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DAMPING CHARACTERISTICS OF DAMAGED FIBER COMPOSITE COMPONENTS

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16. Abstract

Defects in fiber composite components produce changes with respect to the vibrational characteristics of the material. These changes can be recognized in the form of a frequency shift or an alteration of the damping process. The present investigation is concerned with questions regarding the possibility of a utilization of the changes in suitable defect-detecting inspection procedures. A description is given of a method for measuring the damping characteristics of a specimen. This method provides a spectrum of the damping coefficients of the sample as a basis for a comprehensive evaluation of the damping behavior. The correlation between defects and change in the damping characteristics is demonstrated with the aid of results obtained in measurements involving specimens of carbon-fiber composites and acomponent consisting of glass-fiber-reinforced plastics.

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DAMPING CHARACTERISTICS OF DAMAGED FIBER COMPOSITE COMPONENTS

Klaus Eberle

Summary

Damage to fiber composite components causes changes in vibration behavior which are discernable as a frequency shift or change in damping. The question of whether this change can be used as a means of fault recognition, will be discussed on the basis of examples.

The report first describes a modified method of measuring damping, which uses specimen pulse stimulation to obtain a spectrum of damping coefficients, and which permits a comprehensive evaluation of the damping behavior. Finally, the correlation between damage and change in damping is explained on the basis of measured results for carbon-fiber reinforced plastic samples and a fiberglass-reinforced plastic.

1. Damping Measurement and Damping Spectrum

As a typical material property, damping is usually determined as a function of the parameters of stress amplitude, frequency and temperature, using standard methods. The investigation of various damping types usually is done according to the mathematical-physical breakdown of damping forces into structural damping, viscous damping and Coulomb damping. If these forces are to be taken into account in a computer analysis of the vibration problem, then one needs the results of damping measurements in the form of modal or global damping coefficients. These are obtained from experiments where a sample or a component is harmonically excited to a stationary vibration state and the energy dissipation is determined. One known example for this is the vibration extinction test--the measurement of amplitude decay after switching off the stimulus force.

Instead of harmonic excitation of the specimen, a shock or force pulse can be used, which simultaneously excites several vibration modes which decay more or less independently of each other. Through modification of the known evaluation method (described briefly below) it is possible to determine simultaneously the decay constants of all excited vibration modes, and a presentation of the results yields a comprehensive description of the damping behavior.

The time signal of a shock-induced vibration has a profile typical for the function x(t) shown in Figure 1. The measured quantity x is a representative acceleration, velocity, deformation or elongation of the test object, which is taken as the sum of sine functions of different frequency and damping. Through successive spectral analysis of the measured value plot x(t), i.e. Fast-Fourier Transformation from the time range into the frequency range, one obtains various amplitude spectra.

