Fatigue life prediction of the automotive exhaust system under RLDA

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Abstract: More than ever, there is a need to optimize the mass of exhaust systems due to increasing cost of raw materials and fuel coupled with ever stringent environmental regulations. In order to meet the cost, performance and timing requirements, it is necessary to have a fatigue approach which leverages prediction tools, testing equipment and previous & current road load measurements during various phases of product development. The purpose of this paper is to present the fatigue approach used in Faurecia. This approach takes into account the multiaxial and random aspect of exhaust system loading. The loading data is typically leveraged from a vast "living" database during early design phase. An example of the application of this approach on a muffler is described. First the load measurement on test track called RLDA (Road Load Data Acquisition) is presented, followed by the approach used in design and validation of the exhaust system. Typically, early in the design phase, FE modelling of the component followed by fatigue post processing to estimate the safety factor (with respect to the material fatigue limit) is performed. Later during development, as more testing data becomes available, an approach which combines prediction and testing is used. Validation usually involves fatigue testing performed on representative prototypes and establishing the factor of safety of each component, typically followed by full exhaust system rig testing.

INTRODUCTION

In today's competitive automotive industry durability and cost are key. Durability depends on a large number of factors such the design, the loading and the material characteristics. Normally durability calculations are performed in the critical regions of an exhaust system. Welded regions present the most durability risks and hence most calculations are performed in zones with welds, such as muffler inlets/ outlets, hangers etc. Typically an exhaust system is subjected to static and dynamic loading from the road, the powertrain, self weight, thermal expansion etc. This paper deals with the road load component of excitation (typically 0 to 30 Hz). The stress field from such loading is random, multi-axial and complex and the durability approach involves combining damage accumulation law and multi-axial fatigue model. In the following paragraphs this durability approach is described.

1 THE APPLIED LOAD AND THE POST PROCESSING

Normally the applied load is measured directly on vehicle driven on reference tracks. Each car maker has its own track with different durability events (Belgian blocks, shaped road, hills…). The durability life is defined by associating a number of repetitions for each event. A fatigue equivalent load, which is based on damage equivalency at 1 million cycles, is calculated. We present here an example of the measurement method on muffler outlet and the post processing used to calculate the equivalent load.

1.1 The RLDA acquisition

The load measurement is composed in 3 steps: instrumentation, calibration and acquisition. The system is instrumented with strain gages on the component inlet/outlet and hangers. Depending on the number of degree of freedom desired, strain gages are pasted in ¼ bridge or ½ bridge.

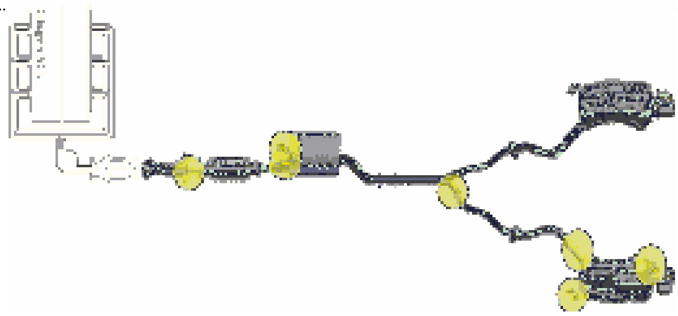

Figure 1. Measurement point in the line

The calibration of the component is then performed in order to determine the relationship between the applied load and the measured strain. The calibration is done by static test on component. For each degree of freedom (3 forces and 3 moments) the strain is measured and the calibration matrix is calculated.

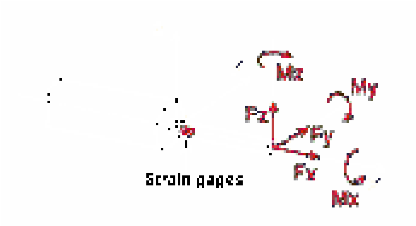

Figure 2. Experimental calibration of the muffler

Once the system is instrumented, it is mounted on the vehicle and the measurement is performed for the different events. Figure 3 shows an example of the evolution of the 6 dof for a muffler inlet. We notice that bending moment components are more significant than torsion, shear and tensile components.

