CONCEPTION AND MANUFACTURING OF A LIGHTWEIGHT LEAF SPRING WITH ADJUSTABLE SPRING RATE

W. Hufenbach[1], F. Adam[1], M. Pohl[2], S. Spitzer[1], D. Weck[1,*]
[1]Institute of Lightweight Engineering and Polymer Technology
Technische Universität Dresden, Dresden, Germany
[2]Leichtbau-Zentrum Sachsen GmbH, Dresden, Germany
[*] Corresponding author (daniel.weck@tu-dresden.de)

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1 Introduction

Springs within the suspension of vehicles are commonly designed for maximum load. Thus, the driving dynamics of the unloaded or lightly loaded vehicle is poor. Furthermore, the high stiffness of the spring leads to dynamically caused peak loads on the structure of the vehicle [1], [2]. To avoid these problems, springs with adjustable spring rates are necessary. Especially in trucks, air springs are common, where air pressure is used to adjust the spring rate. However, these air springs are high-maintenance and more expensive compared to classic metallic leaf springs. This paper presents a new concept to adjust the spring rate of a lightweight spring system containing glass fiber-reinforced polypropylene (GF/PP) leaf spring elements.

2 Concept and dimensioning of an adjustable leaf spring system

Classical leaf springs are mounted at the ends while the point of load application is located in the middle. In contrast to this classical spring system, the new concept consists of a cantilever beam of length l with a fixed bearing (A) at one end, a loose bearing (B) with the distance a and the point of load application at the free end (see Fig. 1). Based on the differential equation of the bending line, the deflection w at the point of load application caused by the force F can be derived as shown in Fig. 2. Consequently, a small shift of the loose bearing which is equivalent to a small variation of the ratio a/l leads to high changes of the deflection w assuming a constant force F. This effect is used to adjust the spring rate F/w of the novel leaf spring system.

To design such a lightweight spring system with leaf spring elements a dimensioning strategy has been developed (see Fig. 3). Based on the system requirements (SR) which include the limits of the stiffness range (F_1/w_1, F_2/w_2), a basic spring rate C of the leaf spring is identified during a preliminary design (PD). Using this information a maximum and minimum geometric ratio a_1/l and a_2/l is determined from the diagram (D). Finally, the spring system is designed and verified in a subsequent strength analysis (SA).

3 Design and manufacturing of composite leaf springs

Composites exhibit high specific mechanical properties. Within the application of leaf spring elements, glass fiber-reinforced polypropylene (GF/PP) is advantageous because of its high deformability, the possibility of fast processing and the opportunity to integrate additional functions like load application elements or sensors [3]-[7].

To validate the concept of adjusting the spring rate of the spring system, the dimensioning strategy was used to calculate three exemplarily chosen GF/PP leaf spring elements with different textile reinforcements: unidirectional rovings (UD), woven fabrics (WF) and multilayered weft-knitted fabrics (MKF).

General conditions for the calculation were the length $l = 500$ mm, the width $b = 50$ mm and the maximum deflection $w = 50$ mm for the leaf spring elements. The limits of the stiffness range are derived from the dynamic loads of the unloaded and the fully loaded vehicle. For the chosen example, the limits of the force to deflection ratio are set to $F_1/w_1 = 7.6$ N/mm and $F_2/w_2 = 13.6$ N/mm. The resulting basic spring rate is calculated to $C = 1.22$ N/mm. To achieve the same basic spring rate C of the spring system regardless of the used reinforcement, it is necessary to align the thicknesses of the leaf spring elements to compensate the different Young's modulus resulting from the used reinforcement. The calculated thickness for the unidirectional reinforcement is $t_{UD} = 7.5$ mm, for the woven reinforcement $t_{WF} = 9.6$ mm and for the multi-layered weft knitted reinforcement $t_{MKF} = 8.6$ mm, respectively. Using these data it is possible to determine the ratio between the bearing distances and the length of the leaf spring elements to $a_1/ = 0.6$ and $a_2/l = 0.7$. The following strength analysis shows no violation of stress limits.

The leaf spring elements were manufactured using an autoclave process. The preparation includes the tailoring and stacking of the textile reinforcements (18 layers of woven fabric, 16 layers of multilayered weft-knitted fabric). For the element made from unidirectional rovings, the semi finished product was fabricated by winding 24 layers on a tool, which was especially developed for the designed leaf spring element (see Fig. 4). It contains a 50 mm wide reel for the placement of the rovings and a centering pivo to mount it in the winding machine. Two shims were used to press the winded rovings into the reel. After the setup on the autoclave table was completed, the consolidation was done at a maximum temperature of 195 °C and a pressure of 0.6 MPa. Finally, the leaf spring elements were cut from the GF/PP plates to their final dimensions by abrasive water jet cutting.

