REVIEW OF THE CONTRIBUTIONS

of the thesis

Author's note

Since everything in the thesis presented is entirely original and different from all the existing fatigue life investigations, the initial list of contributions has been inevitably long. A trial has been done to reduce the formulations of contributions to less, general paragraphs (in Italic) followed by subparagraphs. However, the subparagraphs have made the description of contributions still as large as to evoke a recommendation, on the part of the Department Council (on June 21, 2011), for shortening. Thus, only the general paragraphs (in Italic) are presented below. Readers who would want to see the submenus of the general paragraphs as concretized subparagraphs can do that after finding Expanded Review of Contributions link on the Home page of the IDD site. After all, 13 Scientific Contributions are presented below on three pages. They are followed by two Theoretical and Applied Contributions and five Practical Contributions.

SCIENTIFIC CONTRIBUTIONS

1. *A new, original scientific research line has been revealed which is radically different from the existing CCA approach in the fatigue life science and which is called Integration of Damage differentials* (*IDD*). *The hitherto existing notion of loading cycle is not basic but particular. In the IDD basis the notion of loading differential lies and damage differential is searched per it. In fact, a completely different concept and strategy for solving the fatigue life problem under any loading is proposed.*

2. *It has been revealed that the great theoretical and applied fatigue life problem is generally and uniformly solvable namely based on the IDD concept in accordance with the contemporary achievements of numerical integration of any differential equations in finite differences or finite elements under any integration conditions, by means of the contemporary computers. Thus, nowadays, it is already possible to redirect the accumulated world CCA experience to IDD.*

3. *The first IDD problem has been formulated* (*Subchapter 1.6*) *and solved* (*Subchapter 2.1*)*: under arbitrary and non-proportional oscillograms* $\sigma_x(t)$, $\sigma_y(t)$ *and* $\tau_{xy}(t)$, *how to redefine the variant* d*s differential from the* σ_x-σ_y-τ_{xy} *coordinate space* (*Fig. 1.1-3b*) *into a differential* d*s which is invariant of the axes x and y. The idea of the transforming ellipse has been generated. The invariant* d*s differential proves to be in a new, special three-dimensional space* σ'-σ''-dτ *where* σ' *and* σ'' *are the principal stresses, and the third dimension* dτ *is infinitesimal. In that three-dimensional space, an invariant trajectory is described by adding each next invariant* d*s differential. The latter has two components in the* σ'-σ'' *plane, and the third* dτ *component is perpendicular to the* σ'-σ'' *plane. That third component is the most interesting: it takes into account the rotation of the principal axes. The invariant* d*s differential revealed results from single possible logic. It leads to new terminology of the loading kinds.*

4. *Fatigue damage differential* $dD_r = R_r ds_r$ *has been introduced* (*Subchapter 2.2*) *per the* ds_r *differential and thus a new basic notion has been revealed: damage intensity* $R_r(s) = dD_r(s)/ds_r$ *under r-loading as a derivative of damage function* $D_r(s)$. *The argument s is the distance from* ds_r *to the coordinate origin of the* σ'-σ'' *plane, at a given value of* $k = \sigma''/\sigma'$. *The problem of determination of* $R_r(s)$ *arises. It has been solved* (*in Subchapter 2.3*) *based on a so-called input* R_r *prototype in a way allowing IDD to reproduce a given S-N line under cyclic r-loadings having one and the same k value. Further on, the problem of determination of* R_r *in the whole* σ'-σ'' *plane arises. It has been solved* (*in Subchapter 2.4*) *in a way allowing IDD to reproduce two or more given S-N lines based on corresponding* R_r *prototypes under cyclic r-loadings having different values of k. With that, the notion of fatigue limit has been replaced (in Section 2.7.7) by the more general notion of* L_r *limiting line which surrounds* L_r *area of* $R_r = 0$ *in the* σ'-σ'' *plane* (*L_r is no-damage area where the* ds_r *differentials do not cause damage*).

5. *Fatigue damage differential* $dD_c = R_c ds_c$ *per* ds_c *differential has been introduced and thus a second kind of damage intensity* $R_c = dD_c/ds_c$ *under c-loading has been revealed. An idea has been developed* (*in Subchapter 2.5*) *for determination of* R_c *in the entire* σ'-σ'' *plane what has involved aspects unrevealed before in the CCA investigations. Therefore, at the present stage of IDD developments, in following the logic of building the IDD theory, conditional* R_c *prototypes have been introduced. They are analogous to the* R_r *prototypes and thus the* R_c *intensity is set in comparison to* R_r. *The ratio* $f_c = R_c/R_r$, *averaged in the* σ'-σ''

plane, has been introduced. It takes the role of empirical factor of sensitivity of the material to non-proportional c-loadings in comparison to r-loadings.