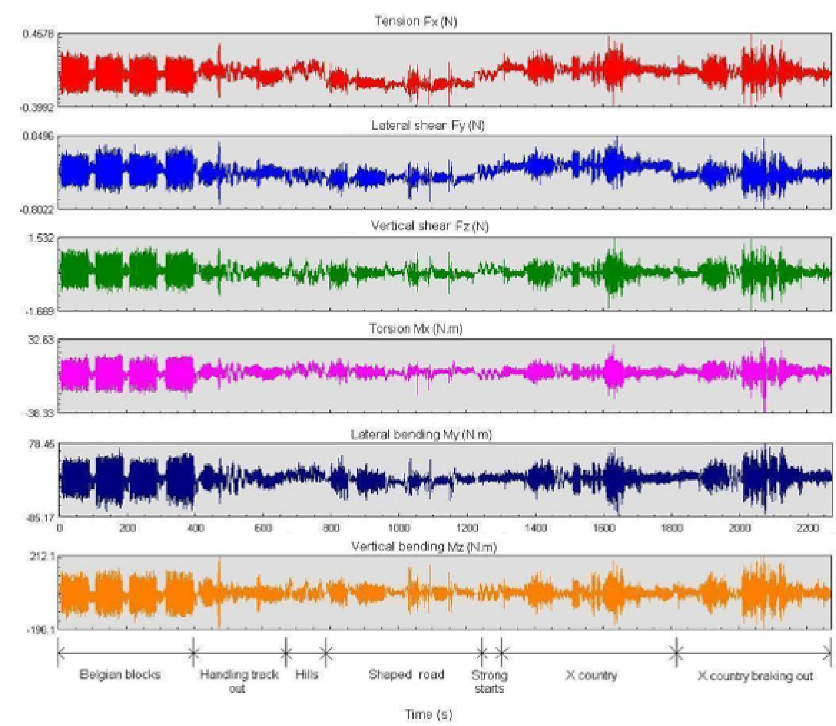

Figure 3. Example of load measurement on the muffler outlet

1.2 Determination of the equivalent load

In most cases the applied load can be reduced to two bending moments. The other degrees of freedom (torsion and tension) are negligible and their influence on the fatigue life of the component is very small. This assumption has been validated by doing both fatigue test and calculation with the 6 dof. The fatigue life has been compared in these 2 cases, the results show that only the 2 bending moments contribute on the damage of the system. In this case, an equivalent load can be calculated as described in Figure 4.

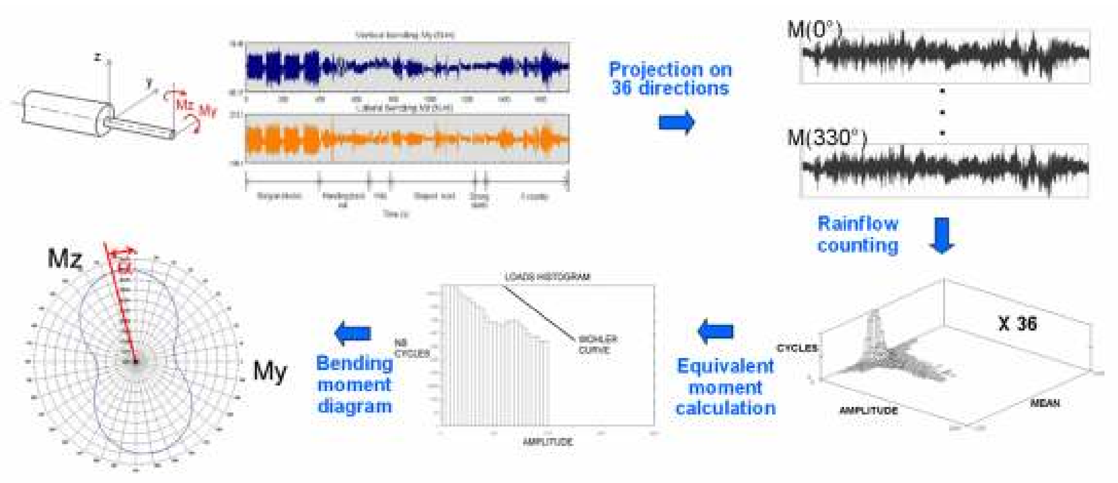

Figure 4. Calculation of the equivalent load

The equivalent load is determined using an internally developed software – WinDME. This software uses a damage model as described by the Wöhler curve in combination with Miner law for damage accumulation. In this calculation the occurrence of each event is taken into account. The equivalent load, Me, is calculated at 1 million cycles and the output of the post processing is a bending moment diagram (Figure 4).

2 CALCULATION APPROACH

The goal of the calculation approach is to estimate the safety factor of the component for a given material and the equivalent load from WinDME. Abaqus as FEA software code and the fatigue post processing tool Design Life from nCode are used.

In a thin shell Finite Element model, sheets are described by their mean surfaces. The difficulty in using a shell modelisation lies in the modelling of the mean surface intersections. These zones exhibit a multiaxial stress field compared to biaxial stresses elsewhere. The Finite Element model is usually validated by a static test. The stiffness of all the links are measured in order to calibrate the model (Figure 5). Strain gage measurements are also performed on the part at some places and the strain level is compared to the one calculated.

