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Fatigue Life Analysis of Volvo S80 Bi-Fuel

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ABSTRACT

The dimensioning of Volvo S80 Bi-Fuel has been totally performed in a virtual environment. Several design solutions have been numerically investigated using two dominant load cases. The robustness of chosen solutions have been investigated by calculations with critical spotwelds removed from the FE-model. The final design has been verified with a full four poster shake rig test. Although the rear floor is totally redesigned for the gas tank installation, no fatigue failure has been observed in this area.

The paper gives some insight into the dimensioning process, with special focus on spotweld fatigue analysis. All fatigue calculations were performed using MSC/Fatigue.

INTRODUCTION

An important feature of a modern industrial development process is the use of calculations and simulations at an early stage of the design process. Driving forces in the automotive industry are the need for weight reduction and lower manufacturing cost, whilst maintaining safety and reliability, within a short development cycle.

Mechanical FE analyses are used to estimate the fatigue strength, which for thin-sheet structures is mainly given by the strength of the joints. A FE based methodology for predicting fatigue life of spotwelds in thin sheet

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automotive structures was proposed by Rupp *et al.* at LBF in 1995 [1]. In a joint undertaking between nCode International Ltd., MSC and Volvo Car Corporation (VCC), a spotweld analyser was developed the same year in the MSC/Fatigue environment using the above mentioned methodology, see Heyes *et al.* [2 - 3]. Fatigue life prediction of spotwelded joints has been performed on a daily basis at VCC using this software since then.

The amount of FE-based fatigue calculations has increased dramatically during the last years at VCC, which can be seen in Figure 1. Spotweld calculation is among the most common type of fatigue calculation at VCC. This paper gives some insight into one project where calculations and simulations have been used for the dimensioning of a new product.

SYSTEM DESCRIPTION

The S80 Bi-Fuel is a petrol and gas-driven hybrid vehicle. Unlike the S/V70 Bi-Fuel, the fuel installation is located entirely underneath the body floor, and does not consume space inside the luggage room. Two variants have been developed, one using compressed natural gas (CNG) the other using liquefied petroleum gas (LPG). In the CNG variant, the normal S80 petrol tank is replaced with a tank frame installation with two small gas tanks and a reduced 30-litre petrol tank, as shown in Figure 2. In addition a large gas tank is strapped to the rear floor.

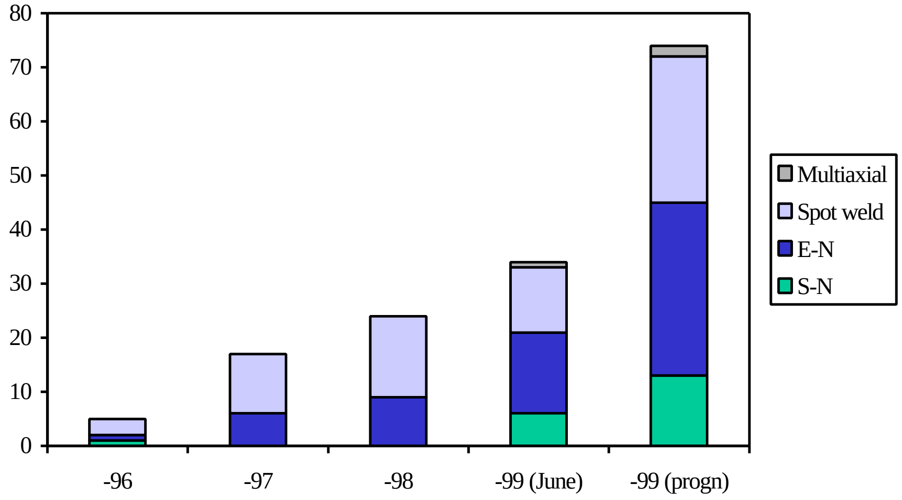

Figure 1. *Number of reported projects where fatigue calculations have been performed using MSC/Fatigue. No difference is made between large projects (several months – complete car body models) and small projects (days, weeks – components, subsystems). A prognosis is made for 1999. The reported Bi-Fuel example corresponds to one marker in the –99 chart, see [6].*

