Using fibre optical sensors for validation purposes in GFRP transverse leaf springs

T. Grünheid-Ott[1a], C. David[1], O. Deisser[1] and R. Schmidt[1]

[1]German Aerospace Centre (DLR e.V.) – Institute of Vehicle Concepts, Germany

[a]Thomas.Gruenheid@dlr.de

Abstract. The integration of composite materials in vehicle structures offers potential for weight savings and improved fatigue strength. In a McPherson suspension, further weight reduction can be achieved by replacing the control arms, coil springs and anti-roll bar with a transverse leaf spring. However, the development of a glass fibre reinforced transverse leaf spring with an integrated wheel control function is challenging due to a large number of design and laminate parameters. The geometry of the tested leaf spring prototype was provided by a previous optimisation process. The tests generate a large amount of data in different formats due to the complex measurement technologies (optical sensor fibres, photogrammetry, strain gauges, load cells). The focus is on automated data processing of both the test data and the FE data, especially the optical sensor fibres, which are modelled in their original positions. The forces, strains and displacements (elastokinematics) of both disciplines are automatically compared visually using charts and a 3D user interface of the leaf spring model including sensor fibres.

Possible Sessions

3. Automotive Applications, 14. Model Validation, 24. Testing of Composite Materials

Introduction

Fibre reinforced components are increasingly used in today's automobiles. Since the early 1980s, glass fibre reinforced longitudinal and transverse leaf springs have been used in the chassis of cars and vans. Various approaches for wheel control functionality using glass-fibre reinforced transversal leaf springs have been described in research papers and patents [1,2,3]. For further mass reduction, the wishbones, coil springs and anti-roll bar of a McPherson suspension can be replaced by a transverse leaf spring. The literature does not provide a methodical approach to designing a transversal leaf spring with wheel control function. In [4], a McPherson-similar suspension with a wheel controlling transverse leaf spring is presented conceptually. In [5], an approach is proposed using an automated CAE process for CAD and FE modelling and result evaluation. The applied metamodel based optimisation process is challenging due to the large number of parameters describing the geometry and laminate. To simplify the process, the low-fidelity approach is used to significantly reduce the level of detail in the FE model and thus the computational effort. Therefor 2D elements are chosen to model the leaf spring. The feasible design found in [5] has been built as prototype. In the present work, an automated validation process is developed using the test results obtained.

Validation

Test setup. For the validation test, the connections to the car body and the wheel carriers are designed to be functional, Fig. 1. To ensure the integrated anti-roll function, the central clamping jaws connecting the car body are positioned to the left and right of the leaf spring centre. Additional bushings allow small relative movements during loading. Clamping plates on both sides are used to transfer the load to the leaf spring. In the test set-up, the force is applied at the points where the joints connecting the leaf spring to the wheel carrier would be in a chassis.

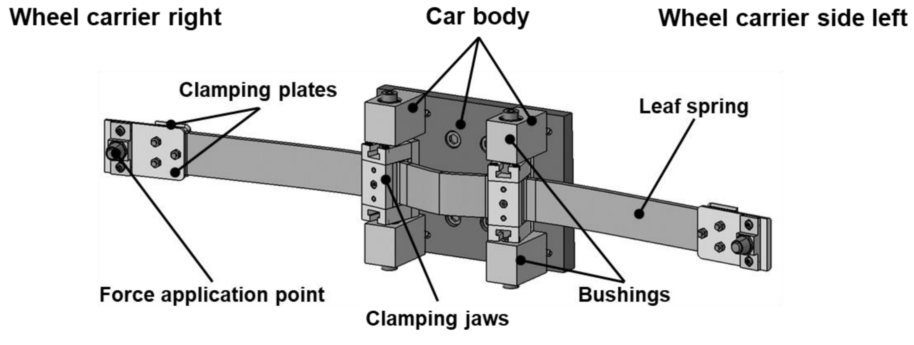

Figure 1. Leaf spring assembly for test

The measurement technologies are not illustrated. Load cells are used to measure forces at the force application points. Strain gauges are placed in areas where increased strain is expected. Optical sensor fibres are embedded in the top, bottom and middle layers to measure strain over the entire length of the component, especially in the clamping area to the car body [6]. Digital image correlation was applied to verify the previously measured strains. Photogrammetry was used to measure the spatial elastokinematics during deflection, with tracking points attached to the leaf spring. For safety reasons, manual photos were taken between 0 mm and 70 mm spring travel.

