EAN 2018
56th conference on experimental stress analysis

Measurement of Operational Stresses of ŠKODA Trolleybus 27Tr

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Keywords: trolleybus, service life, fatigue damage, operational test, strain gauge.

Abstract. This article describes the procedures based on short and long life operational tests used for fatigue damage assessment of trolleybus ŠKODA 27Tr structure.

Introduction

ŠKODA trolleybus 27Tr is based on Solaris New Urbino skeleton. The Slovak authority, for which the articulated coaches were delivered for the first time, asked to make the strength test of the trolleybus body to ensure, that electro-equipment added masses do not influence the safety of the coach operation. On the base of Solaris acceptance and cooperation, the tests were performed by VZÚ Plzeň with the first coach prototype in Pilsen, Bratislava and Žilina, where finally all coaches are operating. The strain gauges had been installed on the raw coach welded structure before all added equipment was assembled in Solaris Company. The preliminary tests were performed in Pilsen. The main tests were realized in Bratislava. Final tests continued in Žilina, where the acceleration long time test was performed.

Trolleybus Operational tests

Test Instrumentation. Totally 62 strain gauges and several accelerometers were used for the test. The data acquisition was performed with a set of 8 HBM SPIDER8 measuring units and with on-line monitoring system EMS DV803 equipped with GSM router for data transferee and with GPS vehicle unit for tracking the trolleybus position. In parallel with strain gauges, the driving millage and derived velocity was measured with the help of two magneto-inductive sensors, tracking the rotational speed of the propeller shaft. The traction engine revolution measurement ensured to stop the data acquisition at the standing coach.

Fig. 1 Bump test

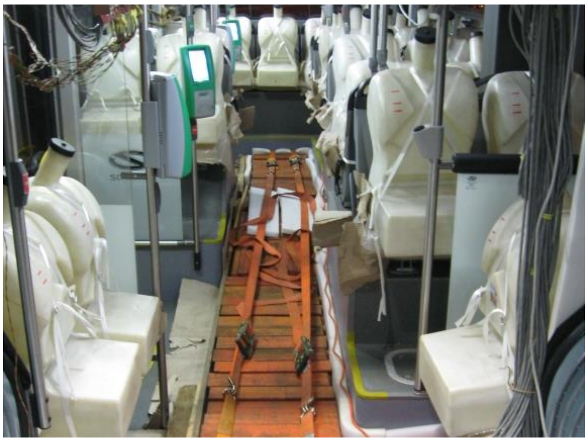

Fig. 2 Distribution of passengers loads

Performed tests. Short tests on the model road were performed in Pilsen. It concerns loading the bus, the bump test over the set of standardized bumps with the velocity of 40 km·h^{-1} (Fig. 1), riding the curve, braking and acceleration and torsion the coach with separate wheels as well as by entering the curb.

Preliminary operational tests were also made in Pilsen on several trolleybus lines for service life estimation of weak nodes (107 km).

The main operational test were performed in Bratislava on two trolleybus lines, from which the first was as mountain ride over the castle and Koliba end station and the second goes to eastern part of Bratislava with very bad pavement (232 km) (Fig. 3). Crossing over the tramlines and driving over the cubed pavement were presented during the test. The bitumen pavement was on several places of low-quality with many pot-holes. Sometimes the roadway was eng and dished with several turnings, which causes not only vertical vehicle excitation, but also coach oscillation around both vertical axes. Tests were performed with empty and loaded coach with substitution of passengers (Fig. 2).

The last part of the test was performed in Žilina. Here the two month tests with passengers at traffic lines without the operator were performed using the on-line monitoring system.

