

INTEGRATION OF DAMAGE DIFFERENTIALS: APPLICATION FROM THE FOREST INDUSTRY INTO THE CIVIL ENGINEERING

Stefan Stefanov

University of Forestry, Sofia, Bulgaria

e-mail: stefanov_sh@abv.bg

ABSTRACT

Integration of Damage Differentials (IDD) method was developed in Faculty of Forest Industry. It is applicable e.g. for fatigue life computation of bandsaw blade. In this regard, stress oscillograms were presented. They vary about a comparatively great mean stress: in the order of the half of the maximum stress. An analogous case in bridge construction is considered in a Ph.D. thesis developed in Sofia University of Architecture, Civil Engineering and Geodesy where IDD was adopted. The great mean stress effect is clarified regarding how IDD takes it into account in contrast to standard methods in the civil engineering.

Key words: fatigue life, integration of damage differentials (IDD), bandsaw blade, bridge, mean stress effect.

INTRODUCTION

„Integration of Damage Differentials” is a method for fatigue life assessment developed in the Faculty of Forest Industry and defended in a DSc thesis (Stefanov 2011a). This method obtained wide international popularity: the web site shown below at (Stefanov 2011a), where the thesis had been translated into English, counted over one thousand visitors. The monograph (Stefanov 2012) also contributes to the popularity. It is disseminated by LAMBERT Academic Publishing. As well, the paper (Stefanov 2011b), published after four more ones in Int. J. Fatigue, enhances the popularity.

IDD is a proposed new scientific line which would re-direct a vast world-wide research experience, accumulated for nearly two centuries, into another course. The basic notion of this experience is loading cycle and therefore the hitherto existing approach is called Cycle Counting approach. With IDD, the basic, general notion is loading differential, while loading cycle is a particular notion, and the damage differentials per the separate loading differentials are inte-

grated (summed). That such differentials are introduced for fatigue life assessment may have the same importance which the differentials introduced in the mathematics and exact sciences generally have: decisive.

However, IDD cannot replace Cycle Counting so far, since the Cycle Counting approach lies in all the state standards (so-called Codes) in the world with regard to fatigue life assessment. The author was addressed by specialists from different countries with the acknowledgement that IDD provokes necessity of re-considering and updating the mentioned state standards. But the specialists also say what is also understood by itself: it would be a tough job. Big engineering societies should be convinced and they should reach a consensus in a situation where their members are usually engaged with the application of the Cycle Counting approach and have contracts including financing for that.

For example, Tim D. Gilman, affiliated with Structural Integrity Associates, Inc., San Jose, CA, USA, expert in the prevention and control of structural and mechanical failures, wrote to the author, as

follows. „The biggest obstacle to acceptance of the integral methodology, at least within my realm, is consensus with the Code committees (American Society of Mechanical Engineers committees and their equivalents abroad). The methodology we use was cutting edge in the 1960s, but regrettably hasn't changed much since then. It is very difficult to gather consensus and move forward. Thanks again for your work.”

From such a point of view it becomes understandable that big international projects initiated by Jan Papuga (see PragTic Project on <http://www.pragtic.com>) were not approved for financing from the EU. The innovations proposed, including IDD (announced by Jan Papuga as a „revolutionary” method), were not accepted. The Bulgarian National Science Fund did not approve, either, 2009 and 2010 projects for development and establishment of IDD. Those projects were presented by the author on behalf of The University of Forestry with additional Bulgarian partnership (of Gabrovo Technical University) and international collaboration (of specialists from Czech Republic, Germany, Italy. etc.).