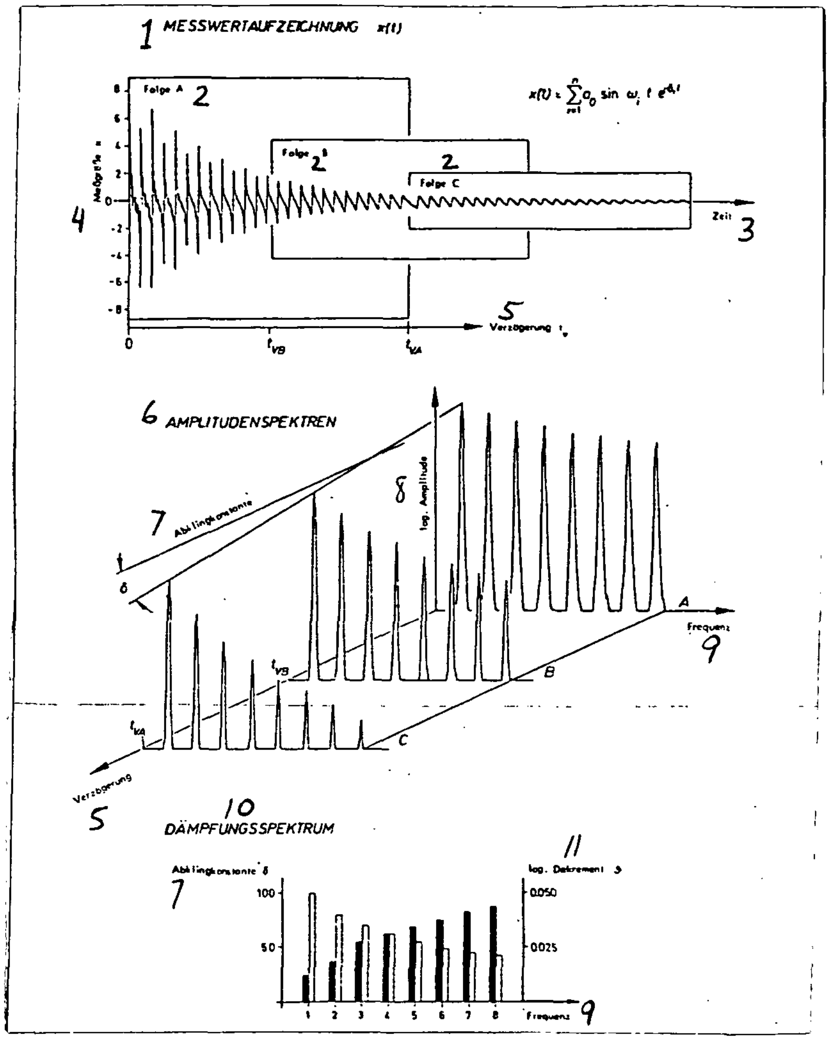


Fig. 1: Evaluation of Shock-Induced Vibrations and Determination of the Damping Spectra.

Key: 1-plot of measured value 2-sequence 3-time 4-measured quantity 5-delay 6-amplitude spectra 7-decay constant. 8-log. amplitude 9-frequency 10-damping spectrum 11-log. decrement

If these spectra are plotted against the delay time tv of the pertinent sequence x(t), then the falling tendency is seen for all spectral lines. Using a logarithmic representation, the particular connecting line is linear and its slope equal to the

decay constants. Finally, if these values are plotted against the frequency, then one obtains the configuration named in the following damping spectrum. It represents the vibrations excited in one pulse direction, and their damping after the pulse (undisturbed vibration extinction).
Among the damping mechanisms acting in composite materials, the visco-elasticity of the matrix and its potential for energy dissipation is dominant. The amount of this dissipation, that is, the damping ability, can assume quite different values, depending on the type of stress state, and is thus typical for a vibration mode. Changes in damping ability thus indicate changes in material properties, e.g. due to elevated temperature, or they are an indication for local changes in stress state, i.e. for damage.

The numerous potential damages in a fiber composite, with regard to type of damage, extent and distribution, indicate that the damping will also be affected in many ways and will not show up in only one vibration form. This finding was the starting point for the derivation of the damping spectrum which is applicable for weak and linear damping. With this tool, it was possible to investigate fiber composite samples and one component, to see how detectable damage changes the specimen damping behavior.

2. Damping in Carbon Fiber Reinforced Samples

Within the framework of a project by the German Research Society (DFG), a larger number of carbon-fiber reinforced tensile samples were available, which had been taken from a 1 mm-thick symmetrical cross-layer composite. The investigation of the damping behavior proceeded first in the undamaged state, and later in the damaged state, which was produced by static stress with simultaneous subcooling. Depending on the amount of stress, intermediate fibre breaks occurred in the 90-degree layers, with different crack densities, whose detection was verified by x-ray examination with contrasting.

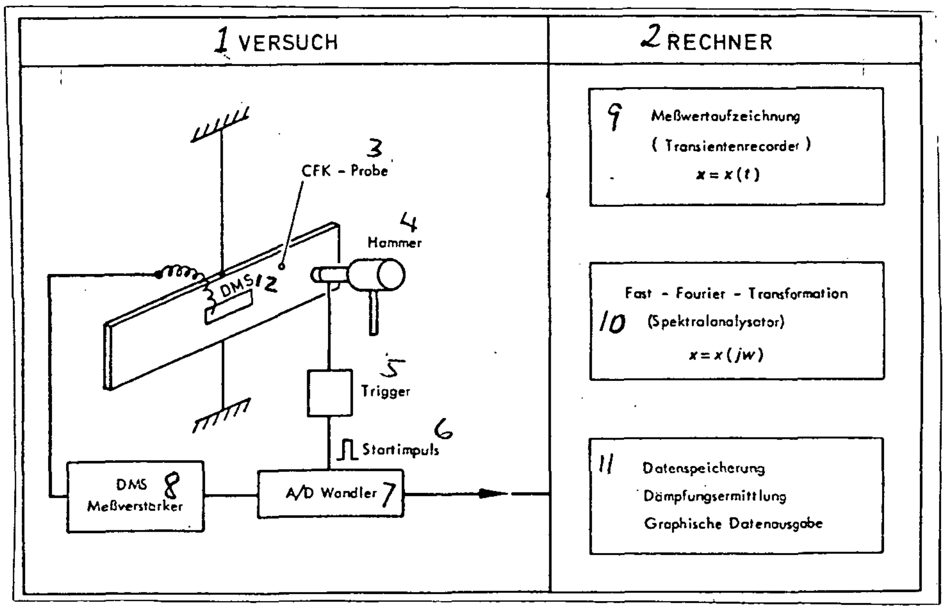
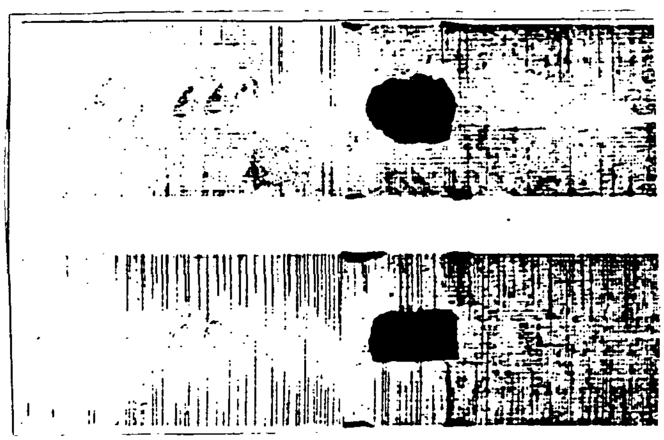


