PRACTICAL RESULTS CONCERNING THE PREDICTION OF DAMAGING EFFECTS FOR LIGHTNING IMPULSES (LEMP)

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ABSTRACT

The tests were carried out on a carbon fibre reinforced structure with wires of different kind of installation and shielding. The peak value of the current impulses ranges from 5 kA up to 200 kA and the comparison shows, that a reasonable linearity exists for carbon fibre reinforced material and that the deviations are on the save side. The verification of the linearity has been checked by the low-level method. This method uses the transfer function of the whole test arrangement, with the current impulse as the excitation signal and the induced voltage on the wires as the response signal.

INTRODUCTION

The transient electromagnetic fields have a strong influence on the electronic components in all apparatus due to the high electric and magnetic field. An overall estimation of the field stress shows, that between disturbances and destruction there is usually a factor of 10. Furthermore, it is very often important for a prediction whether the investigated system has a linear or non-linear behaviour. The most important parameter are the voltages which will be induced in the wires connecting sensors and components with the control unit.

LIGHTNING IMPULSE SIMULATION

The simulated lightning current is composed of the waveform components A and C or D and C. The characteristic parameters of these waveforms are described in several standards, for example [1]. The current waveform A or D is generated by an impulse generator which forms a damped or undamped oscillating current. The current source for component C which immediately succeeds component A or D is a rechargeable battery. Fig. 1 illustrates the test circuit.

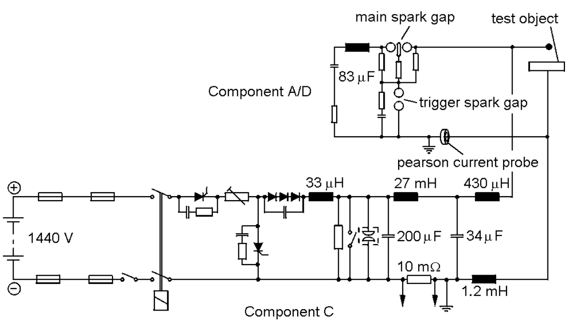

Fig. 1 Test circuit for simulation of lightning current components according to Fig. 2

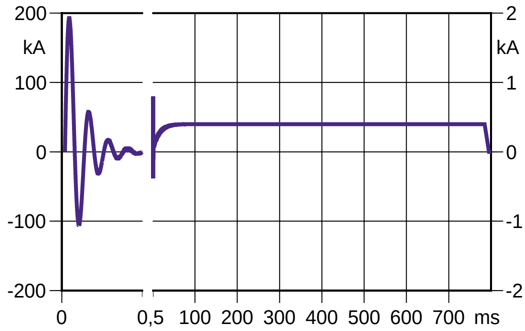

Fig. 2 Lightning current wave shape consisting of Components A and C

TEST OBJECT

The original wing box component with a length of 9.8 m is part of a wing, extending from the engine nacelle to the wing tip. It is a simplified trapezoid wing box without the characteristic camber of the aerodynamic wing profile. It is composed of top and bottom skins and front and rear spars with metallic fasteners. The test object in Fig. 3 is a part of the original wing box and the materials are aluminium and carbon fibre (CFC).

MEASURING ARRANGEMENT

The lightning current is fed into the specimen at rib R16 and flows to rib R7 and the back via a return conductor system which consists of 16 individual conductors. They are fixed at defined distance to the top and bottom skin in order to adjust an appropriate current distribution in the skins. The wires installed in the wing box run at the spar and in the interior of the wing box starting at rib R7. Shielded and unshielded single wires are used. Fig. 4 shows the measuring arrangement for the tests of indirect effects.