Even internal projects within The Faculty of Forest Industry were not approved: „Fatigue of materials and machines in the forest industry” 2011, and „Fatigue of band-saw blade and other machine components in the forest industry” 2012. In those projects, the goal was put to carry out, publish and herald studies (in continuation of already existing initial studies), including on the highest international level, which would advance The Faculty of Forest Industry as well-known or leading among the similar faculties in the world with regard to competence on the fatigue of materials and machines in the forest industry, and primarily on the fatigue of bandsaw blades. The basic premise for reaching such a goal was asso-

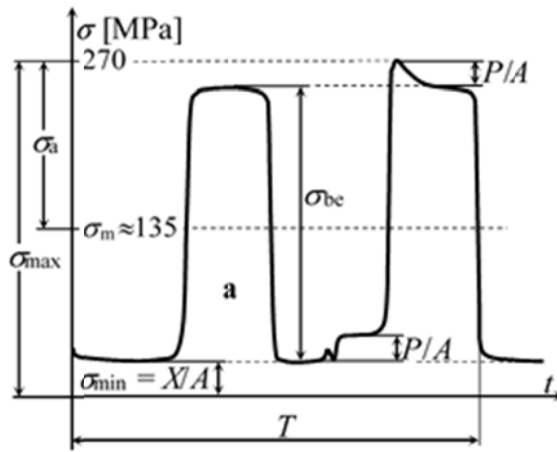
ciated with the fact that the new IDD research line had been developed in Faculty of Forest Industry for thirty years. However, one of the reviewers even stated that “insignificant scientific contributions” were presented (an interesting verdict towards the IDD background mentioned above).

The author hopes, notwithstanding, that the new young generation of researchers in Faculty of Forest Industries would take over the torch for IDD application and, generally, for fatigue computation to the machines and technical equipment in the forest industry. Following such an idea, the author encouraged the presentation of the INNO paper (Vichev and Koynov 2011), as well as the collaboration with V. Atanasov (Stefanov and Atanasov 2014) and (Atanasov 2014).

Anyway, no Ph.D. student in Faculty of Forest Industry was directed to a subject like „Fatigue calculation and IDD application in the forest industry” supervised by Stefanov. But that is why, the author is satisfied that a Ph.D. student in Sofia University of Architecture, Civil Engineering and Geodesy set IDD application to civil engineering constructions as a basic part of her Ph.D. thesis (Kindova-Petrova 2014). After studying (Stefanov 2011a, b) and several more IDD papers, Kindova-Petrova found out that IDD, unlike standardized methods (Codes) in the civil engineering, takes into account the mean-stress effect (comparatively high mean stress as a mean level of an oscillogram of a variable stress is meant).

Respectively, comparative numerical analysis of obtained IDD fatigue lives and EUROCODE fatigue lives was done in (Kindova-Petrova 2014). Meanwhile, a computer program called “ODIDU” was created in MATLAB environment for fatigue life computation under one-component random loading, including by means of the IDD approach. As a matter of fact, based on

MATLAB environment, updating a part of the IDD software was done in (Kindova-



Petrova 2014). That part is the „Integral” program in (Stefanov 2011a).

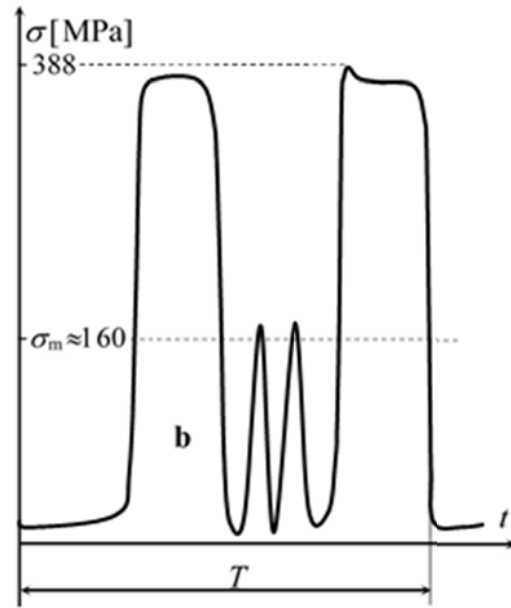


Figure 1: Oscillograms $\sigma(t)$ with a vertical (a) and a horizontal (b) bandsaw

