
**On the Accuracy of the Determination of the
Endurance Capability of transmission line conductors
by the CIGRE Method CSC22-WG04**

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Transmission line engineers throughout the world have been carrying out vibration measurements for the past 60 years whenever vibration dangers for the conductors have been evidenced because it is regarded as a quantitative reliable method (2;3;3;4;5;6;7;8).

In the recent years numerous measurements of the aeolian vibrations of transmission line conductors have been carried out using modern recorders and the results have been evaluated and interpreted following the method recommended by CIGRE CSC 22 WG 04 in 1979,1985 and 1988 (9b;10;11;12) .The experience gained thereby can give an indication of the credibility of the measurements and of the above-mentioned method.

The publication of this experience seems advisable since in a recent working group report CIGRE 22-89-WG 11 (1) certain questions are posed regarding vibration tests on outdoor test spans which use recorders to determine the endurance capability of the conductors due to aeolian vibration according to the CIGRE 22 WG 04 method.

1. INFLUENCE OF THE VIBRATION RECORDER ON CONDUCTOR AEOLIAN VIBRATION

Laboratory tests (1) have determined a sizeable influence of the SEFAG Recorder on the vibration behaviour of the conductor.

Thus result clearly contradicts other investigations.

1.1 Tests in Canada.

Many years ago -in 1970- this question was investigated in connection with the first commercial produced version of the Ontario Hydro recorder. This recorder has a weight of about 8 kg and was rigidly attached to the suspension clamp which brought about a considerable increase in the dynamic polar moment of inertia.

The dynamic moment of inertia of the suspension clamp together with the influence of a part of the conductor ($\approx 1\text{m}$) is about $0,011 \text{ kgmsec}^2$. The Ontario Hydro recorder increases it by $0,033$ to $0,044 \text{ kgmsec}^2$, about a four-fold increase.

In Canada, the country where this recorder was developed, investigations were undertaken. Fig. 1 shows the results of comparative measurements on a one mile outdoor test line. The data presented in the report (14), maximum bending amplitude p-p in mils and the number of cycles in the test time were converted into the data used by the CIGRE method, average bending stress, single peak and megacycles per year.

