IEEE Guide on Conductor Self-Damping Measurements

IEEE Standards Board
Approved March 3, 1977

Sponsor
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of the
IEEE Power Engineering Society

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Foreword

(This Foreword is not a part of IEEE Std 563–1978, Guide on Conductor Self-Damping Measurements.)

This Guide has been prepared jointly by the IEEE Task Force on Conductor Vibration and the CIGRE (*Conference Internationale des Grandes Reseaux Electriques a Haute Tension*, International Conference on Large High Voltage Electric Systems) study committee 22 — Overhead Lines — Working Group 01 on Mechanical Oscillations. It is the first in a series of guides planned for standardizing the measurement of the inherent energy dissipation characteristics of overhead conductors, the performance of aeolian vibration damper and ultimately the prediction of the vibration amplitudes and the dynamic mechanical strain in conductors resulting from wind induced vibration. An objective of these guides is to establish universally accepted procedures and parameters for developing methods for controlling aeolian vibration.

This Guide was prepared by the Subcommittee on Conductor Vibration of the Towers, Poles, and Conductors of the Transmission and Distribution Committee of the IEEE Power Engineering Society. The membership of this subcommittee was:

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IEEE Guide on Conductor Self-Damping Measurements

1. Scope

With the increasing interest and concern regarding the vibration of overhead conductors, and the emphasis on the improvement of existing methods and the development of new techniques for controlling the problem, there is a growing requirement for reliable information on the self-damping characteristics of conductors. This parameter is a principal factor in determining the response of conductors to alternating forces, such as arise from wind flow over conductors. This guideline has been prepared for the purpose of encouraging investigators contemplating making measurements of the inherent damping characteristics of conductors, to adopt the methods outlined herein. It is anticipated that the resulting information, being in a compatible and consistent form, will provide a reliable basis for studying the vibration and damping of conductors in the future and for the comparison of data of various investigators. The methods and procedures recommended are not intended for quality control test purposes. SI units are used throughout this document with the commonly employed English units shown in parentheses.

There are several methods available for measuring the energy dissipated by a cable vibrating in a principal mode. These can be divided into two main groups which are usually referred to as the "free vibration" and "forced vibration" methods. The vibration of a cable in a principal mode can be observed only in the absence of any exciting force, that is, after the force has been disconnected and the other modes have decayed to insignificant values. The energy dissipated can then be derived from the rate of decay of the vibration. This method can be greatly affected by the method used to disconnect the driving force as the slightest additional disturbance of the conductor causes other vibration modes to be generated and this must be avoided.

With the relatively low rates of decay which are usually associated with stranded conductors, the "forced vibration" method is satisfactory as the contribution of the modes, other than the one which is being excited, is not significant if the frequency of the exciting forces corresponds closely to the resonant frequency of the mode under test and if the exciting force is substantially sinusoidal and of sufficiently low magnitude. Two forced vibration methods are therefore suggested:

1.1

The "power method" [1][1] in which the conductor is forced into resonant vibration by an electrodynamic shaker and the power input into the system is determined directly from the product of the excitation force and the resulting velocity at the point of application of the load. This represents the power dissipated by the conductor provided the two quantities are sinusoidal and are in phase with each other. It assumes also that the losses of the terminations are small compared with the dissipation within the conductor. The "power method" also permits the mechanical resistance per unit length of the conductor to be determined directly from the ratio of the force to the velocity.

[1]The numbers in brackets correspond to the references listed in Section 9 of this guide.

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1.2

The "standing wave" method [2], [3] in which the power transfer P_1 from the vibration generator towards the ends of the span at any particular node 1, is derived from the inverse or the reciprocal of the standing wave ratio, that is, the ratio of the nodal and antinodal amplitudes and is given as follows:

$$P_1 = \sqrt{Tm}\frac{V^2}{2}\left(\frac{a_1}{Y}\right)$$

where

$\sqrt{Tm}$	the wave or characteristic impedance (At very high frequencies this may be modified due to the effect of the stiffness of the conductor.)
$\frac{Y}{a_1}$	standing wave ratio
V	single amplitude velocity at antinode
T	conductor tension
m	conductor mass per unit length.