4 Test of composite leaf springs

The manufactured leaf spring elements were mounted in a special test rig (see Fig. 5). A pneumatic cylinder applies the force *F*, which is measured by a load sensor. An inductive position encoder meters the displacement *w*. The optical tracking system PONTOS detects the behavior of the spring under load. The fixed bearing is designed as a revolute joint. The loose bearing is realized with an aluminium cylinder with a radius of 7.5 mm to minimize the stress at the contact surface between the bearing and the leaf spring element. The pneumatic cylinder for applying the load is also mounted with a revolute joint to follow the movement of the leaf spring element.

After the mounting of the leaf spring element in the test rig, the adaptor at the load sensor was positioned in the load transfer element. The start situation of the test is a horizontally orientated specimen and a vertical orientated pneumatic cylinder. During the test, the pressure in the cylinder was risen and the resulting load was monitored until the position encoder detected a deflection of $w = 50$ mm. Two records were taken with the measuring system PONTOS: (1) at the beginning (F = 0 N) and (2) at the end of the test (w = 50 mm) (see Fig. 6). This test was repeated for the leaf springs with different reinforcements at several distances *a* in the range from 300 to 350 mm (equivalent to an a_1/l-ratio from 0.6 to 0.7.

The measured values show a good agreement with the calculated bending line. Exemplarily, Fig. 7 shows this comparison for the WF-element. Only a small variation could be measured between the leaf spring elements with different reinforcements (see Fig. 8).

6 Conclusions and outlook

The presented study shows a method to adjust the spring rate of a novel leaf spring element. For dimensioning of this system a strategy was developed and validated. The tests of manufactured leaf spring elements with different reinforcements show a good agreement between the calculation and the measured characteristic.

Further steps in the investigation are the development of an automatic system that adjusts the spring rate and the detection of the long-term behavior of the leaf spring elements. The measurement of the applied load on the leaf spring element is reasonable for a control cycle for the adjustment of the spring rate. A good possibility is the integration of the sensor in the leaf spring element [8]-[12]. The second part for the automatic system is the development of an actor which changes the distance *a* between the bearings. Furthermore, the long-term behavior of the composite leaf spring elements has to be investigated in order to reach the status for series-production.

7 Acknowledgements

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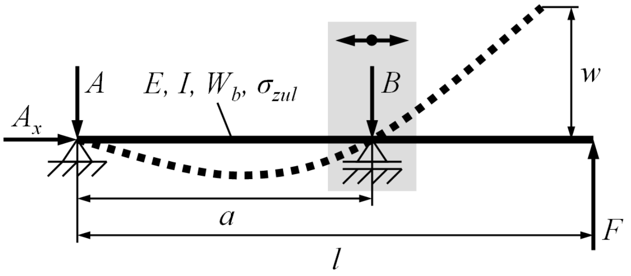

Fig. 1: Concept of an adjustable leaf spring

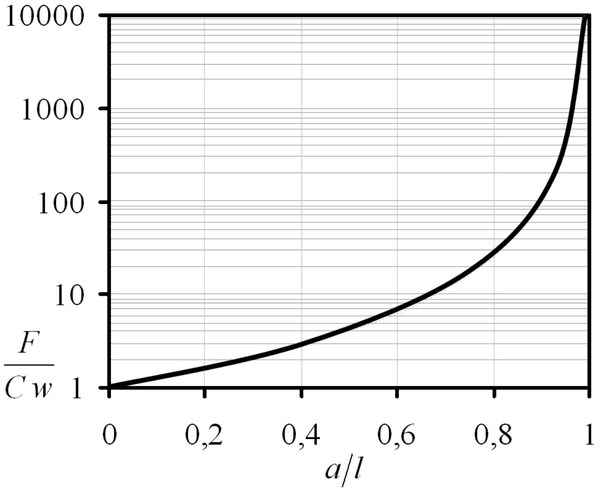

Fig. 2: Force-deflection-ratio of the leaf spring system vs. geometric parameter *a/l*

