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RESEARCH ON THE PARAMETERS INFLUENCING THE NUMERICAL ANALYSIS OF THE FATIGUE BEHAVIOUR OF A FORKLIFT-ARM

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Rezumat

Estimarea duratei de viață a unui motostivuitor pentru o referință obiectivă constiuie nu doar o cerință a legislației aplicabile, dar și o provocare pentru personalul tehnic de specialiate. Este binecunoscut faptul că din cauza solicitării de oboseală elementul care cedează primul la un motostivuitor este furca acestuia. O simulare ce utilizează suita SolidWorks și rezultatul său este prezentată în acest articol. Acesta permite identificarea zonelor critice de cedare prin oboseală. Având la bază desenul subansamblului și schema de încărcare a produsului original a fost realizat la scara 1:1 modelul supus analizei cu element finit. Zonele de racordare au impus și efectuarea unei analize comparative a rezultatelor obținute în funcție de alegerea meshului și a elementului de discretizare. Avand drept punct de plecare proprietățile mecanice ale materialului precum și a asocierii cu curbele caracteristice de cedere prin oboseala (Wohler) se propune o metodă de estimare a duratei de viață remanente a structurii respective. S-au luat în considerație și aspectul legat de obținerea unor rezultate exacte fără un consum excesiv al resurselor de calcul.

Cuvinte cheie: analiza element finit, furci motostivuitor, comportare la oboseala, durata de viata remanenta

Abstract

Estimating the remaining service life of a forklift for an objective reference is not only a requirement of the applicable legislation but also represents a challenge for specialized technical staff.

It is well known that the first fatigue failure element of a forklift is its fork. A simulation using the SolidWorks suite and its result is presented in this article. It allows the identification of critical areas of fatigue failure.

Based on the design of the subassembly and the loading scheme of the original product, the model under analysis with finite element was made on a 1: 1 scale. The filet areas also required a comparative analysis of the results obtained depending on the choice of mesh and discretization element.

Starting from the mechanical properties of the material as well as the association with the characteristic fatigue yield curves (Wohler), a method for estimating the remaining service life of the structure is proposed. The aspect related to obtaining exact results without an excessive consumption of computing resources was also taken into account.

Keywords: finite elements analysis, forklift forks, fatigue behaviour, remaining service life

1. INTRODUCTION

Forklifts are common equipment, but they present a certain risk in operation. For this reason, their operation and maintenance are rigorously regulated.

The periodic evaluation of their technical condition is often imposed by the applicable legislation, being necessary to evaluate their remaining service life according to existent regulations. This matter represents a challenge for specialists.

In this paper we intend to perform a study and a technical analysis of the metal structure behaviour of lifting equipment from the family of high-capacity forklifts (Caterpillar DP 70), for which it is necessary to establish an estimated remaining service life. As a result of a previously completed study in which the fatigue behaviour of the whole equipment was assessed, the present study focuses on the subassembly with the biggest problems in terms of fatigue behaviour, namely the arm itself of the manipulative fork.

2. CALCULATION ALGORITHM

Due to the significant degree of complexity of the problem, the simulation of fatigue behaviour was performed using the SolidWorks application suite, version 2014 - 64-bit architecture systems version, also performing intermediate stages of verification that were supported by classical methods of calculation, as well as other numerical applications (e.g. AxisVM 12-light version, etc.). It should be noted that the fatigue calculation stage itself could only be completed

with the help of the main SolidWorks suite (finite element analysis-F.E.A.), this approach being possible with a still relatively small number of applications. The modelling itself was performed on a real scale (1:1), according to the received subassembly drawing (Fig.1), the structure (Fig.2) having the discretization scheme (mesh) depending on the chosen working option (Fig.3).