1. OSCILLOGRAMS HAVING A COMPARATIVELY GREAT MEAN STRESS: WITH BANDSAW BLADES AND A BRIDGE CONSTRUCTION

In Fig. 1a, an appearance of an oscillogram $\sigma(t)$ is shown as a result of the study carried out in (Stefanov 2013). A vertical bandsaw UB400 is meant. The oscillogram applies to a point of the external side of the blade where the variations of $\sigma(t)$ keep the same algebraic sign. The maximum stress σ_{\max} of the oscillogram is formed by summation of components X/A , σ_{be} and P/A , where X is the internal tensile force in the non-cutting branch of the blade, A is the area of the blade's cross section, σ_{be} is the stress of bending the blade onto the semi-circumferences of the two wheels, and P is the cutting force component that is longitudinal to the blade. The oscillogram of the kind of Fig. 1a was introduced for the first time in (Stefanov 2013) where the statically indeterminate problem for determination of X was set and solved. By forming such an

oscillogram the basic premise for fatigue calculation of a bandsaw blade is set.

In Fig. 1b, an oscillogram with a horizontal bandsaw („Wirex 1/ZM”) is shown as calculated in (Atanasov and Stefanov 2014). It took place in the dissertation (Atanasov 2014). In this oscillogram, apart from the two big peaks due to the consecutive bending of the blade onto the semi-circumferences of the one and the other wheel, smaller peaks due to the bending of the blade onto the blade guides are also available. Such an oscillogram was also for the first time presented in the cited papers. It is specific that σ_{be} is significantly greater in Fig. 1b than in Fig. 1a due to the smaller wheel radius with a horizontal bandsaw comparatively to a vertical one.

If an oscillogram vary in a sinusoidal way between σ_{\min} and σ_{\max} , the mean stress is $\sigma_m = (\sigma_{\min} + \sigma_{\max})/2$, and the amplitude is $\sigma_a = (\sigma_{\max} - \sigma_{\min})/2$. However, if the variations of the oscillogram between σ_{\min} and σ_{\max} are more complex like in Fig. 1a and Fig. 1b, then the mean level σ_m of the whole

oscillogram is not formed by the equation $\sigma_m = (\sigma_{min} + \sigma_{max})/2$ but in a more complicated way (Stefanov 2011a). Anyway, Fig. 1 clears that σ_m of a bandsaw blade is a com-

paratively great stress: in the order of the half of σ_{max} . Starting from σ_m , the amplitude σ_a is measured.