Fig. 2: Computer-Based Damping Measurement of Bending Vibrations of Carbon-Fiber Reinforced Samples

Key: 1-experiment 2-computer 3-carbon-fiber reinforced plastic sample 4-hammer 5-trigger 6-start pulse 7-A/D converter 8-strain guage, measurement amplifier 9-measured value recording (transient recorder) 10-fast-Fourier transformation (spectral analyzer) 11-data storage, determination of damping, graphic data output 12-strain guage

The test technology is explained with reference to Figure 2. Samples were suspended elastically and nearly undamped, from the middle, and excited by a hammer pulse to bending vibrations. A strain guage vibration recorder was used; it was required for elongation control during prestress and predamage. Triggered by a measuring cell in the hammer, the output of the measurement amplifier was fed via an A/D converter to a computer and stored as a time-dependent data record. Next, the described evaluation procedure took place in the computer and the results displayed in the form of damping spectra in a frequency range up to 5 kHz.

The carbon-fiber reinforced plastic samples measuring 250 x 32 x 1 mm were divided into two groups corresponding to their cover layer orientation. In one sample group, the cover layer of the laminate ran parallel to the sample longitudinal axis (0 degrees), in the other sample it was rotated by 90 degrees. To describe the level of damage to a sample, the crack density determined from the x-ray photo, was selected; it attained various values, depending on the choice of the elongation limit value for the prestress (Figure 3).



1 Probe	2 Vorbelast. in %	3 Rißdichte 1/cm
S 3.660	0.59	3.5
S 3.680	0.81	19.8
4 CFK-Laminat 1mm $[0°/90°/0°/90°]_s$		

Fig. 3: X-ray Photos of Cracks in Carbon-Fiber Reinforced Plastic Samples after Different Prestress

Key: 1-sample 2-prestress in % 3-crack density 1/cm 4-carbon fiber reinforced plastic laminate

Samples with 90 degree cover layer exhibit a damping behavior which increases with the frequency of the vibration modes--as shown in Figure 4. With increasing crack density, the decay constants of the evaluated bending vibration forms also increase. The generally rising, but interrupted trend is thus explained since the crack density only approximately describes the degree of damage and does not take into account the distribution of cracks over the sample thickness.

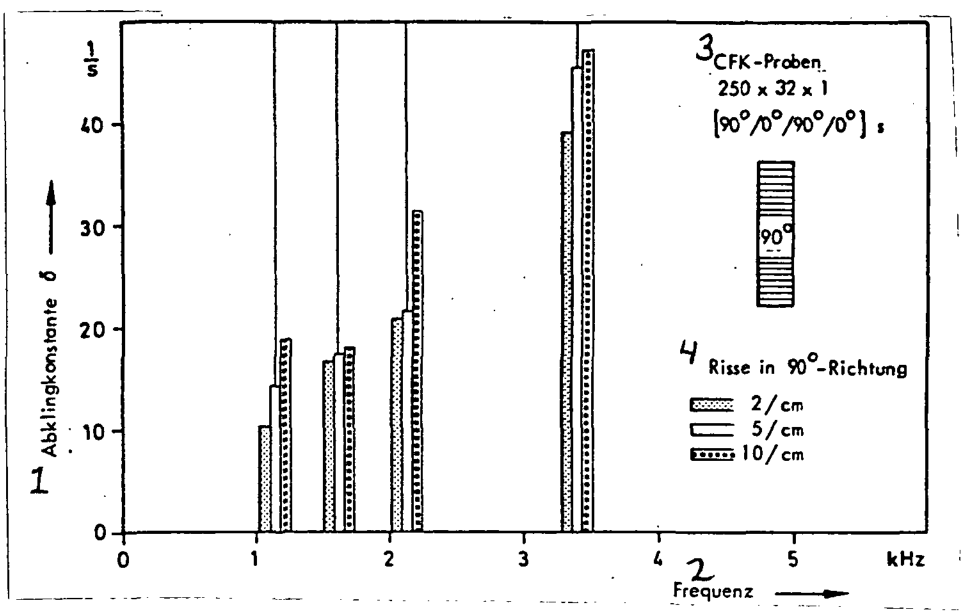


Fig. 4: Damping Behavior of Carbon Fiber Reinforced Plastic Samples with 90 Degree Cover Layer and Different Crack Densities