FE modelling. The application of 2D elements instead of 3D elements reduces the computational cost per load step by a factor of 30 to 60. Stresses across the part thickness can be estimated from geometric relationships and the laminate. The critical parameter ranges can be defined as parameter constraints during optimisation or the estimated stress can be output as a response after simulation. The interactions between the leaf spring and the clamping jaws (car body) are changed by modelling with 2D elements. On a 2D element surface, clamping affects the entire thickness of the part. The low-fidelity approach provides a numerical representation of this relationship that is sufficiently accurate. The numerical relationships between the leaf spring and the clamping jaws, as well as the effects on the virtual strains and elastokinematics, can be analysed and compared with the test results. To evaluate the effects of the numerical connection, the optical sensor fibres of the prototype were mapped onto the top, bottom and middle layers of the FE leaf spring. Three different connection approaches are modelled, simulated and compared.

Evaluation. A large amount of data in different formats from different disciplines (strain gauges, sensor fibres, load cells, photogrammetry, FE simulations, etc.) is generated during both the tests and the FE simulations. Automated evaluation of the validation tests and simulations is essential as soon as optical sensor fibres or photogrammetric data are in use. Fig. 2 shows a newly developed evaluation routine including a visualisation function. Data streams from the different disciplines are processed internally, stored in a standard data format (hdf5) and finally visualised using charts and/or a 3D user interface. For example, error bars can be added to charts to reflect possible systematic measurement or FE modelling uncertainties. In the 3D view, the leaf spring is represented by 2D elements and the sensor fibres by 1D beam elements. The strains derived from the simulation can be mapped directly to these elements. Similarly, the sensor fibre strains of the test can be visualised with the 1D elements.

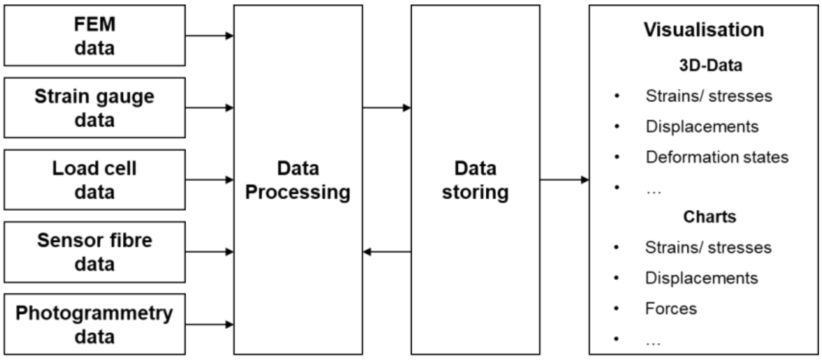

Figure 2. Evaluation and visualisation tool

Conclusion

Based on a simplified model of a transverse leaf spring and a large amount of complex test data generated by the prototype of this leaf spring geometry, an application for automated evaluation and visualisation had to be programmed. This forms the basis for the processing of all measurement results. With this application, complex correlations such as strains from sensor fibres and spatial deformations (photogrammetry) can be directly displayed and evaluated. The validity of the FE simulation can be directly evaluated. It can be shown that the FE simulations of three different joining approaches (clamping jaw on car body) can be compared and evaluated with the test in terms of strains and spatial component deformations, here limited to the range from 0 mm to 70 mm. In the future, once the data has been measured, this approach will allow a direct comparison between test and simulation. Implausibilities between test and simulation can thus be identified more quickly and directly.

References

[1] P. Zandbergen, *A composite beam as a multifunctional suspension component*, University of Twente, Enschede, The Netherlands (2004).

[2] P. Zandbergen und S. Chambers, *Wheel suspension for a motor vehicle with a transverse leaf spring*. US Patent US7029017B2 (2004).

[3] J. Winter, S. Fiebig, T. Franke, R. Bartz, T. Vietor, *Spline‐based shape optimization of large‐scale composite leaf spring models using Bayesian strategies with multiple constraints*, Structural and Multidisciplinary Optimisation, Springer (2022).

[4] O. Deißer, T. Gruenheid, M. Schaeffer, *An innovative and safe active light weight design chassis concept*, ATZ chassis.tech (2021).

[5] T. Gruenheid, O. Deisser, R. Sturm, *Methodology for automated designing of composite structures in suspension systems*. NAFEMS World Congress (2021).

[6] LUNA Inc., ODiSI 6000 Series, Data Sheet (2022).