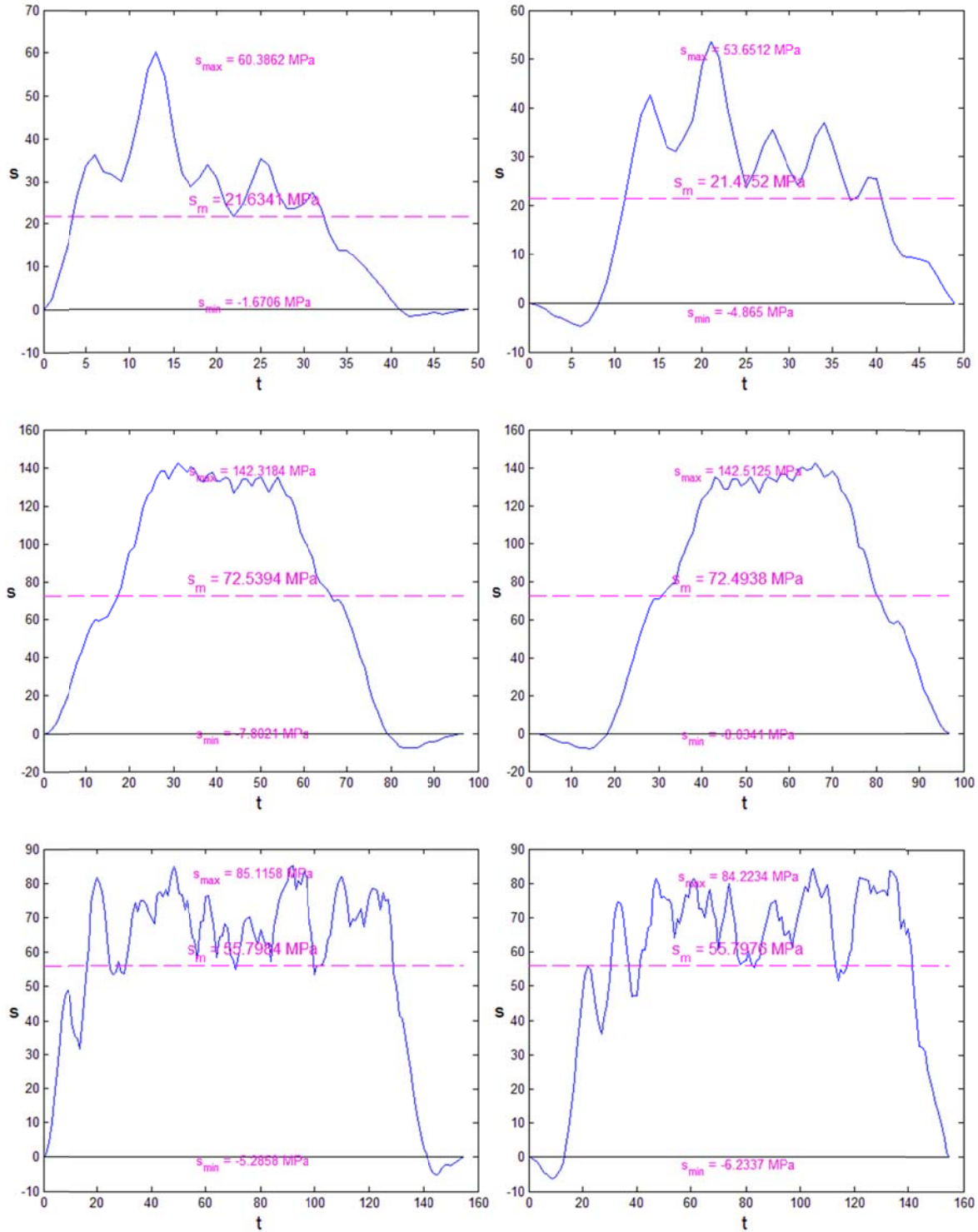


Figure 2: Oscillograms of stress $s(t) \equiv \sigma(t)$ in the main beam of the bridge in Fig. 3 caused by trains of different types while passing in the direction Plovdiv – Parvomay

In Fig. 2, oscillograms of a stress are shown after taking them from the dissertation (Kindova-Petrova 2014). They are valid for different types of trains. The stress is $s(t) \equiv \sigma(t)$ in the main beam of the bridge in Fig. 3. A series of details about the oscillograms (Fig. 2) can be seen in the dissertation. Here



Figure 3: Bridge over Chaya river

This problem is one of the toughest points in the fatigue life science. Many thousands of papers in the world were devoted to it for the last two centuries. All of them follow the Cycle Counting approach and refer to how to use a $S-N$ line (fatigue curve), valid for a zero mean stress, also in the case when the mean stress is not zero. In other words, how to apply a fatigue curve of s_a-N type (amplitude-life where the life is number of cycles N to fatigue failure), valid for fully reversed cycle i.e. for $s_m = 0$, also to a given arbitrary oscillogram which has $s_m \neq 0$. And, since this question cannot find a single and all-acknowledged solution, the

it is to notice that these oscillograms also have a comparatively great mean stress $\sigma_m \equiv s_m$ which is in the order of the half of $\sigma_{\max} \equiv s_{\max}$. Thus, the problem of how to take into account the mean-stress effect on the fatigue life arises in both cases (Fig. 1 and Fig. 2).

Codes either avoid it or are in conflict with one another.

Concretely speaking, the Bulgarian civil engineering standard EH 1993-1-9:2005 needs improvement according to (Kindova-Petrova 2014). Hence, the interest for application of IDD to the civil engineering came to being. The IDD approach is radically different: any damages per stress cycles are not searched in advance and schematized (the two-century Cycle Counting approach is not followed) but damage differentials are directly summed on the differentials of stress variation. Correspondingly, the IDD point of view for taking into account the mean-stress

effect is different. This point of view is interpreted for the first time out of (Stefanov 2011a) in the next section.