Key: 1-decay constant 2-frequency 3-carbon fiber reinf. samples 4-cracks in 90-degree direction

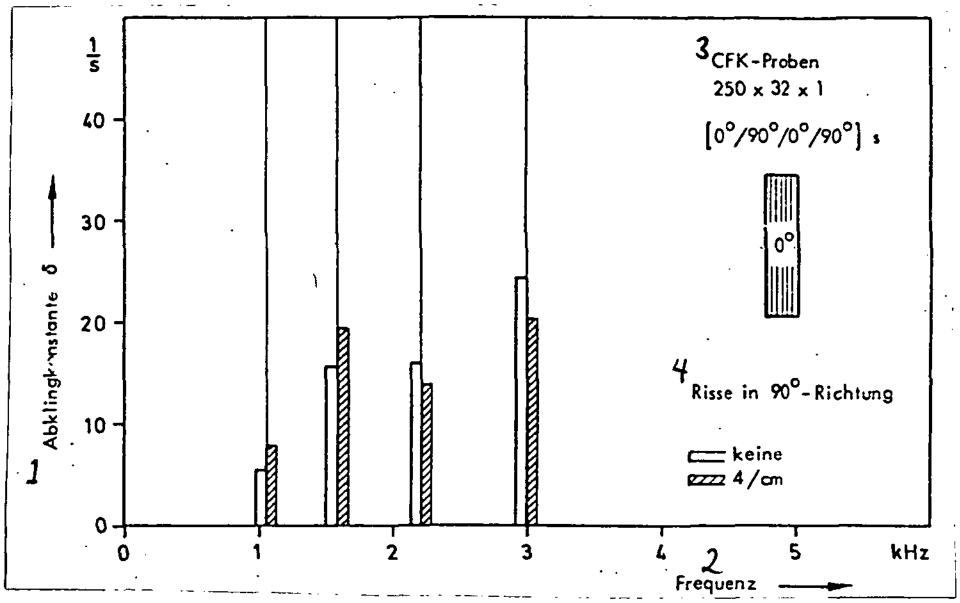


Fig. 5: Damping Behavior of Carbon Fiber Reinforced Plastic Samples with 0 Degree Cover Layer and Different Crack Densities

Key: 1-decay constant 2-frequency 3-carbon fiber reinf. samples 4-cracks in 90-degree direction

Samples with 0-degree cover layers, whose damping values increase with increasing frequency in the undamaged state, react individually to cracks. The example in Figure 5 shows an increase in damping at frequencies of 1160 Hz and 1600 Hz; but a decrease for the next higher modes at 2250 Hz and 3000 Hz.

In summary, for the cross-layer laminate we find that the damping reacts much more sensitively to damage than the shift in resonance frequencies, and thus it is better suited for the interpretation of damage or damaged zones.