Then the power dissipated between two nodes 1 and 2 is simply

$$P = P_1 - P_2$$

The first method is simpler, faster, and requires somewhat less sophisticated instrumentation and is satisfactory for most measurements provided the termination losses are small. These can be determined by comparing the power inputs for two spans of different lengths identically terminated. (See discussion on Termination (Section C1) on methods for reducing losses to a satisfactory level.) Where it is not convenient to change the span length, it is necessary to employ the "standing wave" method to determine the losses due to the termination of the conductor. This method although more time-consuming, is preferred by some investigators. It does require special care in measuring the conductor amplitudes particularly at nodes where they are usually very small and in ensuring that only the component at the excitation frequency is measured.

The guideline provides information on the requirements for the test span and on the testing conditions, and suggests the form in which the results be presented.

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2. List of Symbols (see also Fig 1)

P	power dissipated per unit length	milliwatts per meter
T	tension	newtons
ℓ	loop length	meter
y	freeloop single amplitude at antinode	millimeters
Y	freeloop double amplitude at antinode	millimeters
V	transverse velocity at antinode—single amplitude	meters per second
a_n	double amplitude at n^{th} node	millimeters
f	frequency	hertz
m	mass per unit length	kilogram per meter
D	diameter of conductor	millimeters
F	single amplitude exciting force	newtons
RTS	rated tensile strength	newtons
L	free length of span	meter

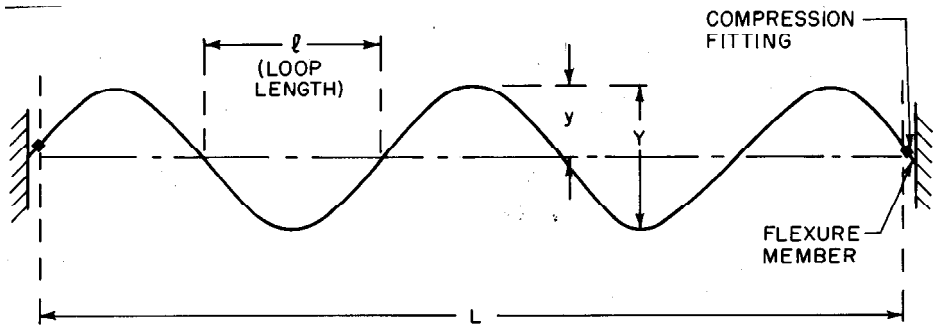

Figure 1 — Schematic Representation of Vibrating Conductor Span

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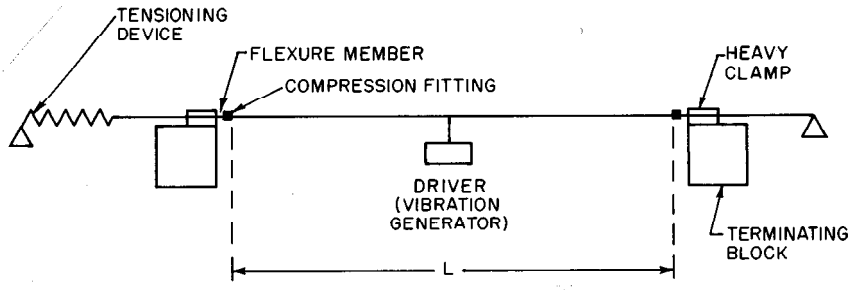

Figure 2 — Test Span Arrangement

3. Self-Damping Definition

The self-damping of a conductor subjected to a load T is defined by the power dissipated per unit length of a conductor vibrating in a natural mode, with a loop length ℓ and an antinode displacement amplitude y and a frequency f. The power per unit conductor length P is expressed as a function in the nth mode [4]:

$$P = f_n (T, \ell, f, y)$$

4. Conductor Definition

The conductor, to which the damping data are referred, should be clearly described. Together with the usual conductor data (stranding, weight per unit length, nominal RTS), information should be supplied on the type of lubricant or grease applied to it or whether it is degreased, and on the origin of the tested specimen (that is, if new ex-factory or taken from previously erected lengths). If the specimen is taken from a previously erected length, the tensile loads to which it has been subjected and the period of time during which it has been on the line should be stated.

5. Test Span Arrangement

The test span arrangement should be briefly described and shown in a sketch similar to Fig 2. The free length L of the test specimen should be stated.

The free span length L, for damping measurements required for aeolian vibration problems, should preferably be at least ten times longer than the longest loop length used in the tests. For consistent results, a span length greater than 50 m is recommended but satisfactory results can be obtained with spans in the range of 30 m. For shorter spans, the termination losses can be critical and it may be essential to use the standing wave method to measure the power loss in the conductor.