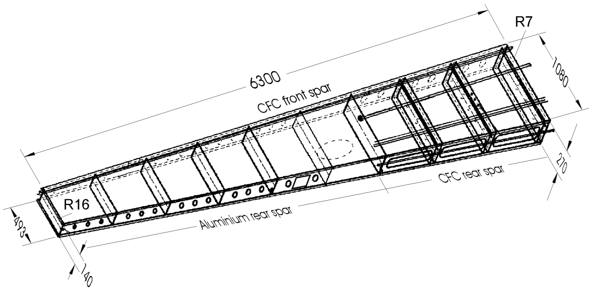

Fig. 3 Test object

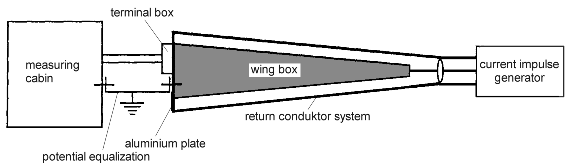

Fig. 4 Measuring set-up

LINEARITY TESTS

In order to study the linearity of the wing box the induced voltages of two unshielded single wires are measured at impulse currents of about 20, 100 and 200 kA. It is a precondition for the linearity measurements that the impulse currents show the same wave form at different amplitudes as shown in Fig 5.

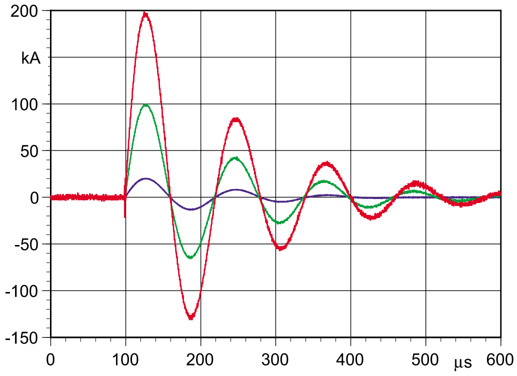

Fig. 5 Current impulses as excitation signal

Fig. 6 shows the three measuring signals which are measured on an unshielded wire at different peak values of the impulse current. The wire runs at the front spar over the whole length of the wing box and is connected with rib R16. Fig. 7 shows the three measuring signals which are measured on another unshielded wire at different amplitudes of the impulse current. This wire is installed in the interior of the wing box and is connected with the metallic rib R10.

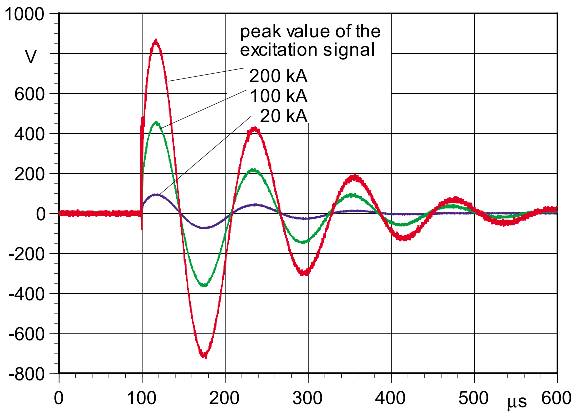

Fig. 6 Response signal at the unshielded wire at the front spar

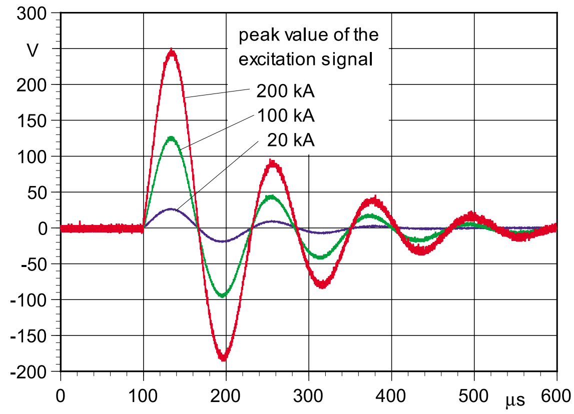

Fig. 7 Response signal at the unshielded wire in the interior of the wing box

The results are summarised in Table 1. The deviations from the linear behaviour are -0.5 % respectively -1 % up to an impulse amplitude of about 100 kA and lie within the range of the measuring error. The deviations up to an impulse amplitude of about 200 kA are about 5 % which shows a slightly non-linear behaviour. This is not critical because the deviation from the linearity is still small and the calculation by extrapolation on the basis of small impulse currents leads to higher values than measured at rated impulse currents.