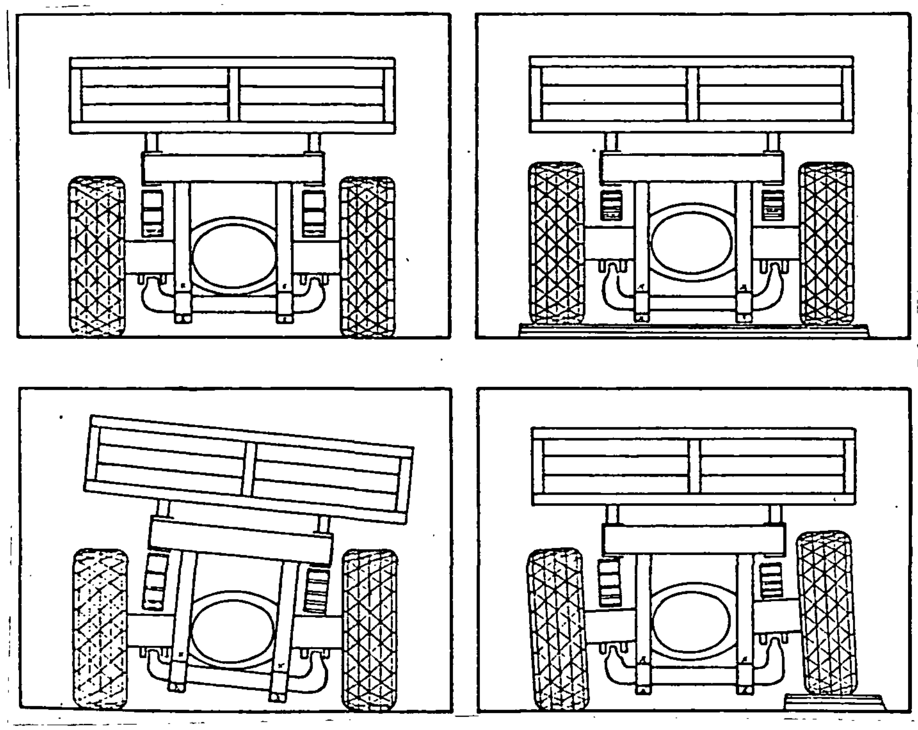


Fig. 6: Operation of a Truck Stabilizer

3. Damping Behavior of a Fiberglass Stabilizer

Stabilizers on vehicles serve to compensate differing loads on the suspension, as may occur when driving around curves or over an obstacle. Figure 6 shows the operation of a stabilizer on a truck rear axle; Figure 7 shows the fiberglass component.

The C-shaped stabilizer consists of a coiled torsion tube and two bending-stressed legs in a sandwich arrangement; they are interconnected by a combination of adhesive and riveting. The damping measurements taken on this component were part of a study to replace the commerical steel part by a fiber composite part having the same strength but lower weight.

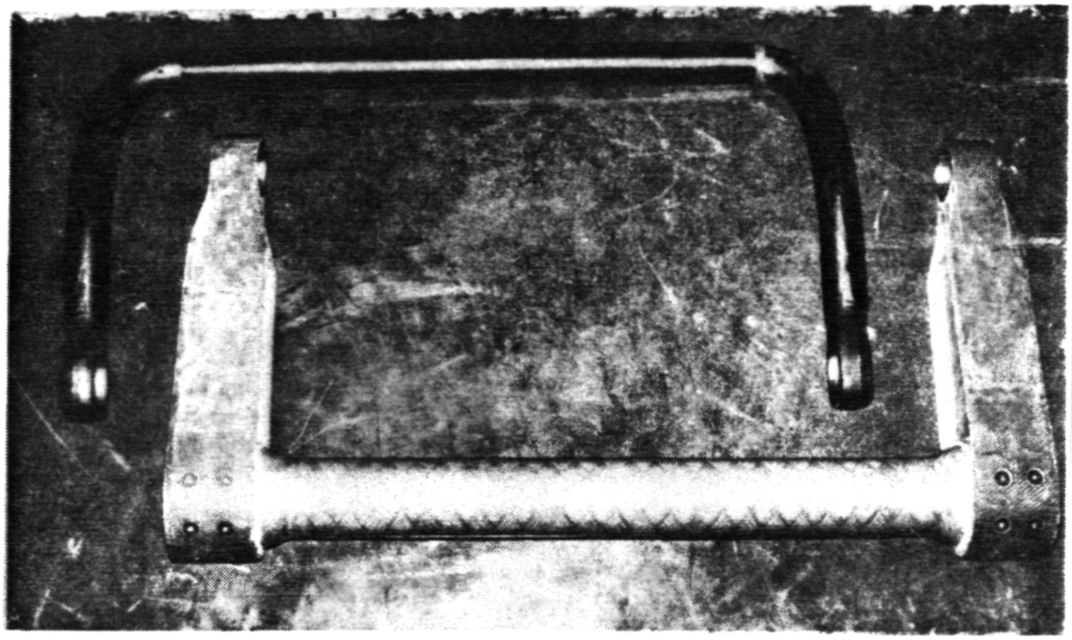


Fig. 7: Fiberglass Stabilizer and Commercial Steel Part

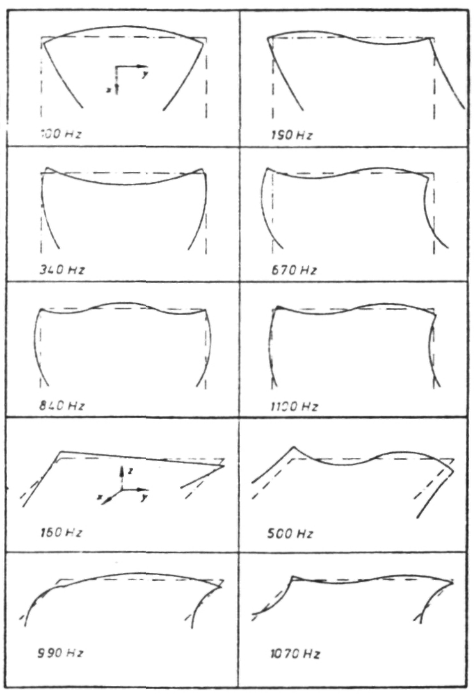


Fig. 8: Vibration Shapes of the Fiberglass Stabilizer

In contrast to the measuring method for carbon-fiber reinforced plastic samples, the shock excitation of the specimen was applied in two directions in order to record as many vibration modes as possible in the range up to 1500 Hz. Figure 8 shows a selection of the excitation shapes which exhibit only bending deformations (for shock direction parallel to the stabilizer plane), or primarily torsion deformations (for excitation perpendicular to the stabilizer plane).