2. „HISTORY” AND „FUTURE” IN AN OSCILLOGRAM, MEAN (STATIC) LEVEL AND CONTINUITY

When cycles are searched instead of dealing with instantaneous (running, current) ordinates of the oscillogram $s(t)$, any possibility is excluded to determine the current (instantaneous) value of the damage $D_{\Sigma}(t)$ accumulated till the current time t . If dealing with cycles, then, in order to form a cycle after t , “viewing/ peeping/ dipping into the future” is needed to see how the loading runs after t . And the “future” may differ, and, thus, different cycles may appear leading to different results for the fatigue damage accumulated to t . However, the material suffers only one real value of this damage depending only on the loading history to the time t . The material “does not know the future” of the loading after t : the appearance of the next peak, its level, and so on. Not the material but the seekers of cycles are who want to know future peak(s) because they want to complete next cycle(s) after the last known peak. There is a logical paradox here: some damage has already been done but for its evaluation by means of a Cycle Counting method researchers need to preliminarily know the next development of the loading.

IDD is the method able to avoid such a “paradox of dipping into the future” of the loading. As a mathematical approach, IDD allows determination of $D_{\Sigma}(t)$ till the t time, as well as determination of damage differential dD per time differentials dt , only based on the loading history till the t time. This also means that IDD forms $D_{\Sigma}(t)$ as a continuous function. In other words, IDD forms the cumulative damage as a continuous pro-

cess, as it actually is, without inserting sudden portions (quanta) of damages from built cycles.

Nevertheless, the logical paradox considered, respectively the representation of the cumulative damage as a process discontinued into portions, does not stop any relevantly applied cycle counting method to determine fairly well the damage accumulated till the last already known peak of the oscillogram. However, after conceptual imperfection is available, there will be also irrelevantly applied cycle counting methods and wrong fatigue life assessments.

The mechanism of memorizing the loading history and its influence on the cumulative damage remains inscrutable. Therefore, a preliminary survey of the whole oscillogram is inevitable in order to find out the static s_m level and compose a corresponding $S-N$ line by accounting s_m . The necessity of this “dipping in the future for s_m ” is a tougher paradox than the one mentioned above. Methodical complications occur, as well, if some s_m is formed and kept for some length of time, and later s_m is shifted.

Like the Cycle Counting approach, the present version of the IDD method also needs a preliminary survey of the whole oscillogram for determination of s_m . That is, an „old” manner is set that implies an “old” problem. However, this is not a limitation from the IDD concept: when the Cycle Counting followers really discover an indisputable way to account the influence of a static stress $s_m = s_m(t)$ being formed to t , that way will be immediately exploited by IDD, as well.

First of all, the introduced damage intensity $R = R(s) = dD(s)/ds$ throws new light on that Cycle Counting problem: whether amplitudes $s_{a,i}$ should be arranged at one and the same s_m or at different $s_{m,i}$ levels. From

the IDD point of view, if changing the damage per a range (a half-cycle) to another value per the next range due to changing $s_{m,i}$, then the damage intensity $R(s)$ will discontinue. Indeed, during the infinitely small increase ds of s at the transition from the previous range to the next one, the intensity $R(s)$ will go through a finite increase i.e. discontinuity. However, $R(s)$ implies some physical damage intensity which should be mathematically continuous. Actually, the material “is getting accustomed” to s_m of the whole oscillogram and cannot immediately react to each shift of $s_{m,i}$ from one range to the next one.

Anyway it is obvious that $R(s)$ will be influenced by s_m and is formed as $R = R(s, s_m)$. This idea can be expanded: the integrand could include arguments for “memorizing”, “getting accustomed” and others. Obviously, the material starts damaging at the beginning of the loading regardless of future value of s_m . Later, the material “remembers” which values of s mostly repeat and “gets accustomed” to them. For example, a “mean stress memory argument” could be formed from a number of recent ranges to the current time t . This number should be enough so that the stress memory argument would start reflecting the process of “getting accustomed” to static stress s_m formed. As well, the same argument should reflect possible shift of s_m and getting out of the habit for the previous s_m , followed by new “getting accustomed”, and so on.