current peak	current factor	unshielded wire a the front			unshielded wire in the interior		
		voltage	voltage factor	deviation	voltage	voltage factor	deviation
19.9 kA	1.00	91.0 V	1.00	--	25.8 V	1.00	--
96.9 kA	4.87	441.5 V	4.85	- 0.4 %	124.6 V	4.83	- 0.8 %
192.6 kA	9.68	836.7 V	9.19	- 5.1 %	237.4 V	9.20	- 5.0 %

Table 1 Unshielded wire at the front and in the interior [2]

INTERFERENCE TESTS

The impulse current is defined in the SAE-Report AE4L-97-4 [1] and will be used also for type tests of civil aircraft. Fig. 8 shows the comparison between the calculated standard impulse and the actual test impulse.

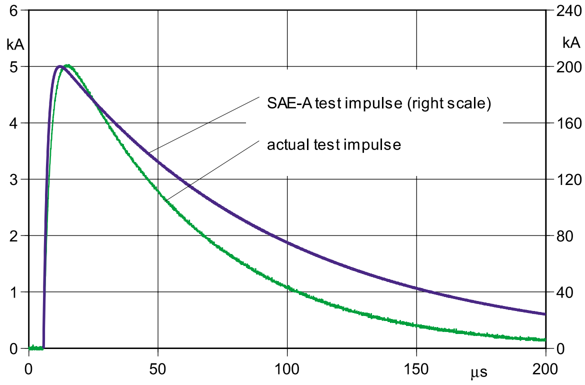

Fig. 8 SAE impulse (calculated) and actual test impulse

The following diagrams show some measurements one cables different in position, screening and type. The curves represent the actual test current in kA or scaled, the induced voltage normalised to volt per meter under no-load condition and the induced current under short circuit condition.

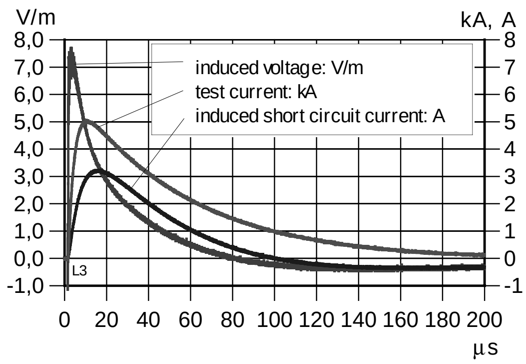

Fig. 9 Induced voltage and current for unshielded single wire

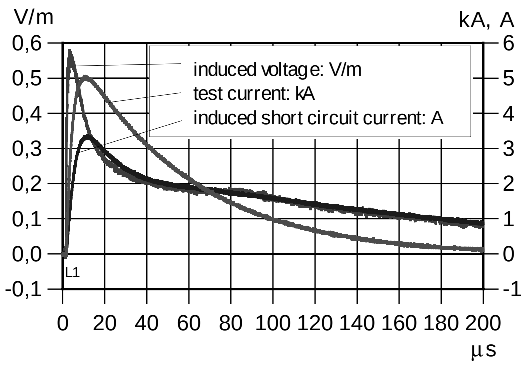

Fig. 10 Induced voltage and current for shielded single wire

The induced voltages contain an inductive component which can be recognised by the fact that the shape of this component is proportional to the derivative of the current. The shielded wires show no significant inductive component. It is obvious that the resistive component has a high amplitude in all cases. This will be caused by the high voltage drop along the CFC structure due its low conductivity [3].

LOW-LEVEL-TESTS

The excitation signal x(t) and the response signal y(t) are detected by sensors or connecting networks. Both signals are sampled simultaneously with a digital oscilloscope. The measured data are transmitted for subsequent processing to a PC. Both signals are transformed by Fast-Fourier-transformation (FFT) from the time into the frequency domain. With consideration of the transfer functions of the used sensors and cables the complex transfer function of the device under test H(jω) is calculated. Fig. 11 shows the schematic diagram.