The pertinent damping spectra as shown in Figure 9, contain a number of modes only for two excitation directions. From a comparison of the two diagrams, the following conclusions (among others) can be drawn:

- The decay constant δ, which can be viewed as a measure for the dissipation power, rises constantly with frequency in the left diagram (case 6b, twisted vibration shapes). That is, the degree of damping ($\vartheta = \delta/\omega$) is approximately constant in the investigated frequency range (ϑ = 0.0066). In the right diagram (case 3a, bending vibrations in stabilizer plane) there are two sections with different damping degrees; up to 400 Hz ϑ_1 = 0.0044 and f> 400 Hz ϑ_2 = 0.0081. This difference results from the behavior of the leg which acts generally as a rigid mass in the low frequency range, whereas at higher vibration modes it even deforms and contributes to the damping.

- The degree of damping for low frequency vibration modes (f < 400 Hz) which primarily stress the tube, is hardly influenced by the load state and is approximately constant. The decay constants of the commercial steel stabilizer, which are also plotted for comparison, prove it to be a nearly undamped component.

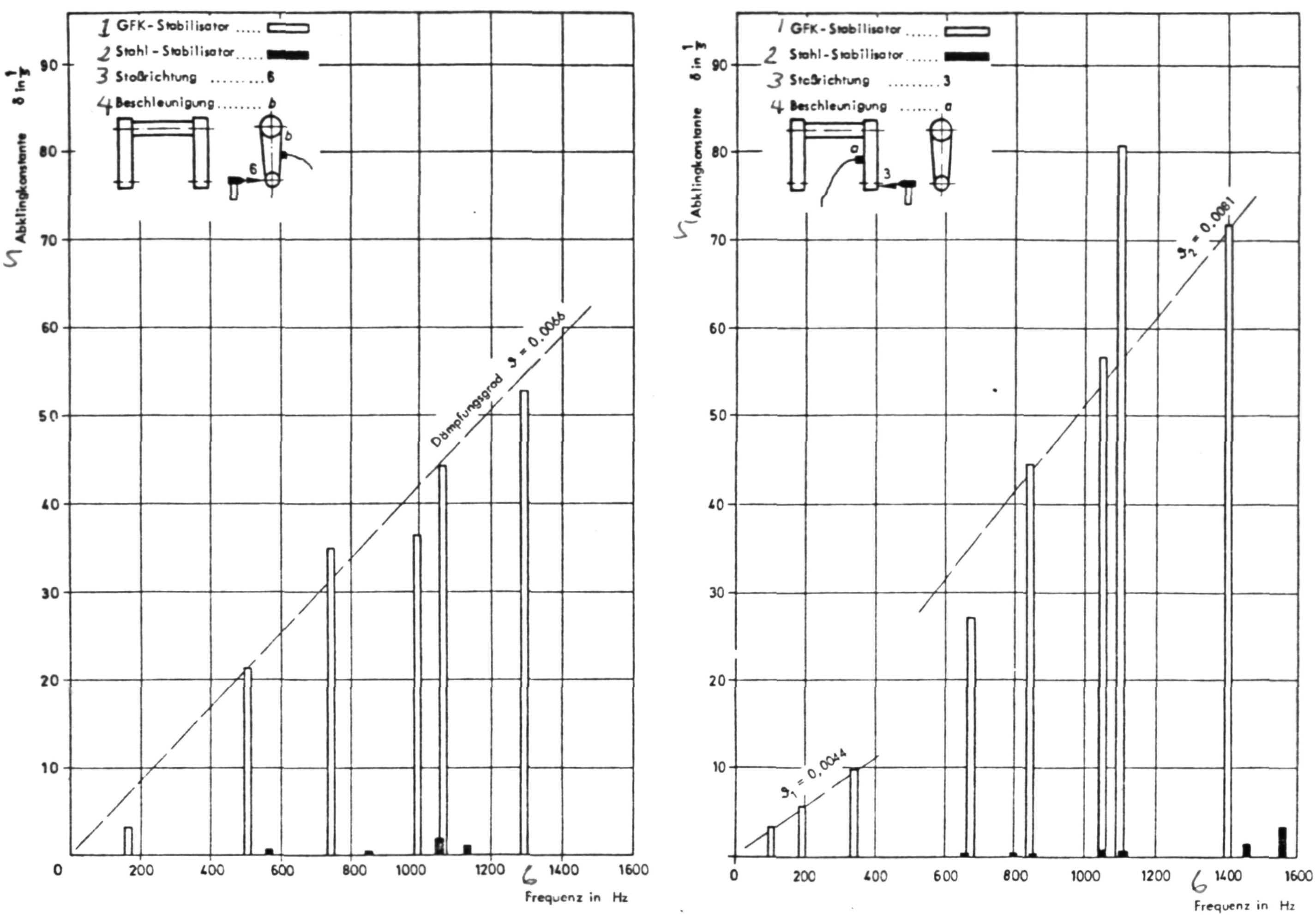


Fig. 9: Damping Spectra of the Fiberglass Stabilizer for Two Perpendicular Shock Directions

Key: 1-fiberglass stabilizer 2-steel stabilizer 3-shock direction 4-acceleration 5-decay constant 6-frequency in Hz

The damage to the stabilizer was caused in a fracture test with constantly increasing load. The test served to check the deformation behavior and to determine the safe fracture load. The stabilizer failed in the region of the bearing when a pressure-torsion break of the tube occurred (Figure 10). The subsequent

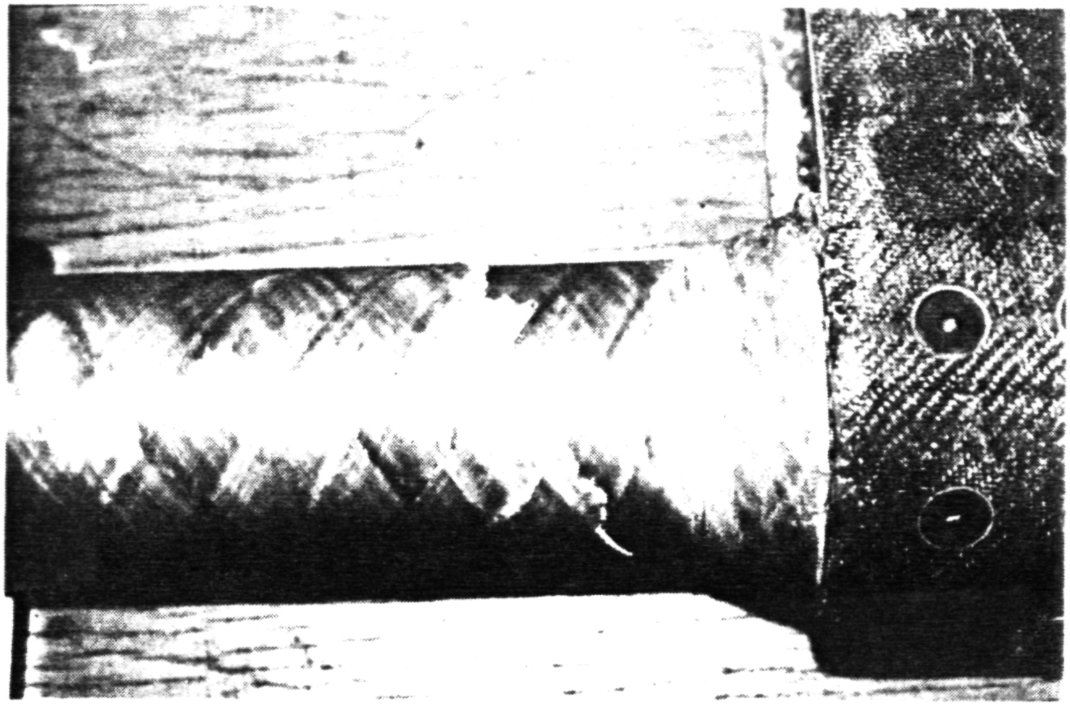


Fig. 10: Damaged Fiberglass Stabilizer

damping investigation under the same boundary conditions as on an undamaged part, produced the damping spectra in Figure 11.

The size of the damage zone causes an overall reduction in resonance frequencies; this factor is insignificant for $f < 400$ Hz, but for higher frequencies it amounts to between 6 and 10 percent. The damping however, increases quickly for all vibration forms. If one compares the spectra of the undamaged and the damaged stabilizers based on the average damping values, then the increase fluctuates between 30 and 38 percent.