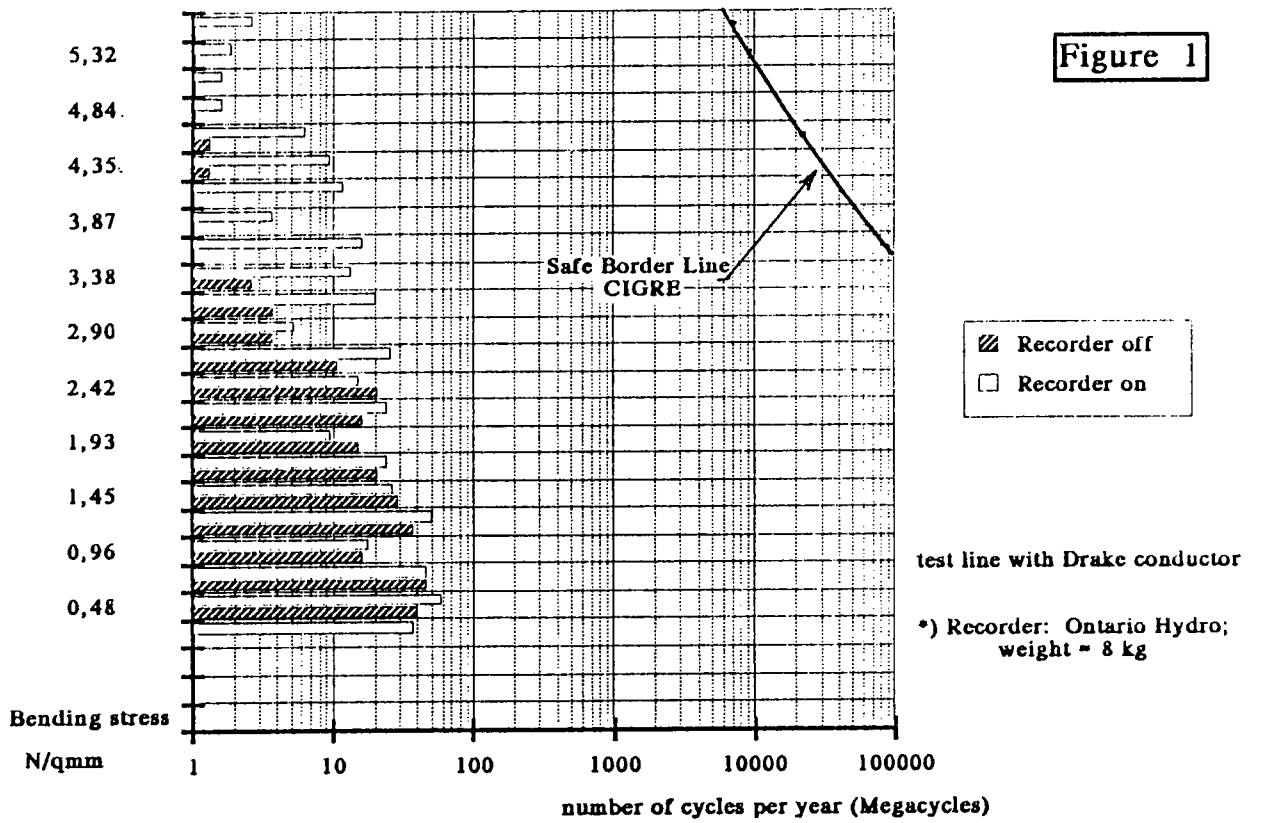
The stresses and cycles measured are mostly higher for "recorder on" than for "recorder off" as Fig. 1 shows. While these differences certainly cannot be neglected, in both cases the high endurance capability (lifetime) values of the conductor are only influenced beyond the range of practical interest.

Similar test-results were established in Finland (15).

1.2 Tests in Germany

The influence of the recorder on the vibration behaviour of the conductor had already been investigated on a outdoor test station in Germany with natural wind excitation. The recorder was mounted rigidly in the normal manner to the suspension clamp of one of the two 340/30 ACSR conductors with 68 N/sqmm tension stress independently vibrating at the same height above the ground. No recorder was mounted on the suspension clamp of the other conductor. The strain at the end of the clamp on the top of the conductor and the free vibration angle were measured on both conductors simultaneously. The conductor bending stresses were measured with strain gauges at the edge of the keepers of the clamps. The results are recorded in Fig. 2. The influence of the recorder, type SEFAG with a weight of $1,1 \text{ kg}$ is negligible.

Influence of a Recorder*) on the vibration behaviour of transmission line conductors



Outdoor tests of the Saskatchewan Power Corporation (CIGRE Report CSC22-1970-03)