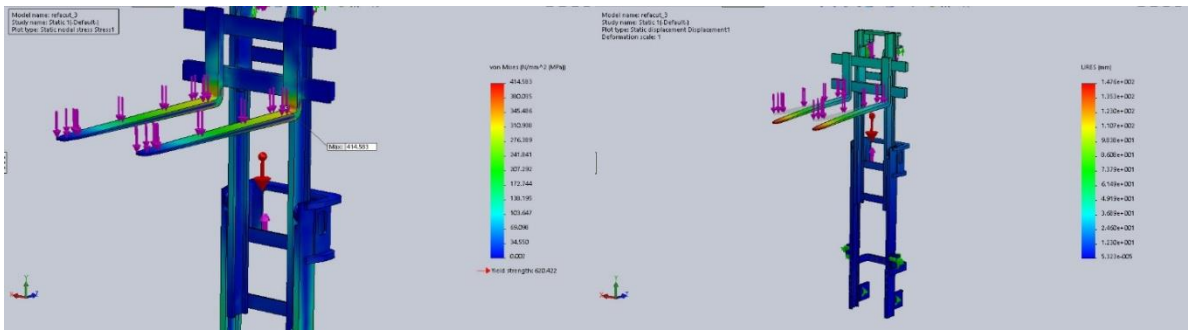


Figure 1. Static study result of general subassembly

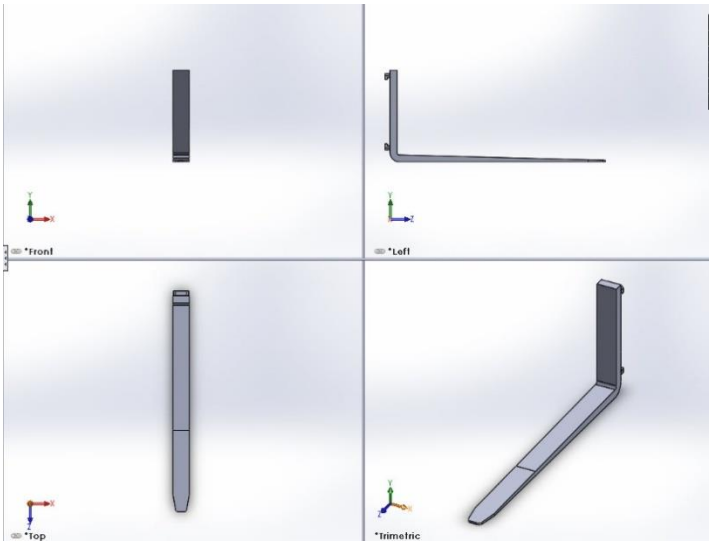


Figure 2. Fork modelling

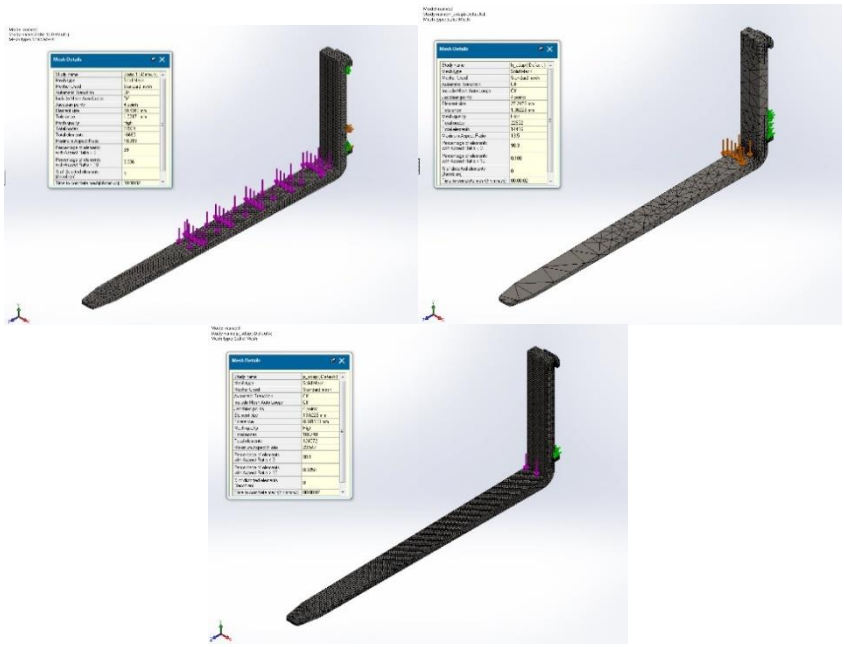


Figure 3. Fork's solid mesh

Based on the chosen discretization method (solid meshing), a basic static study (SolidWorks Simulation / Static) is to be performed according to the calculation scheme imposed by the initial data of the problem, the support scheme according to the overall drawing of the fork support (Fig.4), respectively the loading scheme according to the specifications of the original product (Fig.5). At this moment, a clarification of the loading scheme is required, being performed stages of the study in which the payload is evenly distributed over the entire length of the arm. The only difference consists in the activation of the working mode "Large displacement" (excessive deformations) [Appendix 1, pos.1], situation which requires considering the changes in terms of structure stiffness.

