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INVESTIGATION AND ASSESSMENT ON THE FATIGUE POTENTIAL OF ELECTRONIC COMPONENTS FOR FORKLIFT TRUCKS DUE TO MECHANICAL VIBRATIONS AND SHOCK LOADS

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Abstract. *To simplify the designing of electronic components for forklift trucks with regard to their specific operating conditions, a test forklift truck has been equipped with industrial-standard instruments to measure the occurring electrical and mechanical stresses. To evaluate the fatigue potential of these components the acquired measurement data were analyzed in the time and frequency domain and compared to a classification with the rain-flow counting algorithm. To compare the failure characteristics of the examined electronic components, lifecycle tests was carried out on an electrodynamic shaker. These experiments were performed on individual electronic components, similar to the components of the drive modul of the test forklift truck, which were operated at the same time under typical operating electrical loads. Additionally, the influence of vibration and shock excitation could be checked for the control behavior of these components.*

1 INTRODUCTION

Due to their flexible capabilities forklift trucks are used in almost all industrial and commercial sectors. By the increasing electronics in control elements to raise energy efficiency and ease of use, the electronic components got a significant impact on the availability of the overall system forklift truck.

By its use in forklift trucks electronic components are exposed to particularly high vibration and shock loads. This results from the nearly undamped chassis and the high masses of forklift trucks due to the required high payload and compact design [3].

To simplify the designing of these components, in the research project "Dimensioning electronic components in industrial trucks" initially a forklift truck for tests was acquired with measuring equipment to measure the electrical and mechanical stresses on individual components as closely as possible and then evaluate their fatigue potential.

2 SWING AND IMPACT LOADS ON ELECTRONIC COMPONENTS OF A FORKLIFT TRUCK

2.1 Load recording and evaluation

For the load recording, which referred to practical working cycles, the forklift truck was equipped with a modular data acquisition system from National Instruments, to measure the mechanical accelerations in all three directions and the electrical parameters, such as voltages and currents, with an overall sampling rate up to 125 kS/s [1]. The measured data of the work cycles were evaluated for their occurring maximum loads and characteristic frequencies in the time domain and frequency domain. By the demonstration in form of spectrograms, where the incidence of certain frequency bands are shown in different colors in any particular period, not only the relevant frequency ranges are easily detectable visualized, also individual characteristics curves are compared visually with each other. Figure 1 shows the profile of the vertical acceleration with the corresponding spectrogram, measured on the base frame of the forklift truck at the crossing of a 7 mm barrier, in a style similar to the DIN EN 13059 test set [5].

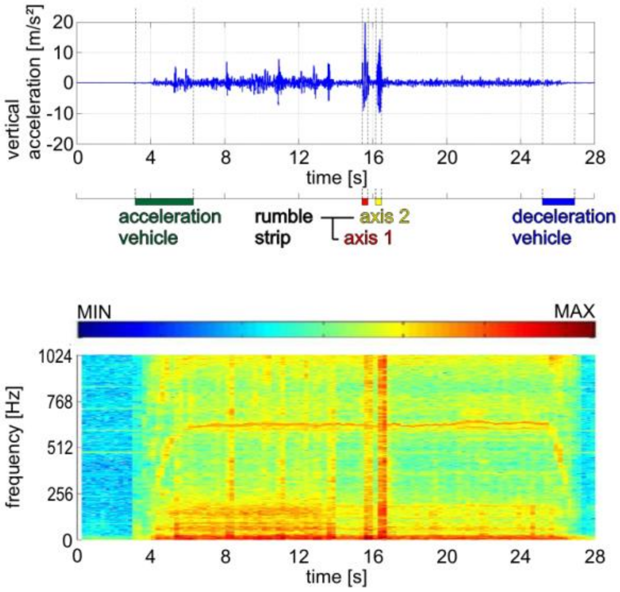

Figure 1: Course of the vertical acceleration (top) with corresponding spectrogram (below).

At the same time measured current course of the supply of concurrent flow of the drive control is to be seen in Figure 2.

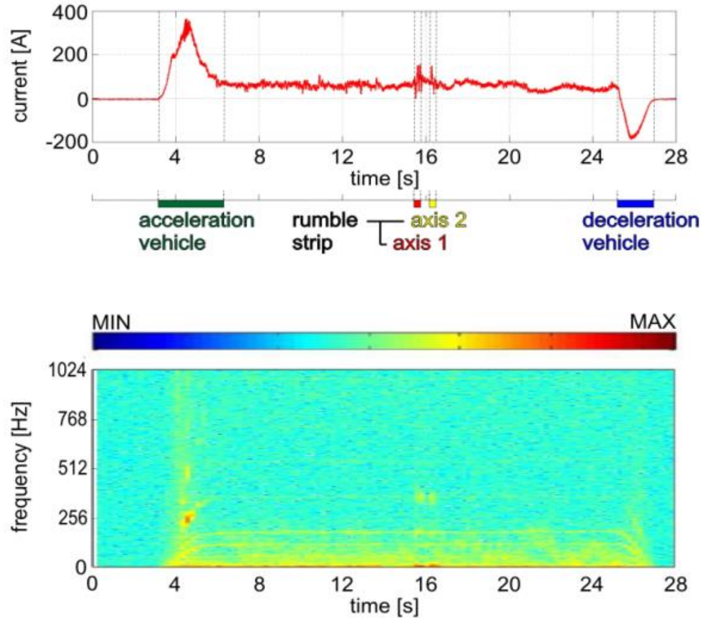

Figure 2: Current-time curve (left) and frequency spectrogram (right).