Urbach 25.9.1989

Measurements of Transmission Line Conductor Vibrations

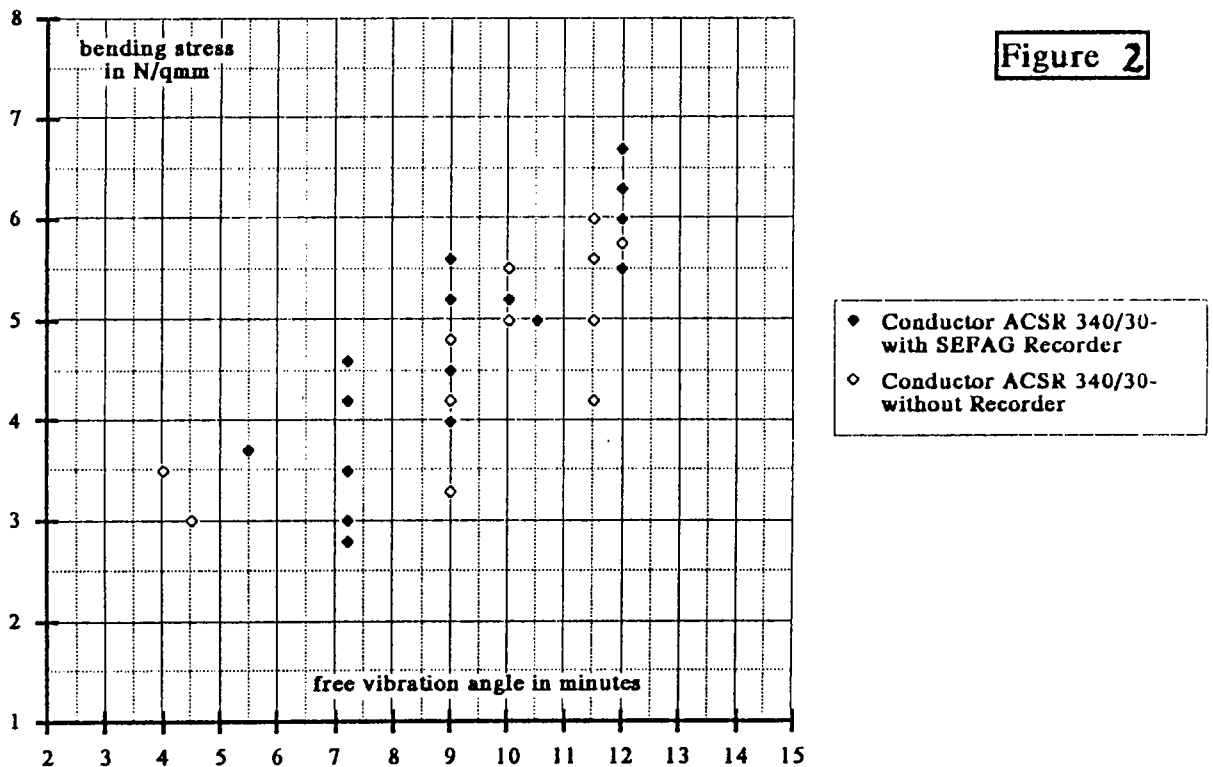


Fig. 2 Influence of the Inertia of the Recorder on the Vibration Behaviour

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Thus the SEFAG recorder has apparently only a very slight influence on the conductor stresses. This can also be explained by the insignificant increase in the dynamic moment of inertia - the SEFAG recorder increases it by only 0,001, about 10 %, to 0,012 kgmsec².

The SEFAG recorder, the successor of the Bayernwerke recorder (9a) was initiated by the WG 04 -CIGRE SC 22 in 1968 and developed by the laboratories of the Federal Republic of Germany in Berlin.

1.3 Laboratory Tests

The purported considerable influence of the SEFAG recorder on the vibration behaviour of a 240/40 ACSR conductor with a tension of 46 N/qmm determined in the laboratory (1) is not identical with the results of similar tests on outdoor spans with wind induced vibration, as mentioned under 1.2.

For that purpose the following comments:

- A Hydro-Quebec investigation (16), published in 1987 as IEEE/PES report No 87JC-39 confirms the above-mentioned necessity for outdoor tests to determine the vibration behaviour of conductors.

For many years Hydro-Quebec has been engaged intensively with aeolian vibration of conductors, in the laboratory as well as at a large outdoor test station on the Magdalen Islands, but also through mathematical investigations. In the section "Relevance of Field Evaluation" in this report, the following is stated:

".....The aeroelastic behaviour of bundle-conductor lines is influenced by many factors....."

".... With such large numbers of influential factors, it is argued that only extended field measurements on a well-instrumented test line exposed to a wide variety of winds can provide a sound indication of antivibration-device performance in the control of wind-induced vibrations. Any other laboratory test or any mathematical simulation is likely to be severely limited from a structural and/or an excitation stand-point. At all events, a field test not only provides the best assessment of the performance but also is the ultimate means by which all other methods should eventually be compared for validation....."