6. *Fatigue damage differential* $\mathrm{d}D_\tau = R_\tau \mathrm{d}\tau$ *per* $\mathrm{d}\tau$ *has been introduced. Thus, a third kind of damage intensity* $R_\tau = \mathrm{d}D_\tau/\mathrm{d}\tau$ *has been revealed under* $\mathrm{d}\tau$*-loading i.e. under constant principal stresses in rotating principal directions* (*principal axes*). *This loading* (*Subchapter 2.6*) *came as a discovery thanks to the IDD point of view. It will put to the test all the existing fatigue life criteria. That is why it is appealed to laboratories to enable research under* $\mathrm{d}\tau$*-loading provided that they have the necessary experimental facilities. An idea for determination of* R_τ *in the entire* σ'-σ'' *plane has been developed. Due to the lack of previous investigations, conditional* R_τ *prototypes have* (*again*) *been introduced analogously to the* R_r *prototypes. Thus, the* R_τ *intensity is set* (*again*) *in comparison to* R_r. *The ratio* $f_\tau = R_\tau/R_r$, *averaged in the* σ'-σ'' *plane, has been introduced. It takes the role of empirical factor of sensitivity of the material to rotation of the principal axes.*

7. *A basic version of formula of* $\mathrm{d}D \sim \Delta D$ *has been proposed* (*in Subchapter 2.7*) *and grounded under any mixed loading where* $\mathrm{d}s_r$, $\mathrm{d}s_c$ *and* $\mathrm{d}\tau$ *simultaneously appear. The formula is:* $R_r(\mathrm{d}s_r^2 + f_c^2\mathrm{d}s_c^2 + f_\tau^2\mathrm{d}\tau^2)^{1/2} \sim R_r(\Delta s_r^2 + f_c^2\Delta s_c^2 + f_\tau^2\Delta\tau^2)^{1/2}$. *This formulation gives the attractive opportunity to use the traditional S-N lines under cyclic r-loadings for fatigue life assessment also under any non-proportional loading thanks to the factors* f_c *and* f_τ *of the material sensitivity to loading non-proportionality. The task has been put for building, enlarging and précising an empirical data bank for* f_c *and* f_τ *as a result of IDD verifications. Within that bank, the values of* f_c *and* f_τ *are to be appropriately selected to serve for every new application of the IDD method developed. Together with* f_c *and* f_τ, *the parameters* N_c *and* N_τ *in ratios to* N_r *will also participate in the data bank. They set the areas* L_c *and* L_τ *in the* σ'-σ'' *plane where the differentials* $\mathrm{d}s_c$ *and* $\mathrm{d}\tau$ *cause no damage. Those areas are surrounded by limiting lines* L_c *and* L_τ *replacing the previous notions of fatigue limits under non-proportional loadings.*

8. *It has also been revealed* (*in Section 2.4.2 etc.*) *that the IDD concept allows a simple and uniform approach to taking into account non-zero static* (*mean*) *stresses* $\sigma_{x,\mathrm{m}}$, $\sigma_{y,\mathrm{m}}$ *and* $\tau_{xy,\mathrm{m}}$ *of the oscillograms* $\sigma_x(t)$, $\sigma_y(t)$ *and* $\tau_{xy}(t)$: *based on* $\sigma_{x,\mathrm{m}}$, $\sigma_{y,\mathrm{m}}$ *and* $\tau_{xy,\mathrm{m}}$, *an equivalent static stress* $\sigma_{\mathrm{equ,m}}$ *is calculated and the input prototypes of the damage intensity are adapted to* (*are made compatible with*) *that* $\sigma_{\mathrm{equ,m}}$. *In comparison to* $\sigma_{\mathrm{equ,m}} = 0$, *a non-zero* $\sigma_{\mathrm{equ,m}}$ *moves up the* R_r*-prototypes* $\sigma'_{\max}$-N (*and increases their indicators of slope*) *according to the well-known Smith relations, and thus the* R_r *intensity decreases. The accumulated world experience about S-N lines valid for non-zero levels of cyclic r-loadings is applicable again. But now it is applicable directly, without any additional conceptual complications and contradictions that appear with CCA upon considering the so-called means stress effect.*

9. *The IDD way of thinking contributes* (*in sections 1.3.4, 2.3.7, 2.7.6 etc.*) *to perception of the real fact that only the loading history to the current t time influences* $\mathrm{d}D$ *damage differential during* $\mathrm{d}t$, *and the loading future after the t time, what "the material does not know", cannot influence* $\mathrm{d}D$. *In this regard, CCA actually admits illogicality called in the thesis "paradox of peeping into the loading future". The IDD viewpoint turns thinking in a more logical direction for making out the inscrutable mechanism of influence of static stresses being formed, for taking into account the non-linearity of damage accumulation, for the true damage intensity, etc. With that, new interesting questions, unconsidered before, appear.*

10. *The IDD concept has been also developed* (*in Subchapter 2.8*) *in statistical* (*probabilistic*) *interpretation under any random loading. The idea of the* ds *differentials and their components* ds_r, ds_c *and* dτ *leads simply and logically to a possibility for their direct statistical distribution into one or more nets* (*grids, meshes*) *in a suitable IDD space or an IDD plane. Relations have been deduced between the statistical frequencies or the probabilistic characteristics of the distribution and the damage intensity. Based on them, the fatigue life can be computed. Thus, a new, statistical and probabilistic IDD scientific line of research has separately been opened.*