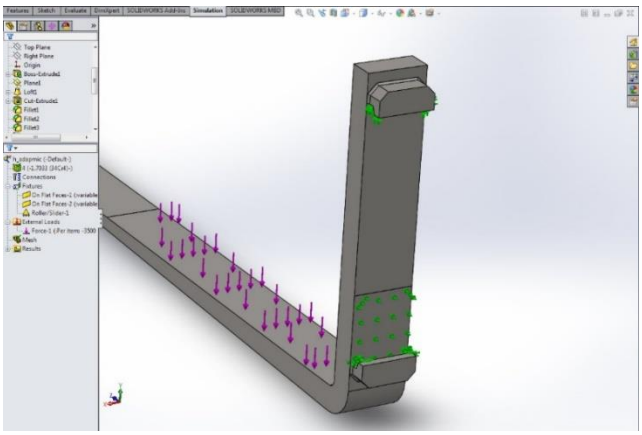


Figure 4. Fork support's restricted degrees of freedom

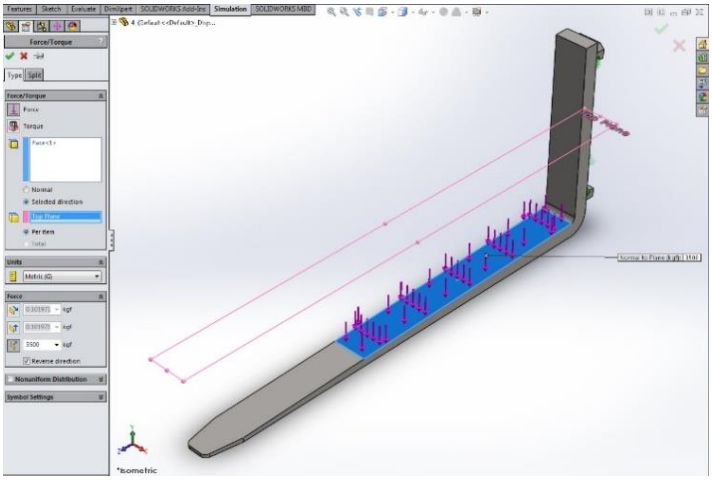


Figure 5. Loading scheme

The output values of the static study consist in establishing the distribution of equivalent unitary stresses (stress state) according to the von Mises criterion (Hencki) –5th or 4thstrength theory, the predominant factor in reaching the limit state being the specific deviation energy [1,2] , the state of deformation of the structure (u_{res}-resulting displacements of the discretization elements) (Fig.6) and, of a special interest for the ongoing study, the pre-assessment of fatigue behavior (Fatigue check plot), criterion for subsequent completion of a detailed fatigue study (Fig.7).

The final fatigue study (Solid Works Simulation / Fatigue) has as a mandatory precondition the existence of an initial static study, as input value, as well as the known characteristic parameters: asymmetry coefficient for the stress cycle, Wohler (S-N) curve associated with the material used, number of cycles [3,4,5]; the output values of the study are the estimated percentage of work capacity loss for the previously specified number of cycles (Damage), as well as the total estimated lifespan (Life), specifying the areas of interest in terms of the appearance of initiation –propagation processes of cracks leading to failure of the structure by fatigue mechanism (Fig.8).

The main problem that arises when using such calculation methods consists in ensuring the convergence of the obtained solutions, the existence of a certain scattering of results being notorious depending on the set of variable parameters used to establish the actual analysis conditions (degree of fidelity for solid modelling, type and shape of the discretization element, the "refining" mode of the discretization network, the used Wohler (S-N) curve associated with the material, etc.). [6]