Vibrations of the conductor + hardware system (with non-linear characteristics) are influenced by time and position-varying external non-periodic wind forces on all the spans of a tension section. In accordance with the differential equation they consist of numerous symmetrical (cosine part) and asymmetrical (sine part) component vibrations each having different frequency and amplitude compositions.

- Conductor vibrations in the laboratory are generated by means of a fixed position shaker, usually with constant frequency and amplitude. The degree of freedom of the overhead conductor of a tension section and the above mentioned external forces of the stochastic wind excitation cannot be realized here; in addition to this the physical similarity laws cannot be adhered to in the laboratory due to the differential equation, e.g. the relation of the conductor diameter to span length or of the moment of inertia of the conductor to the span length, and more importantly the interaction of the spans of a tension section.
- In a laboratory it is possible to alter the form of the vibration - symmetrical/asymmetrical composition of the frequencies and amplitudes - more or less arbitrary by the appropriate regulation of the shaker, but without being able to duplicate the natural conditions because the physical prerequisites are not available.

These are the reasons why laboratory tests are not suitable for making a reliable assessment of the vibration behaviour of a conductor on an actual transmission line under influence of the wind, and accordingly also not for the influence of a recorder on the conductor vibration-behaviour.

2. INFLUENCE OF THE CLASSIFICATION CLASSES OF THE RECORDER

2.1 Matrix of the SEFAG Recorder

The SEFAG recorder, sorts all data according to the 16x16 matrix amplitude and frequency classes, and gathers i.e. adds, all events in the 256 matrix cells of the memory; the IEEE standards (18) are observed. It has to be pointed out that the SEFAG recorder detects and classifies as mentioned above all events during the 10 sec sampling period every 15 minutes as Fig.3 explains.

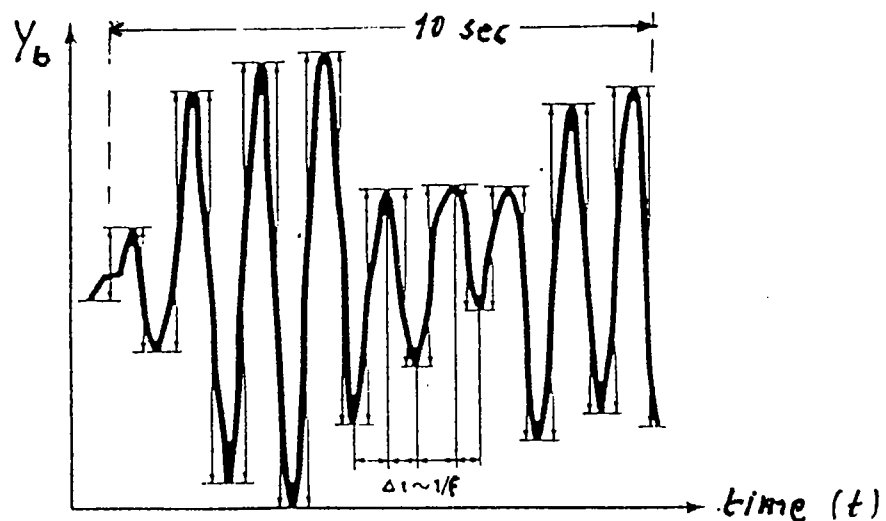


Fig. 3

This is a considerable increase in the information content, compared with previous measurement methods where sampling period was 1 sec and only one amplitude value - the peak to peak of the average amplitude - and the average frequency was retained for further calculations. The stress amplitude ranges of Y_b for instance, have a step value of 0,125 mm, such as from 2,0625 \rightarrow 1,937 (average = 2,0) or from 1,8125 \rightarrow 1,937 (average = 1,875) and so on. The procedure for the frequencies is similar. All values of each matrix range are then associated to the average value and in this way are displayed in the print-out as a total number of events. This is in accordance with the Gaussian distribution law of events.