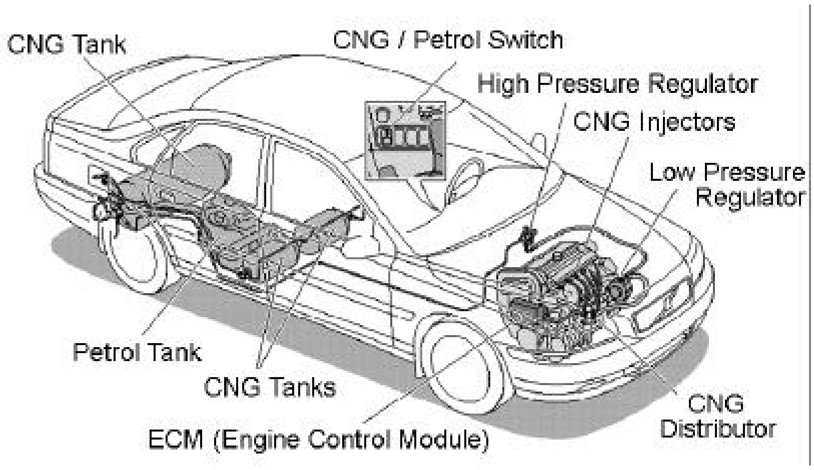

Figure 2*. The S80 Bi-Fuel is a petrol and gas-driven hybrid vehicle. For the variant with compressed natural gas (CNG), the normal S80 petrol tank is replaced with a tank frame installation with two small gas tanks and a*

reduced 30-litre petrol tank. In addition a large gas tank is strapped to the rear floor.

The CNG variant is the most widespread, and therefore calculations have been based on this set-up. The two small gas tanks are omitted in the LPG variant. Instead it has a larger petrol tank and a heavier rear gas tank than the CNG variant. The mass of this heavier LPG rear gas tank is, however, considered in the analysis.

To carry the new systems the spare wheel well in the rear floor panel is replaced by a flatter panel and an extended battery well. A new crossmember for the tank band attachments is welded to the floor. Six attachment points for the tank frame, and four attachment points for the bands of the rear tank, are prepared.

INITIAL DIMENSIONING

The two small gas tanks and the new petrol tank are strapped or bolted to a tank frame. Then the tank frame is bolted to the body at six locations. This solution was chosen for assembly reasons and for simplicity. Disadvantages are added cost and weight.

To achieve safe design for fatigue, it was decided to go for min 30 Hz for the lowest resonance of the tank frame when loaded with all tank masses and installed in the car. The design iterations of the tank frame to reach this target was outsourced, and the optimised tank frame was then built in to a full body model at VCC.

For space reasons, a frame solution for the rear gas tank was not possible. A conventional solution with tank bands was chosen. The design target for this system is the same as for the tank frame, *i.e.* min 30 Hz for the lowest resonance.

The rear gas tank is preloaded into the rear floor plate in order to achieve a stiffer rear floor assembly. The level of preload is of great importance. Sufficient preload is required in order to maintain contact of the tank and the floor at peak vertical acceleration levels from road input. Separation should cause fatigue and noise problems. However excessive preload could also be problematical with respect to fatigue.

The design iterations have been focused on a body able to cope with high preload and to introduce flexibility in the tank bands to cope with building tolerances and pressure and temperature expansion of the tank.

METHOD AND MODEL

The FE-model is based on a S80 body-in-grey model with full trim. Notable changes have been made in the rear end of the car to the fuel installations, see Figure 3. The model has been continuously updated throughout the prestudy in order to optimise the static and dynamic stiffness, weight and fatigue properties.

Spotwelds are represented by “stiff” beam elements joining two sheets of shell elements (CBAR elements with “diameter” 6 mm). The shells are positioned at the mid planes of the sheets. In order to achieve stable cross-sectional forces and moments, an element length of about twice the nugget diameter has been used, see [1, 5]. An in-house program has been used for checking and, if necessary, modifying the mesh close to the spotwelds. The program works directly on the Nastran input file.

MSC/Fatigue has been used for fatigue analysis of sheet metal parts (strain life approach) and for spotweld analysis. In order to save time, a quasi-static method was used. Results from several static load cases (using Inertia relief in MSC/Nastran) were then superimposed and scaled with corresponding time signals. Results from fatigue calculations using transient response results were considered not to give considerably different results for this application.