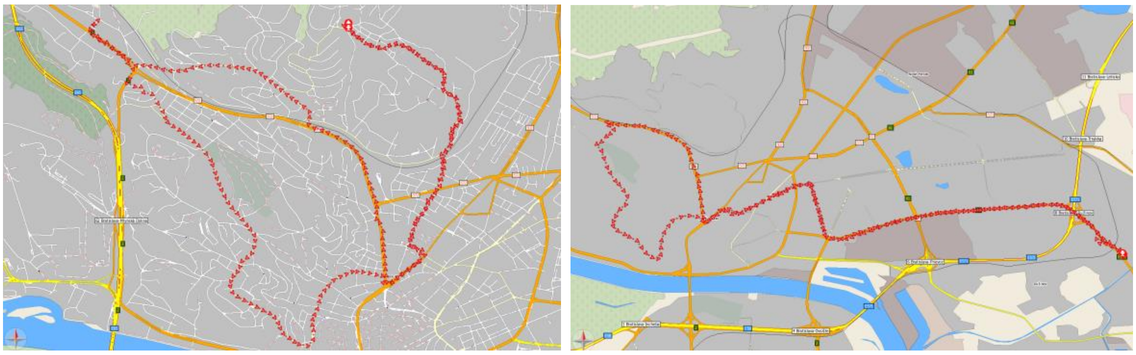

Fig. 3 Two testing loops in Bratislava

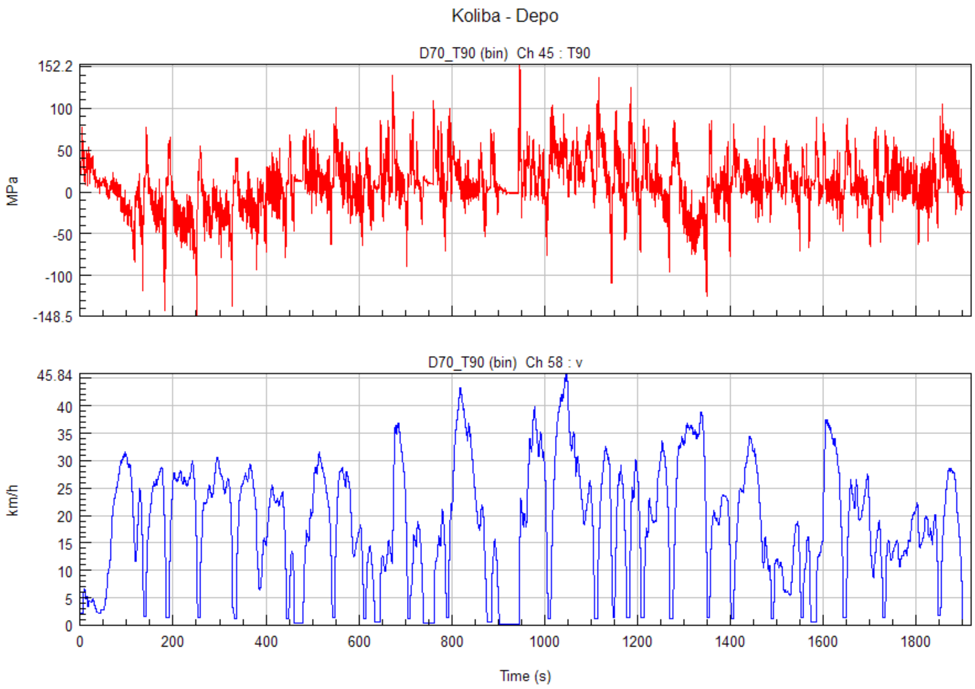

Fig. 4 Example of stress time history obtained during one testing loop and the coach velocity

Data Analysis and Results

Used Material. For the coach structure is mostly used the ferrite stainless steel 1.4003. It deals above all about welded hollow profiles, locally stiffened with added plates or ribs. Following material characteristics were taken from the test: ultimate strength R_m = 450 MPa, yield point R_e = 280 MPa. According test results of welded beam with but weld, given from the producer, the fatigue limit stress amplitude for R = 0 is 75 MPa; this value is valid for nominal stress.

S-N curves. The derivation of S-N curves went out from the recommendations of IIW [2], present standards for traffic vehicles, from the fatigue test of fillet joint from steel 1.4003 [1] and from the fatigue test results, obtained from the customer.

The existing standards classified the welded joints to classes, from which each class has the S-N curve with the same slope of m = 3, but different fatigue limits. For fillet welded joints, which are mostly presented at critical measured destinations, the best suited is the class F2. These curves are designed for the probability of survival P > 95%. Fatigue curves, based on the tests of steel 1.4003 are evaluated as for the probability P = 50% as for higher probability or only the mean curve is given.

When comparing all the standards with performed tests, the fatigue limits fits surprisingly very well.

For all welded joints was conservatively for the fatigue calculation chosen the fatigue limit σ_{ac} = 60 MPa for R = -1 for N = 2E6 and the slope m = 3. There was used only one slope of the S-N curve and the curve was cut at N = 1E7 (IIW recommendation [2]).

For the calculation of service life, the methodology and software, developed in the frame of the project EU CP 940520 Bus-Expert-System were used. During the calculation, which goes from upper given presumptions, the decomposition of stress time history to the closed stress cycles using rainflow method is used. The sensitivity to the mean stress cycle is given to the consideration with the factor M = 0.23, which was derived from the fatigue test results for pulsed (R = 0) and oscillated (R = -1) cycles.

Fatigue Estimations. The measured stresses were put to the Goodman diagrams to check the unlimited service life (Fig. 6). Here the upper envelope curve represents the fatigue limit of the basic material and the bottom of the fillet weld.