Now to associate all the events either to the upper or the lower limit for the calculations of the endurance capability of conductors as it was done in (1), are arbitrary and contradicts the recognized customary statistical methods.

2.2 Errors by classification

In addition to this a general consideration of the influence of the number of classification classes on the accuracy of the measurements is presented as follows:

The assignment of an averaged damage value introduces an error which increases with the difference between the stress cycle to be evaluated and the average stress cycle adopted for the evaluation of the particular class. For a constant evaluation range with broader classes, i.e. a smaller number of classes, the maximum possible error increases. Since generally, some of the stress cycles to be evaluated are smaller and the others larger than the average value a partial compensation of the error can be assumed. The following graph (Fig.4) gives an estimate of the expected error.

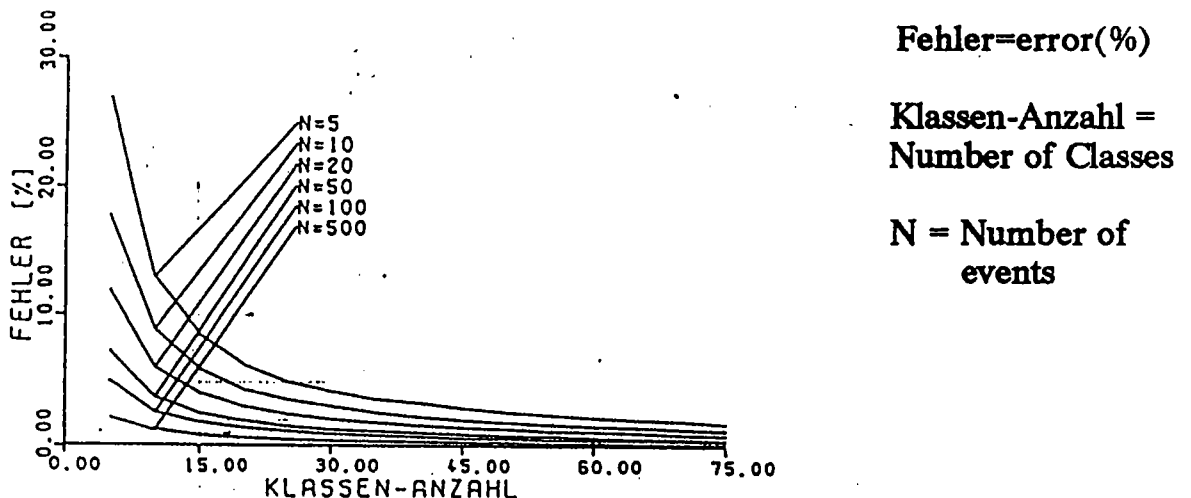


Fig.4

The curves show the class evaluation error related to the exactly calculated damage value against the number of classes for a constant evaluation range. The curve parameter N indicates the number of tension cycles evaluated in each case, which have been distributed over the whole evaluation range with the help of a random number generator.

Fig.4 yields an accuracy of $> 95\%$ for 16 stress classes and number of events 25 and $> 90\%$ for 4 classes. For 16 classes of the SEFAG recorder, the number of events is greater than one hundred thousand, which corresponds to the value indicated in table 3 in (1)

The problem mentioned in (1) of a too coarse division of the amplitudes/ frequencies into only 16 ranges is not justified; the proposed 32 or 64 ranges are not necessary for practical transmission line engineering purposes.

3. "SAFE BORDER LINE" OF CIGRE - S-N/WÖHLER CURVE

In (1) it is further stated that most conductor stresses in one of the measurements carried out by them on a 240/40 ACSR earthwire, lie below a certain level i.e. in a range which can be regarded as safe. References are made to publications in the U.S.A. in which an endurance limit of 22 resp. 21,3 MPa (= 22 resp 21,3 N/sqmm) is mentioned, which has not been verified exactly by means of tests, but has been more or less postulated on the basis of operational experience (17).