LOAD CASES

Calculations using the MBS-code ADAMS have previously been performed to simulate loads transmitted between chassis and car body in Volvo S80 due to driving conditions on the Hällered test track. No new ADAMS simulations with S80 Bi-Fuel have been undertaken. Instead, older S80 signals have been used after some scaling. In order to speed up the design process, two dominant load sequences were identified and used:

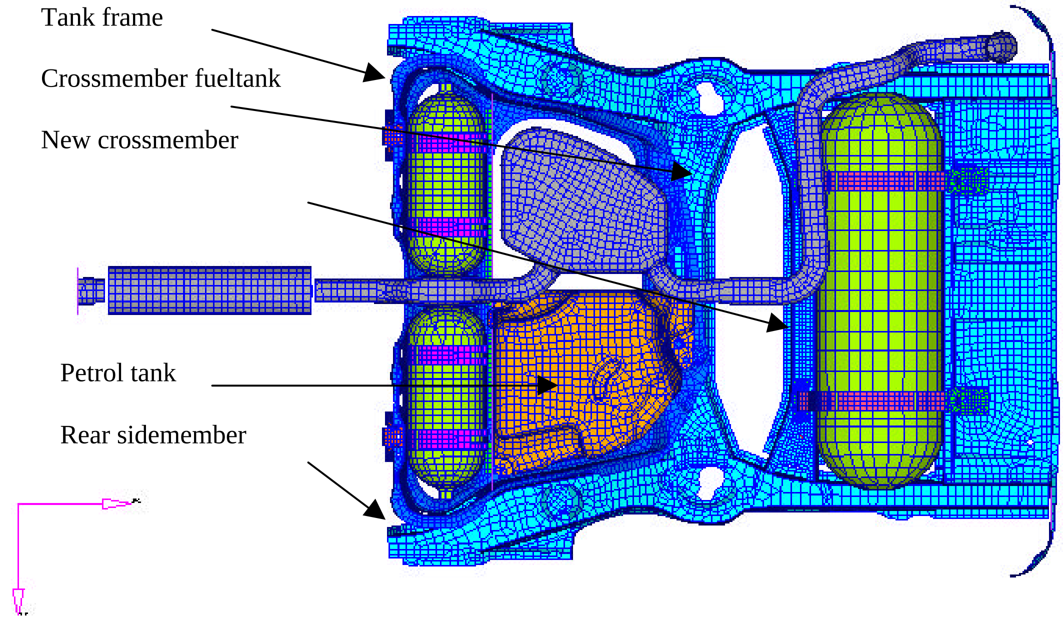

Figure 3. FE mesh of rear gas tank assembly seen from below. Two small gas tanks and a new petrol tank are mounted to a tank frame, which is bolted to the body at six locations. A large gas tank is strapped to the rear floor. A new crossmember for the tank band attachments is welded to the floor.

Torsional Excitation

The first load sequence comes from passing an out-of-phase corrugation. This results in a torsional loading of the car body in a given frequency range. Vertical and lateral load histories at spring and damper points of all four wheel suspensions were used in the quasi-static fatigue calculations. Consequently this amounts to 2 (directions) x 2 (positions) x 4 (wheels) = 16 static load cases for the full body model. Other load inputs from the chassis to the body (for instance from subframes and rear bump stops) are considered to have minor influence on the fatigue life.

Parallel Excitation

The second load sequence originates from the passing of a parallel corrugation. Previous analysis with S80 has shown this to be a severe load case for attachments of heavy components such as fuel tank, spare wheel and battery. The parallel excitation was further simplified to a prescribed vertical acceleration of the car body of +/-2g ($g = 9.81 \text{ m/s}^2$).

The rear gas tank is preloaded to the floor to provide a stiffer assembly. It is essential that separation from the floor is avoided. The attachment is therefore designed to withstand an acceleration of 3g without loosing contact. The desired preload deflection to maintain contact of the heavy gas tank could be calculated knowing the stiffness of the rear floor. This preload then was applied to the rear floor as a static load to achieve the preload stress state equivalent to 3g acceleration. A sinusoidally varying time signal was then applied to the 3g stress state, giving an equivalent stress range between 0g (the tank just in contact due to downward 3g acceleration) and 6g (the preload plus an upward 3g acceleration).

Statistical analysis of the Hällered load signals is possible using the Wöhler equation to estimate the equivalent number of load cycles at a given constant acceleration level and Wöhler constant. The target cyclic life can then be evaluated for given constant acceleration amplitude. Existing load signals from the heaviest Volvo S80 variant were considered. As the S80 Bi-Fuel was analysed in a completely virtual environment, the actual load signals were unknown. Consequently the most severe signals were used for conservatism.

RESULTS

Numerous models were numerically analysed with special concentration on the new unique parts for S80 Bi-Fuel. Generally it was seen that the parallel excitation dominated results for the unique tank installation components.