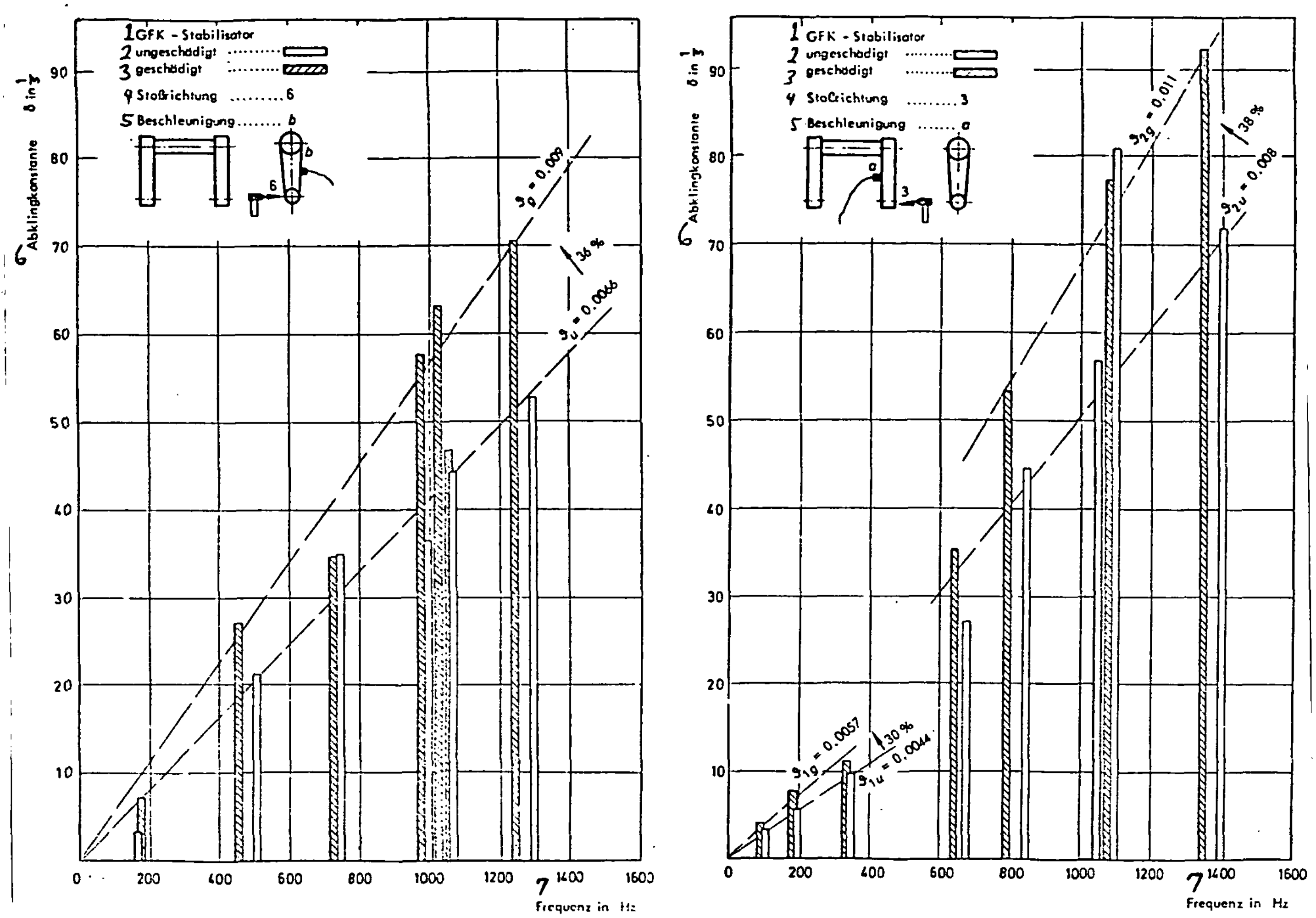


Fig. 11: Damping Spectra of the Damaged Fiberglass Stabilizer for Two Perpendicular Shock Directions

Key: 1-fiberglass stabilizer 2-undamaged 3-damaged 4-shock direction 5-acceleration 6-decay constant 7-frequency in Hz

4. Summary Evaluation

The illustrated method of measurement and evaluation is based on the restrictive assumption that the specimen vibrates like a linear damped system and the vibration modes excited by a shock will decay freely and independently of each other. In addition, the suspension must be chosen so that it transfers little or no damping forces, and so that the damping of the system due to bearings or transducers is negligible compared to the actual, internal damping.

Excepting these limitations, the method is simple to apply and the representation of the decay constants in the form of damping spectra allows a concise and summary evaluation of damping properties. In addition, the damping of vibration forms is much more sensitive to damage in the structure of a composite material and correlates better with the degree of damage than does the frequency shift. Depending on the type and location of damage, they affect the excited vibration modes differently and change the damping spectrum in a characteristic manner.

The original question of whether the change in damping behavior of fiber composites is a suitable means for damage recognition, thus finds a basically positive, affirmative answer. Damping spectra change corresponding to the evolution of damage, but additional investigations with defined, applied damage are necessary for their interpretation. Whether the described method will also be of practical importance, cannot be known based on previous experience; here too, additional investigations are needed.

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