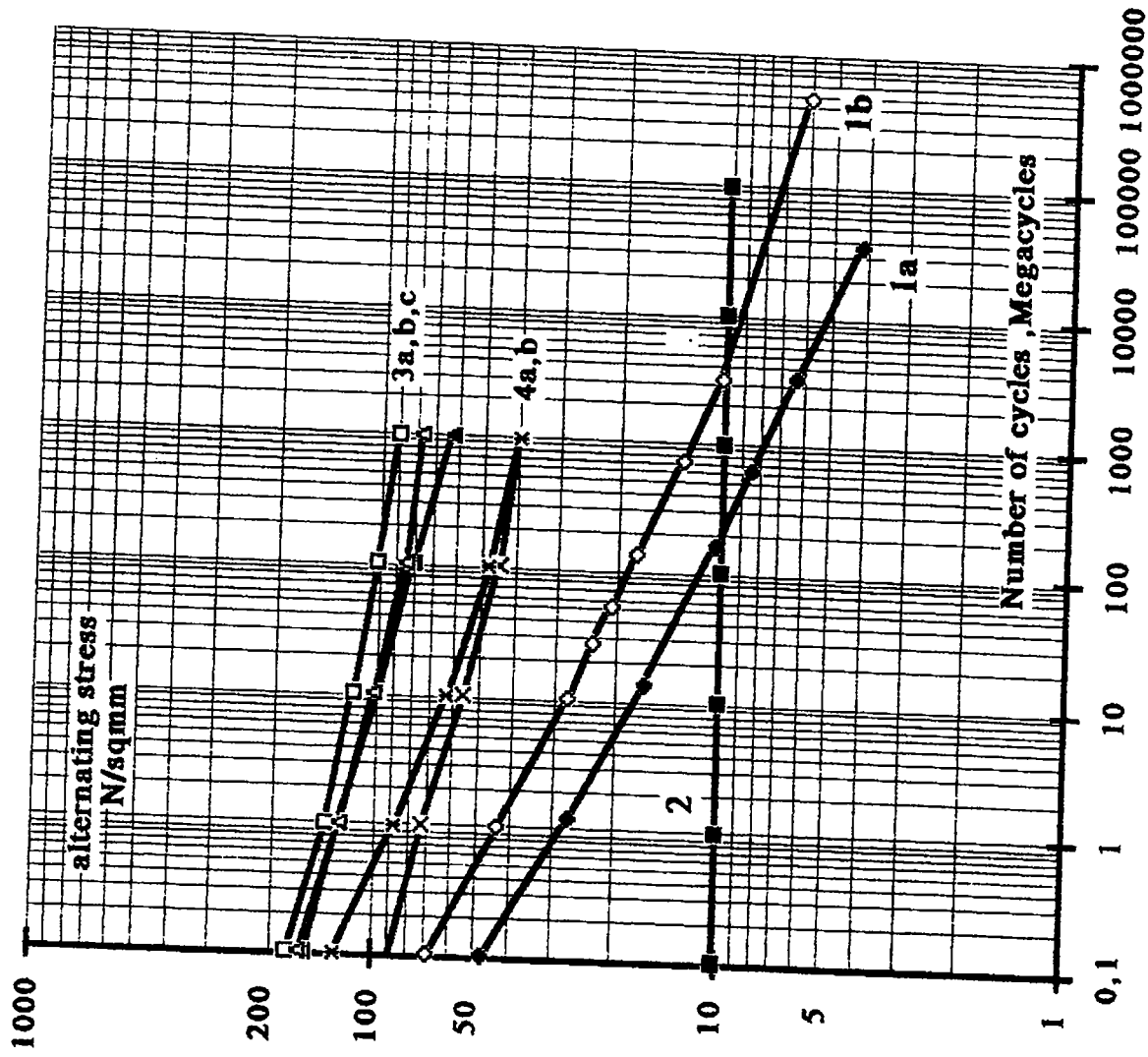
Long term tests on different AA, AAA and ACSR conductors, show the breaking tension decreasing with the number of cycles, at least below ± 10 N/sqmm ($\approx \pm 10$ MPa), as was also defined in the "Safe Border Line" recommendations of WG 04 (10), as shown here in Fig.5. A normal suspension clamp reduces the endurance capability to about 0.5 times the value of the bare conductor.