11. *For the IDD purposes, and also as a contribution to the theory of variable stresses and strains out of IDD, an original differential theory has been developed suggested by the IDD idea and by the* ds *differential. Within the frames of the theory in question, the following problems have been solved: determination of the* $\alpha'(t)$ *function of rotation of the principal axes and the related determination of the principal stresses and strains functions by correct switchover of the* ± *signs in their equations.*

12. *A reduced IDD fatigue life equation* (3.1.2-1) *has been deduced for finding N in the particular case of non-cyclic loading. The equation allows computation of N without any apparent participation of the* ds *differentials but only based on the Newton-Leibniz theorem. With that, the primitive* $D(s)$ *damage function participates together with the no-damage interval* L_r (*or* L_l)*. Thus, under a single non-cyclic oscillogram, the fatigue life computation has been enabled directly, without looking for cycles and their counting, surprisingly to the CCA developed for more than one century.*

13. *Eventually, the developed IDD theory allows a new strategy, as follows. After it seems unrealistic that one of the many proposed CCA life criteria would prove to be always all-applicable and all-valid under any concrete non-proportional loadings of the first and second category, as well as under the unstudied c-loadings and* (*especially*) dτ*-loadings revealed in the thesis, and that the same criterion would hardly give* $(N_{\mathrm{cmp}}/N_{\mathrm{exp}})_{\mathrm{average}}$ *sufficiently close to* 1 *in numerous and heterogeneous verifications, then: it seems* (*Subchapter 5.1*) *more realistic and more practical to proceed from* $(N_{\mathrm{cmp}}/N_{\mathrm{exp}})_{\mathrm{average}}$ *sufficiently close to* 1 *and, based on this, to canalize the investigations into building an all-valid empirical data bank of successful IDD parameters. Such a "reversed" strategy is only possible with IDD since the* N_{cmp} *life can always be computed now in a uniform and universal way under any loadings.*

THEORETICAL AND APPLIED CONTRIBUTIONS

1. *Mathematical and algorithmic problems of a great number have been solved* (*in Chapter 4*) *for computer implementation and application of the author's IDD method. The problems do not have existing analogues and have been put for the first time.*

2. *Unique IDD software called Ellipse has been created. For that, algorithmic and programming problems have been solved in such a volume and complexity which, under different conditions, would engage a whole team of mathematicians and programmers.*

PRACTICAL CONTRIBUTIONS

1. *A practical manual* (*Section 4.1.1, subchapters 4.2 and 4.3*) *has been written which allows comparatively easy mastering and using the Ellipse software in a mass scale.*

2. *A separate practical computer program called Integral* (*Section 3.1.3*) *has been created to serve under r-loading only* (*under a single oscillogram*). *It is essentially simpler and more preferable than the Ellipse software.*

3. *By means of the Integral program, IDD has been applied for fatigue life assessment under random r-loadings* (*one-component loadings*) *done by Polish researchers. The results have proved to be the best in comparison with other, CCA methods.*

4. *An initial version of the empirical data bank of the IDD parameters* f_c, f_τ, N_c *and* N_τ *has been obtained for the first practical category of non-proportional loadings. The bank has resulted from an initial adaptation and following six verifications* (*in Chapter 5*) *based on experimental data obtained by researchers in Germany, Italy, Russia and Bulgaria* (*also in Czech Republic: in continuing verifications out of the thesis*). *By means of the EllipseT and EllipseS programs, 49 fatigue lives have been computed under quite various non-proportional loadings. There has been achieved* $(N_{\mathrm{cmp}}/N_{\mathrm{exp}})_{\mathrm{average}} = 1{,}02$ *always with* $f_c = 2$ *and* $f_\tau = 3$ *except for the fifth verification where, for a steel with significantly lower static strength,* f_c *and* f_τ *have proved equal to 1. The theoretical expectation has been confirmed that the parameters* f_c *and* f_τ *will vary within a comparatively narrow interval* (1 – 3) *according to certain regularity what makes them convenient and reliable to be selected. As well, certain regularity has been outlined for the selection of* N_c *and* N_τ *comparatively to* N_r.

5. *It has been revealed* (*in Chapter 6*) *that the fatigue loadings in machines and technical equipment in the Forest Industry have such complicatedness, poly-variety and complexity that they disclose one of the widest fields for application and manifestation of IDD. This is conditioned by the specificity of cutting and processing the wood as a material: conditions occur for all sorts of fatigue loadings which are not met at many other kinds of machines and technical equipment. Respectively, conditions occur which make the greatest difficulties trying to use CCA methods for fatigue life assessment. Thus, IDD comes at the right time and to the right place since its applicability covers namely the most complicated loadings.*