From the comparison of both curves in Figure 1 and Figure 2 is shown that correlations exist between the mechanical and the electrical stresses of the drive control. These are examined in later test benches with more detail. The recorded acceleration profiles of the simulated stress scenarios were evaluated over its entire course to their damage potential using the rainflow counting algorithm, which is familiar from the fatigue strength. Additionally, the acceleration signal of the individual measurements is divided into 32 classes.

From the resulting rainflow matrix for each load cycle is formed a substitute load cycle for the assessment of damage. It consists of the sum of all load cycles and middle load cycles of each relevant class, see Eq. (1):

$$Sa_{ers,i,j} = \sum_i \left(Sa_{i,j} + M \cdot Sm_{i,j}\right) \quad (1)$$

$Sa_{,ers,i,j}$	substitute load cycle
$Sa_{,i,j}$	load cycle
M	mean stress influence factor
$Sm_{,i,j}$	mean of load cycle
i, j	class limit of the load cycle

The mean stress influence factor M for mechanical stresses is in the fatigue strength a material dependent component and is according to his definition in the range between 0 and 1. So, for acceleration loadings on electronic components it cannot be determined. Thus, for each load scenarios can only be taken comparative statements about the damage potential.

Finally, to ensure comparability of such substitute damage, a damage factor was formed, which is formed from the mean of comparable substitute load cycles. In Figure 3, the different working cycles are compared with their calculated damage factor by different mean stress influencing factors.

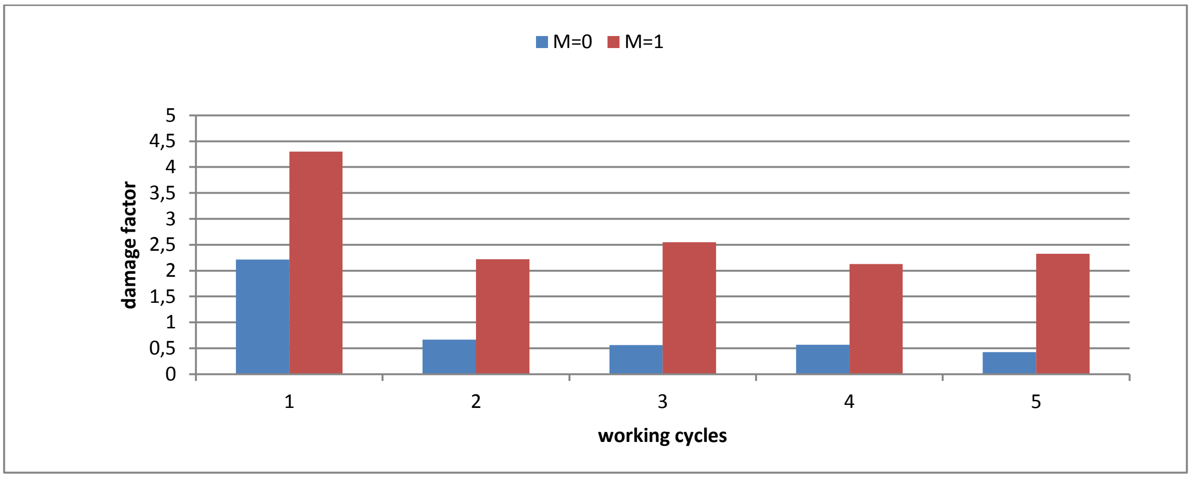

Figure 3: Damage factor of different working cycles.

2.2 Life tests on an electrodynamic shaker

To verify the theoretical damage behavior of mechanical loads components of forklift trucks, which are compared with the rainflow counting algorithm, some electronic components were tested with fatigue tests on a vibration testing system that operated by the DIN EN 60068-2-6 [4]. The aim of the test bench investigation was to develop a failure characteristic in relation to the applied load level and load frequency. The vibration system consist of an electrodynamic shaker, the control and industrial process, several acceleration sensors as soon as the control software Sarturis, which continuously control the function of the specimen by using a CAN Bus interface during the fatigue tests.

To reproduce the operating conditions of the real system as good as possible, during the vibration tests the specimen are connected with the same supply voltage like into the forklift truck. Before the fatigue tests, the natural frequencies have been determined by using the vibration system. From the results of the evaluation the specimen was excited in the corresponding frequency range with constant acceleration in the sine mode.