The strain gauges were installed in sufficient position from welds to be able to use the nominal approach for limited fatigue life calculation. The sensitivity for mean stress cycle was also taken in to account. The linear fatigue damage accumulation hypothesis was used for fatigue life calculation based on stress history decomposition using rainflow method according the relation

$$D = \Sigma(n_i/N_i) \qquad (1)$$

where

n_i … number of stress cycles on i^{th} stress level with the amplitude a_i

N_i limit number of cycles on the same stress level, for the parameters of S-N curve.

The service live L in [km] was calculated according the relation

$$L = NSU \cdot (D_c/D) \qquad (2)$$

where

D_c is the critical value of the fatigue damage, which equals according Haibach hypothesis D_c = 1.

Estimated damage for all measured joints for design service life of 1 million km is shown in Fig. 5.

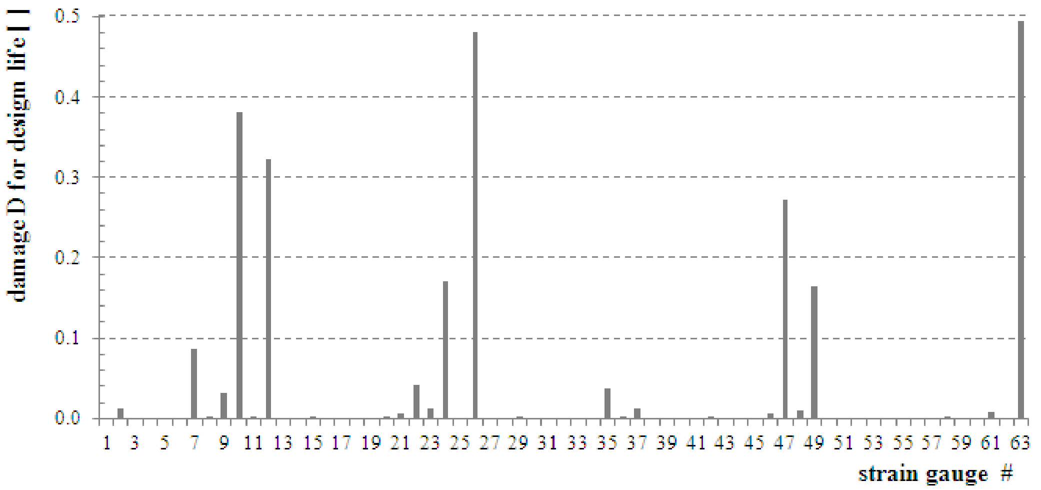

Fig. 5 Calculated damage for measured trolleybus joints for design life of 1 mil. km

Acceleration Evaluation. Measured acceleration time histories were divided to parts with constant millage and for each part the effective values were calculated and FFT spectra were averaged. The resulting spectral densities were compared with those, given in standard (Fig. 7). The goal was to ensure, that the standard values match the real ones.

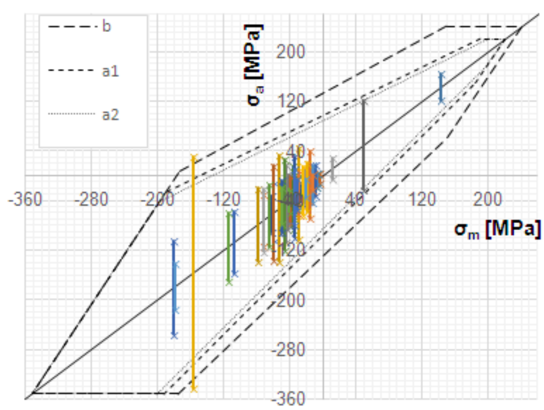

Fig. 6 Goodman diagram for tested parts

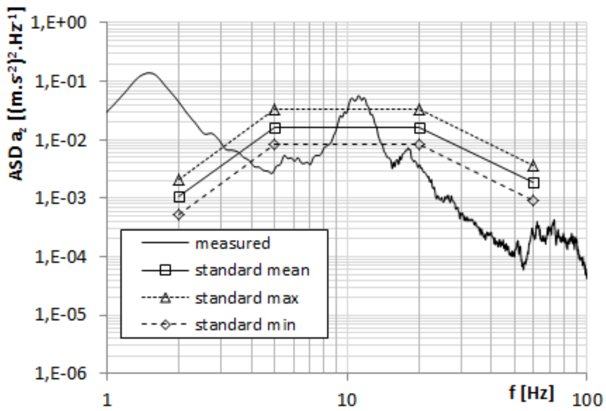

Fig. 7 Acceleration a_z spectral density

Conclusions

The estimated service life of all tested trolleybus joints exceeds the value of 1 million km. The highest damage was found on upper T-joint door pillars and the supporting bracket for the traction engine. The spectral densities of roof acceleration have different form and levels when compared with the standard EN 61373 for rail vehicles.

The article has originated in the framework of the institutional support for the long-term conceptual development of the research organization.

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