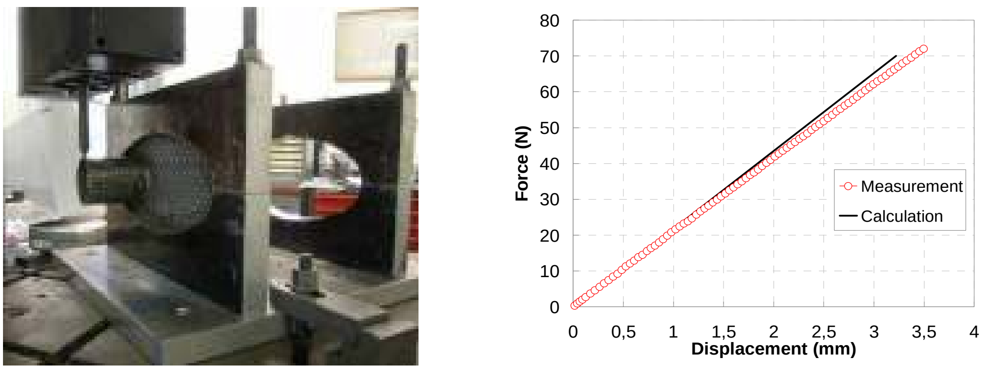

Figure 5. Stiffness measurement of the link between the inner pipe and the baffle

Depending on the type of calculation (static or thermo-mechanic), both solid elements and rigid can be used to model the welds. The other links on the components (spinning, staple, etc…) are modelled by tie contact.

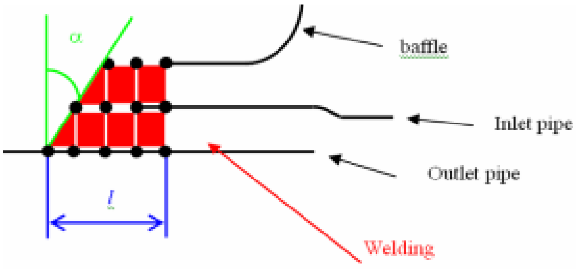

Figure 6. Example of a welding mesh with solid elements

The load used in the calculation is the equivalent loads **Me** at 1 million cycles. The advantage of this approach is that it allows us to work with macroscopic loading magnitudes and then we are independent of the design of the component. Usually the bending moments are enough to get an idea of the component reliability. The load could be applied in the principal direction of the bending moment diagram or the entire diagram could be played. One of the fatigue model used at Faurecia is the Dang-Van criterion which takes into account the multiaxial load. Figure 7 shows an example of the safety factor calculated with this model on a muffler outlet.

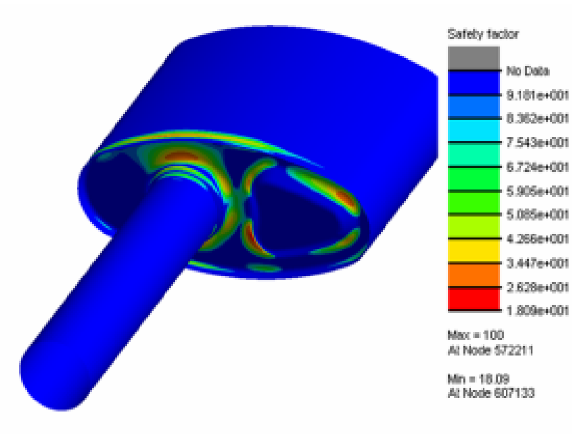

Figure 7. Example of the safety factor calculation in the muffler

3 EXPERIMENTAL APPROACH

Two kinds of experimental validation are usually performed, i.e. component validation during development phase and full system testing during final validation. In this paper only component validation is presented. Depending on the shape of the moment diagram, the validation test is done on a uniaxial or biaxial test rig. The biaxial test is performed if the shape form of the diagram is less than a reference value of the ratio between moments in two principal directions. For the uniaxial test, the principal direction of the bending moment diagram is used. The test rig is electrical. A sample of seven components is usually tested at high temperature; a burner is used to reach a temperature up to 600°. This testing establishes the fatigue limit, **Mf**, of the component at 1 million cycles.

Figure 8. Biaxial test rig

The safety factor is then calculated as the ratio between the experimental fatigue limit **Mf** and the equivalent load **Me** both defined at 1 million cycles. This factor of safety is compared to others in a database to establish suitable confidence for a given application.

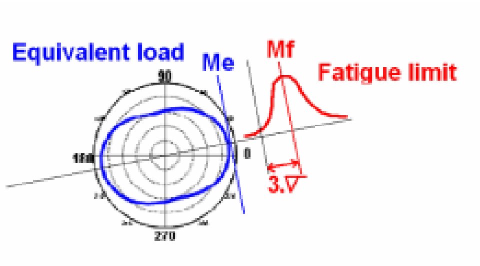

Figure 9. Determination of the experimental safety factor

4 CONCLUSION:

A fatigue approach was developed to predict the durability of the exhaust system. The aim is to optimize the mass in order to be more competitive and to reduce the fuel consumption & the emission of the car. This approach is used today in the various phases of product development; it leverages road load measurements, prediction tools and testing equipment. The improvement of this approach is under development in order to take into account the residual stress near the welding and the influence of the pre-strain on the fatigue life.

5 REFERENCES:

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