From the studies with multiple control levers of the forklift truck a failure characteristics was made like the Wöhler curve, which is known from the material engineering. The failure characteristic is shown in figure 4.

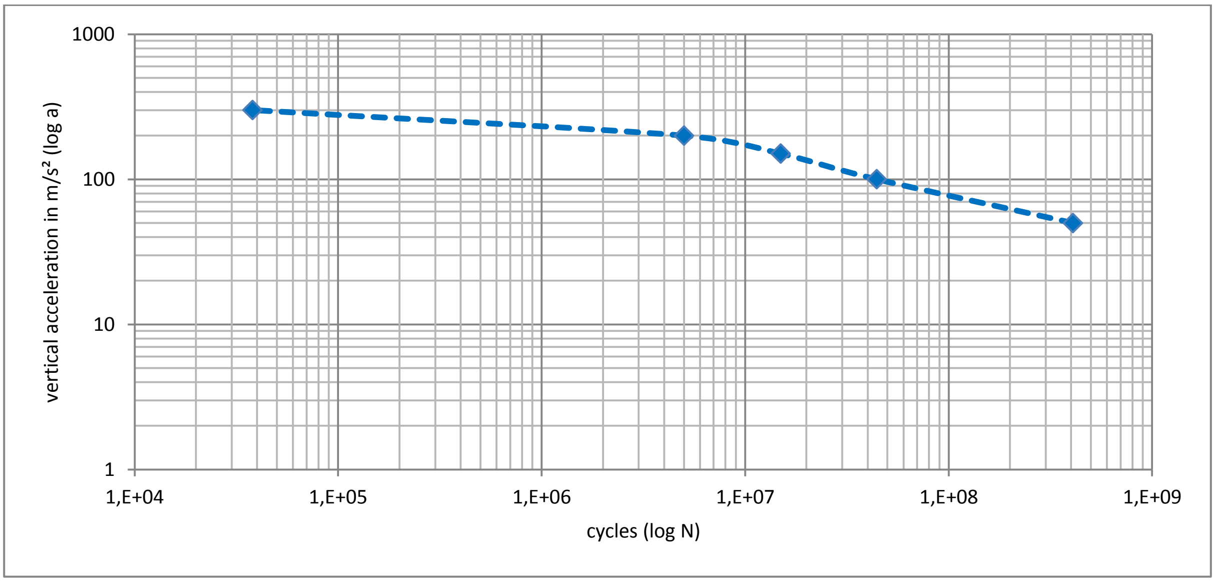

Figure 4: Failure characteristics of the electro-mechanic control lever of the forklift truck.

The failure characteristic shows in the double logarithmic diagram a linear relationship between load level and the possible number of cycles and so it gives lifetime predictions for any other loads. Furthermore, the diagram shows that the control lever, under the given operating conditions, is dimensioned fatigue resistant by this kind of forklift trucks. At the end of the tests the visual examination of the specimen showed, in spite of the applied supply voltage at the control lever occurred only mechanical failure causes.

2.3 Fatigue tests on the power electronics

To test the influence of a high electrical load on the sensitivity of electronic components under the influence of a vibration excitation, the two test benches of the shaker and of the forklift drives were merged. On this drive test bench the entire drive train of the test forklift truck was modeled with the traction battery of the drive control and the drive motor with original components. The simulation of different load conditions, as caused by normal driving resistance or the sudden impact with obstacles like barrier, assumes a coupled load machine with a much higher nominal power than the forklift driving. Figure 5 shows the mounted drive control of the forklift truck at the electrodynamic shaker.

Figure 5: Drive control stressed by vibrations and shocks with applied supply voltage of the traction battery.

The evaluation of the first tests showed that a drive control which operated under full electrical load failed to work earlier than a drive control which operated under low electrical load at the same vibration. The thermometer inside the drive control showed 24°C for the specimen with low electrical load and 104°C for the specimen with full electrical load. In the analysis of the test series was also noted that mechanical stresses were the reason for failure, especially in this case the debonding of solid components inside the drive control.

3 CONCLUSION

The influence of mechanical and electrical loads on the fatigue limit of electronic components of forklift trucks was herein investigated. By applying different levels of electrical and mechanical load on the components with the aid of an electrodynamic shaker test bench, the influence of different operating conditions was simulated.

An electromechanical lever selected as the device under test, was subjected to repetitive mechanical stresses with different amplitude. It was illustrated that the device fails electrically, due to the mechanical fatigue of its components, after less repetitions for higher stress amplitudes than for weaker ones. This behavior follows as expected a characteristic Wöhler curve [2].

Moreover, a drive controller was selected as the device under test. It was demonstrated that under a mechanical stress of constant amplitude, the drive controller fails faster for the case of the maximal electrical stress than for the case where almost no electrical stress was applied. Noteworthy is that the temperature of the selected device rises significantly with the amount of the applied electrical stress.

Additionally, the reliable operation of the drive controller was examined during the electromechanical tests. The results illustrated that as long as the drive controller did not fail, its electrical operation remains completely unimpaired.

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