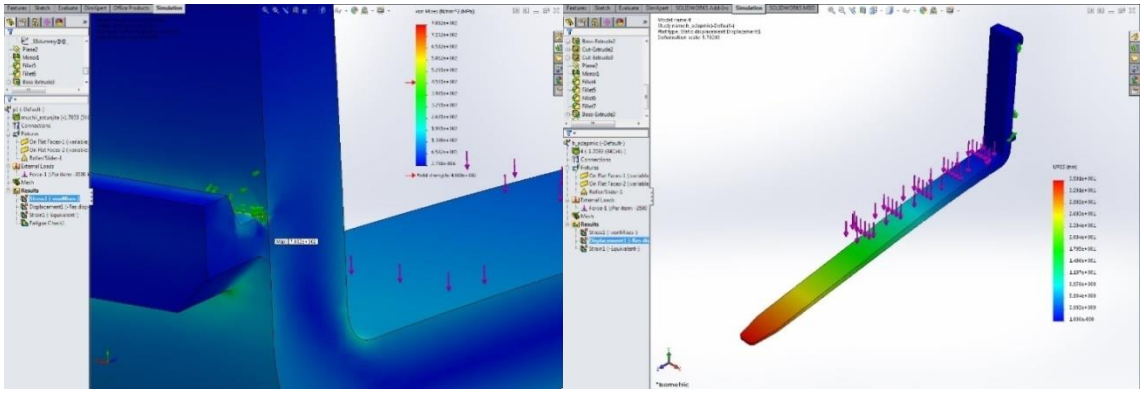


Figure 6. Result of static study

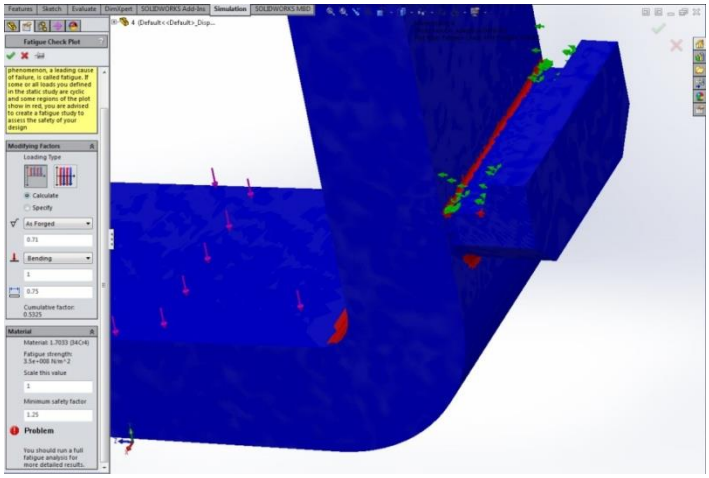


Figure 7. Fatigue study

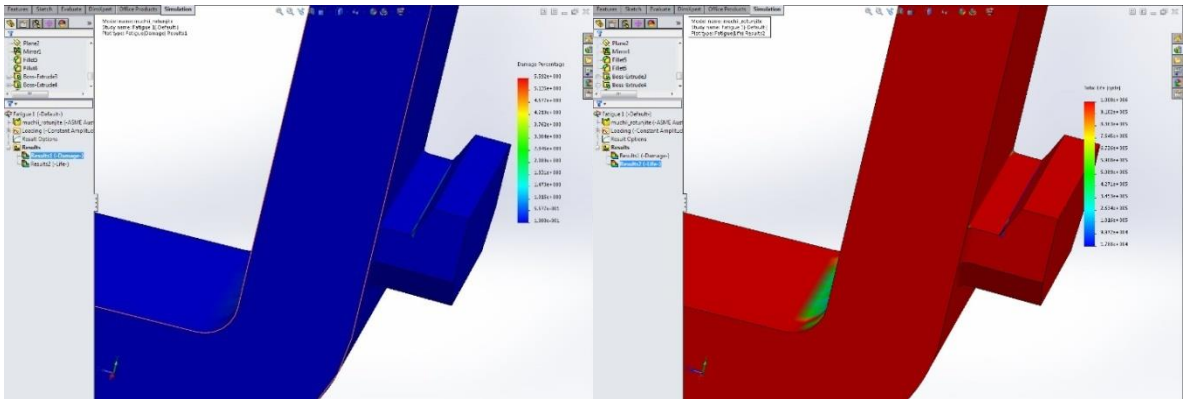


Figure 8. Damage percentage and life service remaining

3. ANALYSIS OF WORKING METHODS

3.1 Discretization scheme (meshing)

A first distinction in approach can be made by using the discretization element with rectilinear sides (standard) versus the curvilinear element (curvature-based mesh), with limited implications however concerning connecting radius, of great use being in this case the performance criterion called "aspect ratio", the ratio between the largest and the smallest dimension of the discretization element, being desirable a value as close as possible to the unit (an element as little deformed as possible).