The first model to be numerically analysed comprised a straight crossmember and a 1.0 mm thick floor plate without swages. This set-up was found to be too flexible and with poor fatigue properties, and was fairly soon replaced by a flared crossmember and a 1.2 mm thick floor plate with four 10 mm deep swages, see Figure 4.

The preload cycling dominated fatigue results for the rear floor area. The most critical area was shown to be spotwelds between the new flared crossmember and the rear floor plate adjacent to the B-plus cable step, see Figure 4. Robustness of the design was investigated with new fatigue calculations with the most damaged spotwelds removed from the model. It was found that further failure or unzipping would not result at the B-plus cable step. Nevertheless a stiffening swage was inserted in the floor plate to support this area as shown in Figure 5. The high preload also required a more concentrated number of spotwelds around the rear floor plate.

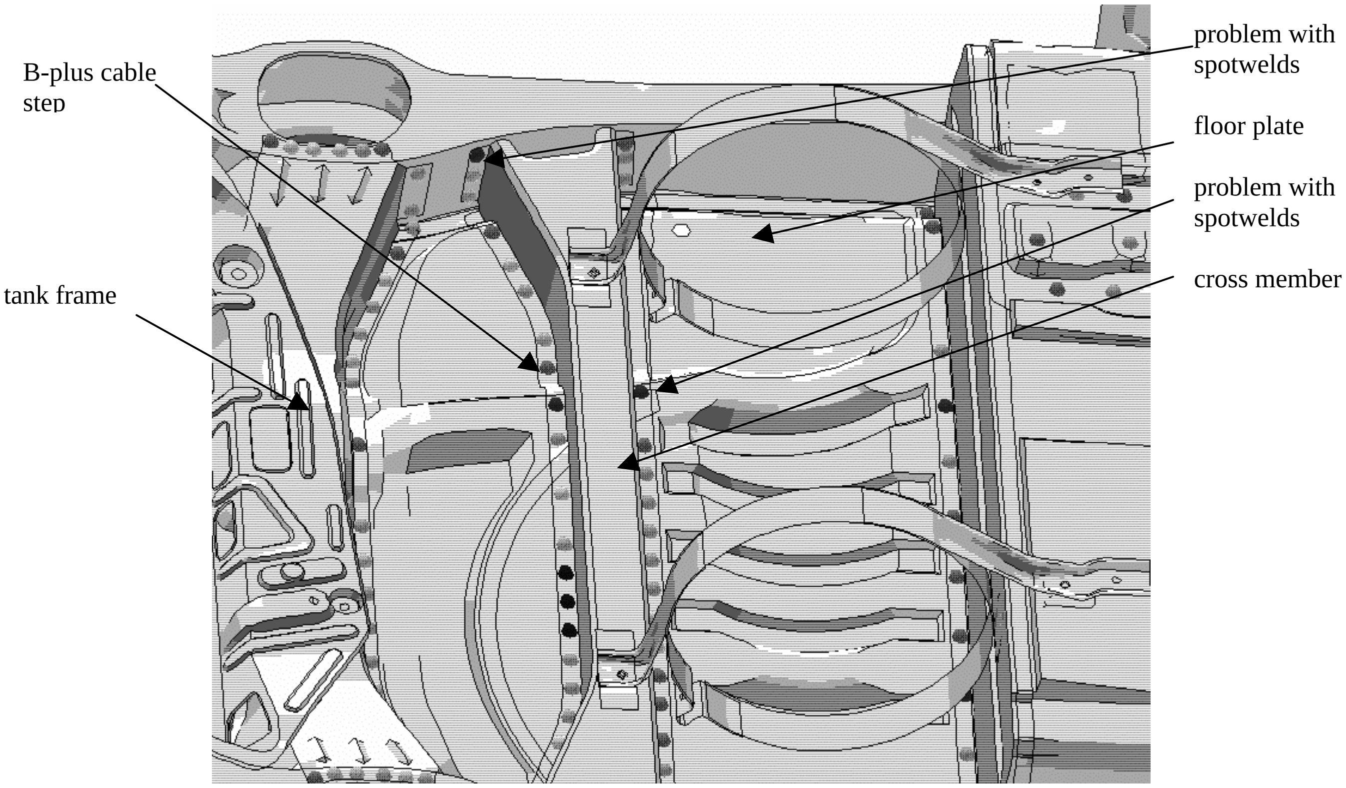

Figure 4. *Virtual prototype with flared crossmember and 1.2 mm thick floor panel with four depressions.*