These tests could be performed either by axial pulsating tension stresses $\pm \sigma_t$ in a normal tensile machine or by flat bending stresses $\pm \sigma_b$ in a special test rig. The results of both kind of tests are more or less identical as CSC-22 WG 04 established some years ago. This is recently confirmed by tests in Germany and Israel.

Recently investigations in Canada give detailed informations about the influence of different design parameters of the suspension clamp on the fatigue strength of transmission line conductors (22;23). The CIGRE "Safe Border Line" considers the influence of a normal suspension clamp.

Fig.5 (double log. scale) shows still the parabolic progress of the S-N curve. Fatigue test results of conductors include in every case the influence of fretting between the layers of aluminium wires and therefore show no asymptotic character of the S-N curve, as considered in (1). But pay attention to the fact that fatigue tests with a continuous frequency of appr. 40 Hz are executed in a relative short time (≈ 5 month). During this time the creep effect, which decreases the tension in the AL or AAA strands of ACSR conductors, take place only partly. In practice the creep over a longer time leads to relax-

Fatigue Limits of ACSR/AAC/AAC-Conductors and wires



- (1a) safe Border Line - "Cigre"
- ◊ (1b) Wöhlercurve max, ACSI
- (2) Safe Border line "IEEE"
- ◻ (3a) Alloy wire test 1
- ▲ (3b) Alloy wire test 2
- △ (3c) Alloy wire test 3
- × (4a) Alumin. wire test 1
- (4b) Alumin. wire test 2

Figure 5

SN-Woehler curves

ation of those strands and with it to a decreasing progress of the fretting. This stand for a more asymptotic character of the S-N curve for ACSR conductor only. In any case the shape of the CIGRE "Safe Border Line" at low stress levels is explained in detail in (10;12;21;22;23).

4. THE OBJECTIVES AND THE ACCURACY OF THE VIBRATION MEASUREMENTS ON CONDUCTORS

4.1 comparative tests

The most important area of the application of the vibration recorder, is that it enables comparative tests to be performed simultaneously so that a quantitative evaluation of the different conductor and hardware types or parameters can be made.

For these objectives a measurement period of 4 weeks is normally sufficient, if the different objects are measured simultaneous. However in areas where the terrain influence changes significantly (e.g. flat terrain with and without snow) two times 4 weeks is more suitable. Numerous test results have already been published (8;9b;12;19;20;21) which demonstrate clearly the value of comparison tests.

4.2 exact determination of the lifetime

As has always been clearly stated by WG 04, the determination (accuracy $\pm 10\%$) of the absolute endurance capability requires:

- an S-N curve derived from the conductor+hardware combination which was the test object in the vibration tests
- a relation of bending amplitude Y_b to bending stress σ_b which has to be verified in tests
- a test time of at least 8 weeks at average climatic conditions

in addition, the following points are cited:

- The statement made in (1) concerning the tremendous influence of the S-N curve on the calculation of the lifetime is well known. The CIGRE "Safe Border Line" recommended in 1979 represents a conservative i.e. safe S-N limit for stranded ACSR, Al or Al-alloy conductor, which considers the influence of normal suspension clamps, as already mentioned in the CIGRE Recommendations of CSC22 WG 04 (10).

As stated in the final report of CSC22-WG 04 (12) an exact investigation of the absolute lifetime of a conductor requires the determination of the S-N curve of the conductor including hardware by means of special fatigue tests.

- For the calculation of the dynamic bending stress $\pm \sigma_b$ from the measured bending amplitude $\pm Y_b$ the Poffenberger-Swart formula of the IEEE is recommended (5;6;10; 12;21). This formula is based on simple