LOAD HISTORIES AND SPECTRA AND PREDICTION
OF FATIGUE STRENGTH IN FORKLIFT STRUCTURES
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The paper describes a method of forming representative load spectra of forklift truck metal structures. This method comprises substitution of cyclic loads having a constant or changing to a specified law of distribution amplitudes for the random loads caused by transport operations. Handling operations loads are then added to obtain a schematized load history which is used to get a representative load spectrum by two-parameter schematization. This spectrum is used to predict fatigue strength of forklift truck metal structures.

1. Introduction

Stress analysis is an effective method of proving forklift metal structure service life and fatigue strength. It generates reliable quantitative data about structural component states of strain and stress in critical points under service loading. The statistical analysis of experimentally obtained load histories and respective load spectra leads to formation of representative load histories, covering one or more working load cycles, which can also be defined as representative ones. This is possible on the assumption that the service load can be considered a stationary ergodic process which is close to the real situation with forklift trucks. The division of working cycles into operations makes possible a separate study during truck travel and stacking. Main methods of obtaining the representative load spectrum from experimental spectra are: approximation to an appropriate distribution law followed by an extrapolation to reach a specified probability addition and multiplication of partial spectra (1) and application of the stress modulation phenomenon (2). Changing of load mass (utilization of truck load capacity), varying of load centre location in handling and transport operations, and dynamic

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loading under various travel speeds and road conditions (asphalt, pavement, dotted road) (3), (4), (5) are taken into account. As regards utilization of truck load capacity and road conditions of loading could be classified as heavy, medium and light. An appropriate combination of those conditions must be chosen when forming representative load histories and spectra.

2. Problem statement

A method is presented of forming representative load histories and spectra in forklift trucks, which is used to predict service life and fatigue strength of load-bearing structures. By this method empirical and theoretical load spectra for transport operations are obtained through one-parameter rain-flow schematization (counting). These spectra serve as a basis for constructing schematized partial load histograms with constant mean stress and an equivalent amplitude which is constant or varying to the Weibull law or binomial law. These histories are then added to the partial load histories of handling operations.

3. Partial schematized load histories

When the equivalent amplitude base at equivalent frequency of occurrence is a constant value they are defined by the following set of equations (5):

\[ a_l = \frac{a_2}{a_1} \quad b_l = \frac{b_2}{b_1} \quad (1) \]

where \( a_1 = 3 \ldots 3.5 \) for welded structures, \( b_1 = 0 \ldots 0.5 \) for base material.

The solution of (1) is given in ref. (5). The procedure is analogous when assuming a Weibull distribution or a binomial amplitude distribution, where the frequency (number) of occurrence of separate new spectrum orders is rounded to an integer. The constructed partial schematized load histories of transport operations with a constant mean stress are added to load histories of the handling processes to obtain partial schematized load histories, which are subjected to one-or two-parameter rain-flow schematization, a partial load spectrum will be obtained, which can be used to predict fatigue strength and service life, e.g., to the requirements of DIN 15018 and FEM.

4. Representative histories and load spectra

Two coefficients are defined in order to take into account the impact of modulation (superposition) on loading: \( q \)-related to the influence of linearity and load location \( q \)-related to...
usage of the rated truck load capacity. Both coefficients represent ratios of real operating cycle mean stress to the mean stress in a cycle under rated load location. Depending on the values of amplitudes \( \sigma_{i,j} \) and mean static stress \( \sigma_{i} \), relative frequency of occurrence \( p_{i} \) for each partial spectrum are defined. For the \( j \)-th and \( l \)-th load history operating cycles, characterized by coefficients \( q_{i,j} \) and \( q_{l} \) and relative frequencies of occurrence \( p_{j} \) and \( p_{l} \), the equivalent load amplitude \( q_{i,j,l} \) and its equivalent frequency of occurrence \( p_{i,j,l} \) will be determined by the equations:

\[
\begin{align*}
q_{i,j} & = q_{i} \cdot q_{j} \cdot q_{l} \\
p_{i,j} & = p_{i} \cdot p_{j} \cdot p_{l} \\
\sum_{i,j} p_{i,j,l} & = 1
\end{align*}
\]

These equations are true when there is zero correlation among load conditions in regard to truck capacity utilization, type of road and influence of kinematics. A three-parameter matrix is obtained in contrast to ref. 1, where it is a two-parameter one. In some cases it manifests as adding of individual loads. The representative loading spectrum is received from several successive operating cycles, covering the major locations of load mass centre and some extreme loading as well. With the purpose of using a computer, we select a maximum of 16 to 24 working cycles (max. 1 hour of operation) with various lengths and surface conditions, possibly different loads, observing the requirements of multivariate analysis. After schematization the number of amplitude occurrences for the individual orders will be extrapolated over the complete truck life.

5. Prediction of fatigue strength

The procedure of fatigue strength prediction as described in DIN 15018 and FEM/1-1-12-1970 comprises comparison between equivalent stress (a sum of equivalent amplitude and mean stress) and allowable stress. It is expedient when converting into equivalent cyclic load with constant or changing to binomial distribution law amplitude, to take into account also the \( \psi \) coefficient of the impact of mean stress in accordance with the known equation of equivalent amplitude \( \sigma_{eq} \) and the Smith-Goohman diagram:

\[
\psi_{i} = \frac{b_{i}}{a_{i}} + \psi_{i}
\]

Instead of amplitudes \( \sigma_{i,j} \), we use the equivalent stress amplitudes \( \sigma_{eq,i} \) to solve the set (3). With DIN 15018 and FEM standards these amplitudes are determined as follows:

\[
b_{i,j} = \frac{b_{i}}{b_{j}} \quad ; \quad \psi = 0.2 \text{ if } b > 0 \text{ and } r < 0
\]

\[
a_{i,j} = \frac{a_{i}}{a_{j}}
\]

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The asymmetry $r_c$ is defined in compliance with DIN 15018 requirements. After solving equation (1) in a reverse manner the amplitude will be converted into mean stress $b_m$ to predict fatigue strength.

### Application

This method has found an application for predicting the service life and fatigue strength of forklift trucks made in Bulgaria. It is equally suitable for static stress measurements and finite element calculations. Data from previous field and laboratory performance tests carried out as per Balkan factory standards are used in both cases.

### Symbols Used

- $b_{1i}, n_{1i}$: amplitudes and frequencies (number) of their occurrence for the $i$-th order of the partial load spectrum
- $m_{1i}, m_{2i}$: exponents of the Weibull's curve
- $D_{m1}, D_{m2}$: material fracture strength
- $D_{1i}, D_{2i}$: allowable fatigue strength to Table 17 of DIN 15018
- $r_{c1}, r_{c2}$: asymmetry of the $i$-th order of the load spectrum
- $D_{m1}$: mean stress of the $i$-th order of the load spectrum

### References


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