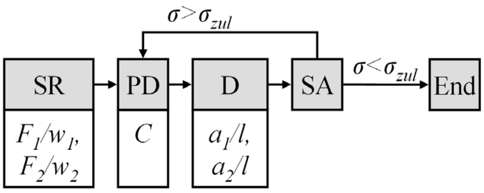

Fig. 3: Dimensioning strategy

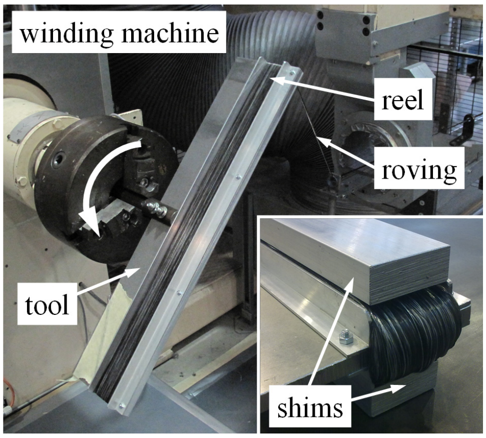

Fig. 4: Winding process

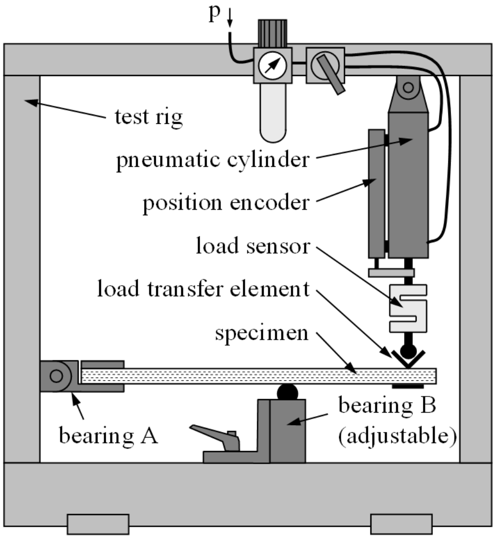

Fig. 5: Test rig

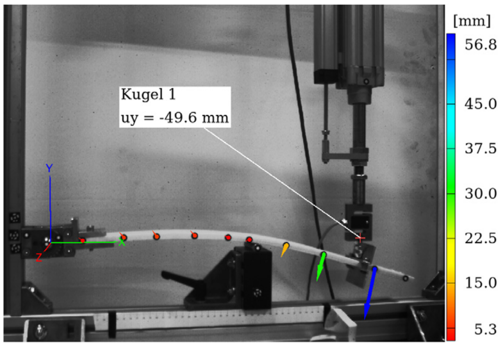

Fig. 6: PONTOS displacement vectors (colored arrows)

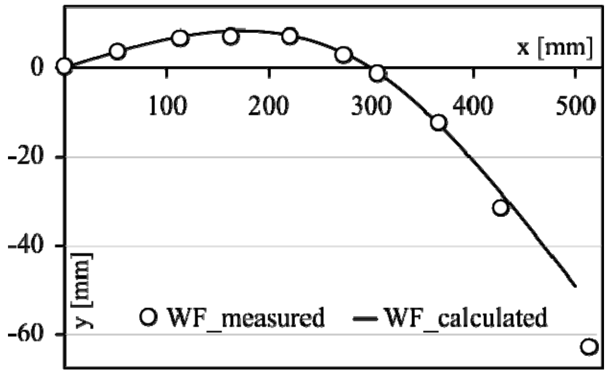

Fig. 7: Comparison of calculated and measured displacements in *y*-direction

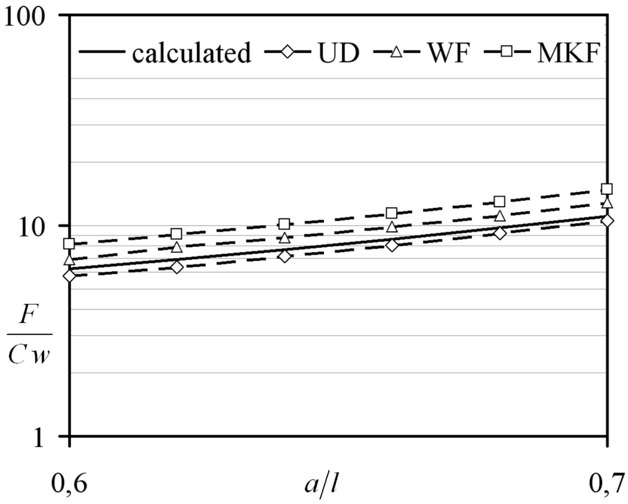

Fig. 8: Comparison of leaf spring elements with different reinforcements