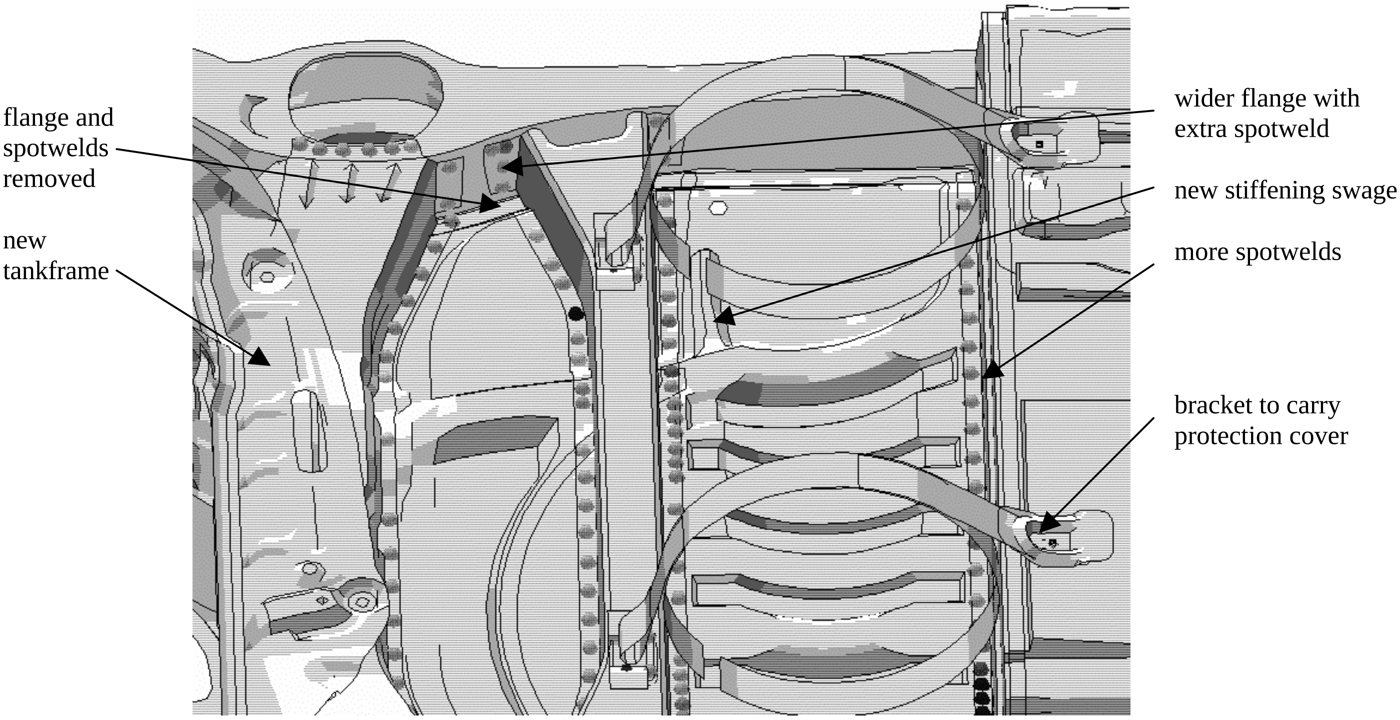

Figure 5. *Virtual prototype with stiffening swage in floor plate and extra spotwelds.*

Preload cycling, however, was shown to have little effect on the tank frame assembly further forward, as shown in Figure 3. Here the more regular vertical acceleration loads (+/- 2g) dominated results at the front attachments. However it was predicted that failure would not occur. The vertical loading also dominated the large tank attachment results. The weld nut plate spotwelds inside the new crossmember were shown to fail unless nugget diameter was controlled.

Throughout the project analysis was also performed to support decision-making in the development process. For example process problems arose with respect to weld gun access to the new crossmember vertical flange, as shown in Figure 5. Consequently part of the flange and the associated spotwelds had to be removed from the new crossmember. The vertical flange was widened and more spotwelds added to compensate.

CONCLUSIONS

The dimensioning of the tank installation in Volvo S80 Bi-Fuel was performed entirely in a virtual environment. Several design iterations were performed before a final prototype was manufactured and physically tested in a four poster shake rig test. Analysis was also performed throughout the project to support decision making in the developing process. The robustness of chosen solutions was investigated by calculations with critical spotwelds removed from the FE-model. Although the rear floor is totally redesigned for the gas tank installation, no fatigue failure was observed in this area after verifying tests.

The paper gives some insight into a project where modern FE-based software has been successfully used to speed up the development of a new product.

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