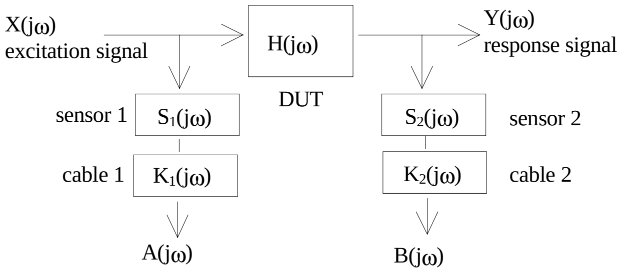

Fig. 11 Additional consideration of the transfer functions of cables and sensors

In order to verify the low level test a damped sinusoidal pulse like Fig. 5 was used. The response signal at the unshielded single wire at the front spar was registered by a suitable measuring circuit. Since the measurements for the detection of non-linearity are relative measurements, it is not necessary to determine the transfer functions of the used sensors and cables or to calibrate the test system. The transfer function is a voltage-current ratio, the linearity is checked by the invariance of the measured transfer functions at different levels of the excitation signal. To determine the frequency range in which the transfer function is valid, Fig. 12 shows the amplitude density spectra of the excitation signal and the response signal. The amplitude density spectra are normalised to their maximum value. It can be seen, that both the excitation and response signal have comparatively small amplitude densities above approximately 20 kHz, so that the calculation of the transfer function becomes incorrect above this frequency [4]. Below 2 kHz the resolution of the spectra is coarse due to the discrete nature of the FFT. The usable frequency range to investigate the linearity of the wing component is therefore 2 kHz to 20 kHz.

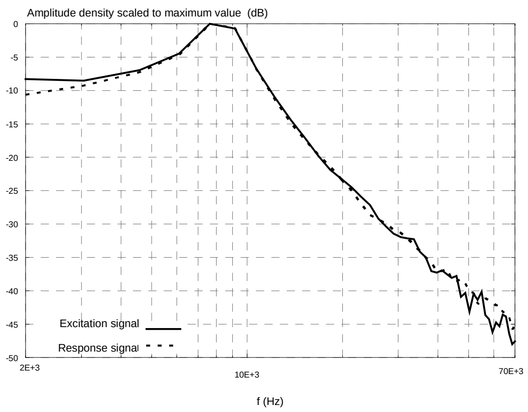

Fig.10 Amplitude density spectra of the excitation and the response signal

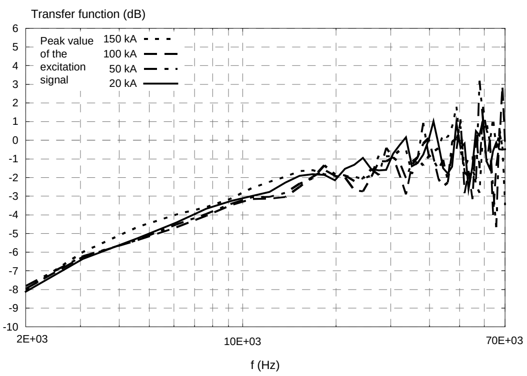

Fig. 11 Calculated transfer functions at different levels of the excitation signal

The different methods, comparison of the peak values and comparison of the transfer functions, give good results in the evaluation of the indirect effects by extrapolation from low values up to the rated values.

REFERENCES

[1] Aircraft Lightning Environment and Related test waveforms Report of EUROCAE WG-31 and SAE Committee AE4L, April 1997

[2] E. Gockenbach, C. D. Ritschel , L. Jung, J. L. ter Haseborg, “Investigations on the Linearity of Indirect Effects with Different Methods”, ICOLSE 99, Toulouse 1999, p. 329 - 332

[3] E. Gockenbach, C.D. Ritschel,” Investigations on the indirect effect of CFC wing box”, Intern. Symp. on Electromagnetic Compatibility, Magdeburg 1999, p. 277 - 282

[4] L. Jung, J.L. ter Haseborg, D.O. Wendt, "Low-Level-EMC-Test-System”, Proceedings. EMC’96, Rome 1996