Thus, the preliminary survey of the oscillogram, as a paradox of needing the loading run after t for calculating damage before t , would drop out. However, then a special “initial” $S-N$ line would be required which is originally independent of s_m and later is influenced by the arguments mentioned above. The “initial” $S-N$ line would be that one valid for symmetrical cycle: the initial damage

intensity is expected to be the most intensive and later it decreases in case $s_m \neq 0$ is formed.

Said conclusively, the effect of $s_m \neq 0$ in the present IDD version is taken into account by using not a standard fatigue curve of the kind s_a-N for determining the damage intensity $R(s)$ but a curve of the kind $s_{max}-N$ where $s_{max} = s_m + s_a$. A series of details in this regard can be seen in (Stefanov 2011a).

3. IDD APPLICATION IN (KINDOVA-PETROVA 2014)

Using the computer program “ODIDU” created in the thesis (Kindova-Petrova 2014), fatigue lives were computed for the bridge (Fig. 3) according to IDD and EUROCODE 3. In the second case, the amplitudes $s_{a,i}$ were transformed to be valid for $s_m = 0$ what is not logical according to the above section but remains as a standardized device of the Cycle Counting approach. As comparative data in tables in (Kindova-Petrova 2014) show, IDD predicts lower lives than EUROCODE 3. The lowering varies from 19.5 % to 96.9 for the above-mentioned different types of trains.

In this situation, the dissertation (Kindova-Petrova 2014) provokes for higher control of fatigue cracks during inspections of the bridge.

CONCLUSIONS

In the dissertation (Kindova-Petrova 2014), the IDD method is popularized also in Bulgaria and is applied to the civil engineering. The IDD advantages are emphasized and the accent is mainly put on the way of taking into account the mean-stress effect. This accent is the main point of the present paper, as well. Besides, IDD application to the fatigue under multicomponent stressing (where the IDD strong point is) of civil engineering constructions is outlined in (Kindova-Petrova 2014) as one of the future

developments in the University of Architecture, Civil Engineering and Geodesy.

After such a kind of acknowledgement of IDD, the author hopes that the possibility for IDD application to the forest industry will be better recognized in the Faculty of Forest industry where IDD was developed. Generally speaking, the fatigue computation of bandsaw blades and other machine components of woodworking machines (Stefanov et al. 2011, Staneva 2012) should become one of the priority research lines in the Faculty of Forest industry, and young colleagues and resources should be directed to that line. A lot has already been done in favor of such computation, although without financing.

REFERENCES

1. Atanasov V. (2014). *A Study on Operational Indicators of Mobile Horizontal Bandsaws*, PhD Thesis, University of Forestry, Sofia (in Bulgarian).
2. Atanasov V. Stefanov S. (2014). *Calculation of Operational Stresses in Blades of Horizontal Mobile Bandsaws*, Innovations in Forest Industry and Engineering Design, 3/2014 (in print).
3. Kindova-Petrova D. (2014). *Studies on Fatigue of Civil Engineering Constructions*, PhD Thesis, University of Architecture, Civil Engineering and Geodesy, Sofia (in Bulgarian).
4. Staneva N. (2012). *Fatigue Study of a Circular Saw Shaft with CosmosWorks®*, Innovations in Forest Industry and Engineering Design, 1/2012, Vol. I, pp. 99–106.
5. Stefanov S. (2011a). *Integration of Damage Differentials (IDD) for Fatigue Life Assessment under Any Loading*, DSc Thesis, University of Forestry, Sofia. Web sites: <http://metodnaintegra-la.hit.bg> (in Bulgarian), <http://www.free-webs.com/fatigue-life-integral> (in English)
6. Stefanov S. (2011b). *Integration of Damage Differentials (IDD): General Presentation and Verification Results*, Int. J. Fatigue, 33 (2011), 8 (Special Issue on Multiaxial Fatigue Models), pp. 977–984.
7. Stefanov S. (2012). *Integration of Damage Differentials (IDD) for Fatigue Life Assessment/ Under any Loading*, LAMBERT Academic Publishing.
8. Stefanov S. (2013). *Development of a Model for the Variable Tensile Stress in Band-Saw Blade*, Innovations in Forest Industry and Engineering Design, 2/2013, Vol. II, pp. 113–122.
9. Stefanov S., Gochev Zh., Trichkov N., Vichev P., Koynov D. (2011). *Initial Study of Stress Variations of a Saw Shaft with Regard to Fatigue Calculation*, Innovations in Forest Industry and Engineering Design, pp. 155–160 (in Bulgarian).
10. Vichev P., Koynov D. (2011). *Review on Studies of Loading Variation in Machines and Technological Equipment in Forest Industry with Regard to Fatigue Calculation*, Innovations in Forest Industry and Engineering Design, pp. 157–162 (in Bulgarian).



UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

1/2016

INNO

vol. V

Sofia

ISSN 1314-6149
e-ISSN 2367-6663

CONTENTS

SAWING OF DOUGLAS FIR LOGS WITH NARROW BAND SAW BLADES IN WINTER CONDITIONS	5
Zhivko Gochev, Valentin Atanasov	
CORRELATION BETWEEN PHYSICAL AND MECHANICAL PROPERTIES OF THE WOOD.....	13
Todor Petkov, Panayot Panayotov	
COMPUTATION OF THE AVERAGE WOOD TEMPERATURE AND THE RATE OF ITS CHANGE DURING UNILATERAL HEATING OF FLAT SPRUCE DETAILS BEFORE THEIR BENDING	21
Nencho Deliiski, Neno Trichkov, Dimitar Angelski, Ladislav Dzurenda	
THE EMISSIONS EMITTED BY SPRUCE THERMOWOOD WITH AND WITHOUT SURFACE FINISHED	28
Daniela Tesařová, Petr Čech	
INTEGRATION OF DAMAGE DIFFERENTIALS: APPLICATION FROM THE FOREST INDUSTRY INTO THE CIVIL ENGINEERING	38
Stefan Stefanov	
STUDY MODULE „PROJECT WEEK“: THROUGH THE EYES OF STUDENTS	46
Regina Raycheva, Vassil Jivkov, Desislava Angelova, Pavlina Vodenova	
INFLUENCE OF DRYING ON DOUGLAS-FIR HEARTWOOD IMPREGNABILITY TO WATER	54
Mohamed Tahar Elaieb, Anélie Petrissans, Ali Elkhorchani, Rémy Marchal, Mathieu Petrissans ³	
ADDITIONAL LOAD FROM RADIAL MISALIGNMENT OF SHAFTS AT THEIR COUPLING	63
Slavcho Sokolovski, Nelly Staneva	
POSSIBILITIES FOR OPTIMIZATION OF DISTRIBUTIVE INDICES FOR AVERAGE COSTS CALCULATION IN JOB ORDER AND SMALL SCALE SERIAL PRODUCTION	71
Nikolay Neykov, Anna Dobritchova, Mariela Cvetkova	
INFLUENCE OF THE TYPE OF UPHOLSTERY MATERIALS ON THE SOFTNESS OF UPHOLSTERY WITH INNER SPRING UNITS	76
Yancho Genchev, Teodor Lulchev, Desislava Hristodorova	
ANALYSIS OF THE DEWINGING PROCESS ON SCOTS PINE SEEDS WITH SMALL-SIZED DEWINGER	82
Konstantin Marinov	
QUANTITATIVE YIELDSFROM THE CUTTING OF THE STEMS OF WHITE PINE (<i>PINUS SYLVESTRIS</i> L.), DEPENDING ON THE THICKNESS AND LENGTH OF THE DETAILS AND THEDEFCTS OF THE WOOD	93
Daniel Koynov	
CHARACTERISTICS OF THE TRUNKS OF SCOTS PINE (<i>PINUS SYLVESTRIS</i>) FOR PRODUCTION OF SOLID WOOD MATERIALS	99
Neno Trichkov, Daniel Koynov	
SCIENTIFIC JOURNAL „INNOVATIONS IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN“	109