Table 1. The influence of discretization type element on filleted surface meshing

element type	method	element size	tolerance	elements number	aspect ratio ≤ 3	von Mises	life
standard	-	13,62 mm	0,68 mm	56638	99,4%	780MPa	1e8 cycles
standard	h-adap.	13,62 mm	0,68 mm	365072	99,4%	3e3MPa*	1e4 cycles
standard	p-adap.	13,62 mm	0,68 mm	56638	99,4%	2e3MPa*	1e4 cycles
curvilinear	-	27,93 mm	-	28992	94,5%	1,2e3MPa*	1e4 cycles
curvilinear	h-adap.	27,93 mm	-	108187	94,5%	1,9e3MPa*	1e4 cycles

The optimization of the discretization network (Fig.3) is one of the most important steps in using SolidWorks Simulation, a process that can result in obtaining accurate results without excessive consumption of work resources.

The used numerical application has two main methods of optimizing the results, namely by modifying the discretization scheme. The principle of the ‘h’ method of optimization (h-adaptive) [Appendix 1, pos.2], consists in using small elements in the error areas. After a first run of the study with the estimation of the areas with high degree of error, the program automatically modifies the discretization parameters, the effect being to increase the accuracy of the obtained results. By comparison, the principle of the ‘p’ optimization method (p-adaptive) [Appendix 2], consists in the special treatment of the elements for the areas considered to be critical. After a first estimation of the error zones, the program

changes the rank of the polynomials describing the deformation state (matrix), the discretization scheme (number of elements) remaining unchanged.

The excessive values of the equivalent normal stress scales [8] are due to the phenomenon of stress concentration in areas with angles or radius fillets (singularities) [Appendix 1, pos.3], the stresses in these areas increasing with the decrease of the local size of the element. The problem can be controlled by activating the "Global" option in the "Accuracy bias" within the initial parameters of the "h-adaptive" working method.

3.2 General parameters of the fatigue study - choice of material

The parameters of the fatigue study (the detailed final study, not the intermediate stage "fatigue check plot") refers to the interaction between different types of defined fatigue events [Appendix 1, pos.4], concerning the fatigue strength calculation method according to the strength theory used [Appendix 1, pos.5], (being established the type of stress for the equivalent fatigue strength calculation used to estimate the number of cycles according to the associated Wohler (S-N) curve associated), up to the type of fatigue resistance diagram for correction [Appendix 1, pos.6], (Goodman- brittle materials, Gerber-tenacious materials, Soderberg-the most restrictive variant), as well as the fatigue reduction factor Kf [Appendix 1, pos.7], in order to be taken into account the differences between the existing conditions when generating the Wohler (S-N) curve and the "real" conditions in which the simulation is conducted.

The choice of the Wohler (S-N) curve associated with the material used is of great importance, the output values of the study being directly and dramatically influenced by it. In this context, the presence of a mathematical apparatus for creating customized fatigue resistance curves can be signaled, the application having a relatively extensive library for use.

Table 2. Fatigue study results

Calculation criterion	Correction (fatigue diag.)	Fatigue strength reduction fact. Kf	S-N curve interpolation	Material S-N	Life
von Mises	Soderberg	0,8	log-log	2340 without stress concentration	5e4 cycles
von Mises	Soderberg	0,8	log-log	2340 with stress concentration	1e4 cycles
von Mises	Soderberg	0,8	log-log	structural steel rolled	3e4 cycles
von Mises	Soderberg	0,8	log-log	carbon steel	1,7e5 cycles

4. CONCLUSIONS

As a result of simulations performed, the suspicion of failure due to fatigue noticed in the pre-assessment stages is confirmed within the static study (fatigue check plot), the results being convergent for several calculation hypotheses from those presented (or combinations thereof).

Thus, depending on the chosen parameters, the critical area of fatigue failure is found not only at the fillet radius area of the arm with the support section, but also in the prismatic elements of support-connection with the fork support area (Fig.7, 8). It is worth noting the weaker statistical presence of events such as failure at the fillet radius (the forks having the general mechanism of failure by plastic deformation), certain external studies confirming the existence of such atypical failure mechanism [7].

Regarding the quantitative aspect of the problem, with direct reference to the probability of estimating the remaining lifespan of the structure, we consider to be of great importance the correct association of the type of material used with the corresponding Wohler (S-N) curve. Thus, instead of the treatment by correction coefficients or other possible mathematical schemes it would be desirable raising a family of curves in laboratory conditions for the real materials used (even in used state, broken or replaced arms) and the direct insertion of obtained data in the fatigue strength diagrams library (through the functions available in SolidWorks CosmosWorks curves-cwcur.dll), the possible subsequent corrections benefiting from a solid reasoning basis.

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