (Fig. 10, a) and damage matrix (Fig. 10, b) are presented for node № 101 with worst damage, localized in front of shaft shoulder, where the bearing on the side of V-belt pulley is assembled.

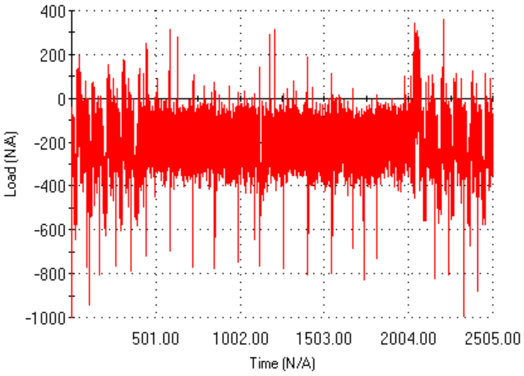


Fig. 9. Load history curve „SAE Suspension"

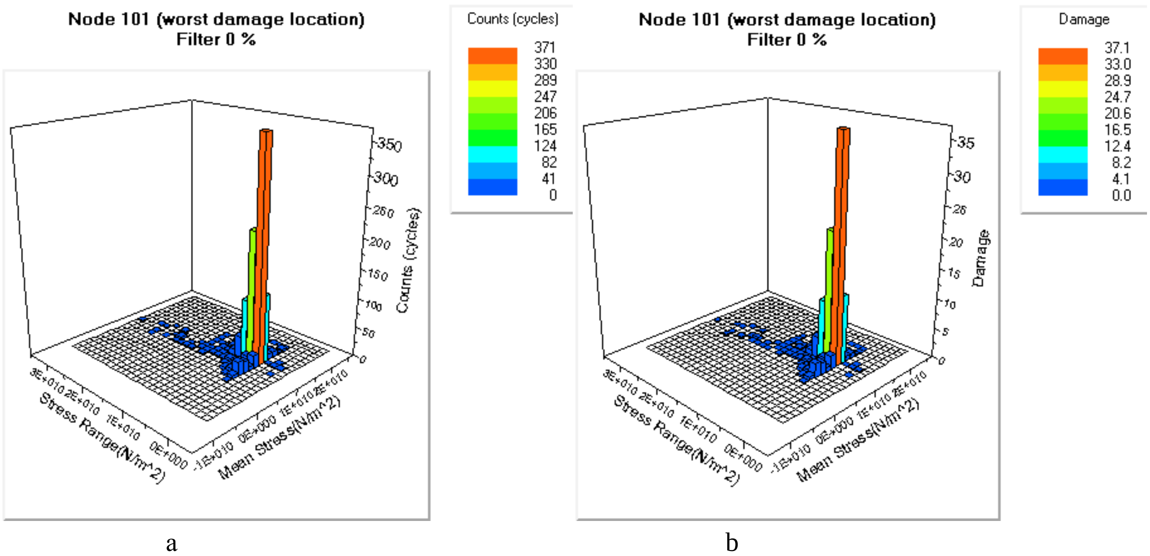


Fig. 10. Rainflow matrix chart (a) and damage matrix (b) for curve „SAE Suspension"

CONCLUSIONS

Modern computer technology is applied in Faculty of Forest Industry – the Fatigue module of CAE system CosmosWorks® is applied by FEA method on the created in SolidWorks® 3D model of circular saw shaft. The present paper can qualify as an open page for application of CAE system CosmosWorks® for fatigue calculations in Faculty of Forest Industry.

The fatigue module offers possibilities, typical for computer era and unthinkable before now: the local stresses in the concentrators into 3D model of circular saw shaft, where fatigue crack can be occur, are determined by FEA; endurance limit and fatigue curve are generated by the computer; loads with constant amplitude and variable amplitude are generated; in the second case accidental loads with different characteristics concerning amplitudes, mean stresses, fatigue damage and others, which are presented with 3D histograms, are generated. CAE system CosmosWorks® can do all this for all nodes of finite elements mesh of circular shaft 3D model and for each other constructive element.

Haw far these computer possibilities can serve for adequate fatigue calculations of constructive elements is a disputable question according the critical analysis in [6] and [8]. Computer systems are used for generating of fatigue loads and fatigue calculations. For example in [9] and chapter 3 of [6] calculations of fatigue life are produced from oscillograms of polish authors, which are generated with a similar computer system and are statistically presented with similar 3D histograms. Used methods are similar to these presented here. So, demonstrated possibilities of CAE system CosmosWorks® in this paper can be applied in the fatigue investigations in Faculty of Forest Industry.

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ИЗСЛЕДВАНЕ НА ЦИРКУЛЯРЕН ВАЛ ОТ ДЪРВООБРАБОТВАЩА МАШИНА НА УМОРА С COSMOSWORKS®

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РЕЗЮМЕ

Във ФГП в последните години се провеждат систематични изследвания на умора, с които настоящата статия корелира. 3D-модел на циркулярен вал от дървообработваща машина е изследван на умора по метода на крайните елементи (МКЕ) с програмата

CosmosWorks®, въз основа на кривата на умора (*S*-*N* крива) за въглеродна качествена стомана 45. Изследвани са различни случаи на умора – с константна амплитуда (коефициент на асиметрия *R*=-1) и с променлива амплитуда. Получени са графики за дълготрайността, повреждането, както и 3D-хистограми на дъждовното стичане и повреждане.

Ключови думи: умора, дълготрайност, циркулярен вал, CosmosWorks®, МКЕ