5.1 Termination

Preference should be given to a test arrangement which would minimize energy dissipation at the span end terminations. If there is uncertainty about this, the energy should be assessed and eventually accounted for by using the “standing wave” method.

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To minimize the energy dissipation at the span terminations, the following precautions are suggested:

1) The terminating fixtures be of massive concrete with a weight of the order of 10 percent of the ultimate tensile strength of the largest conductor to be tested. These should be a single piece and preferably be common or solidly connected with the foundation to avoid relative motion occurring between the various components.
2) The termination losses may be minimized by terminating the conductor by a flexure member, such as a flexible cantilever, to avoid bending the conductor through a sharp radius of curvature where it would normally enter the clamp. (See Fig 4 .)

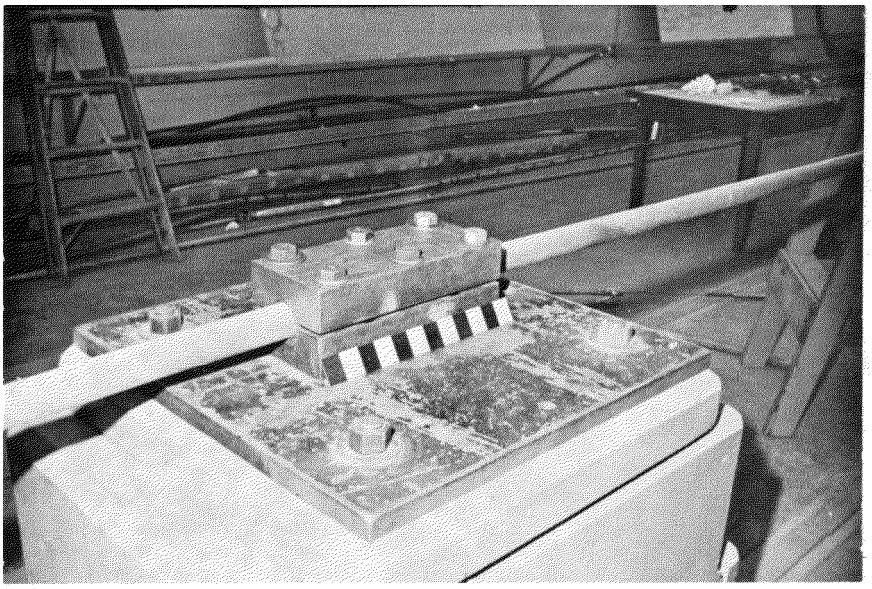

Figure 3 — Conventional Termination

Alternatively, the conductor may be clamped solidly to the concrete terminating fixture with a heavy clamp which should be a good fit on the conductor.[2] (See Fig 4 .)

5.2 Conductor Conditioning

Any excessive looseness in the layers of aluminum should be worked out of the conductor and the terminations should be pressed onto the conductor from the span end rather than from the end of the conductor to prevent looseness from being worked back into the test length by the action of pressing the termination onto the conductor. The conductor should be aged by holding it at the highest tension at which the test is to be made for a 2 h period and preferably overnight.

The methods used to assess that no energy was transferred from the conductor free length to span end terminations and the conductor looseness was minimized should be clearly indicated. Otherwise, the methods used to measure such an energy should be clearly stated, for example:

1) The accuracy of the tensile load measuring methods should be stated.
2) During the test, load variation should not exceed ±2 percent *T*.

[2]Clamps with lengths equal or greater than six times, and with groove diameters not more than 0.25 mm greater than the diameter of the conductor have given good results. Preferably, the clamp parts should be secured to the terminating fixture by a minimum of six bolts. Qualitatively, a termination may be considered sufficiently lossless if the log decrement of the conductor span is less than about 0.005 for the fundamental mode at double amplitudes less than twice the sag. The photographs (Figs 3–5) show typical terminations and a driver arrangement.

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3) The test must be performed indoors in still air.
4) The ambient temperature during erection and during the tests should be given. The temperature should be constant along the span and during the tests. Maximum allowable temperature variations during the measurements should be a minimum and noted.

5.3 Vibration Generator

The armature of the drive unit should be directly connected to the conductor at or near an antinodal point. (See Fig 5 .) For practical reasons, a point near the center of the test span is often preferred, but if this is not possible, the measured conductor velocity, in the loop which includes

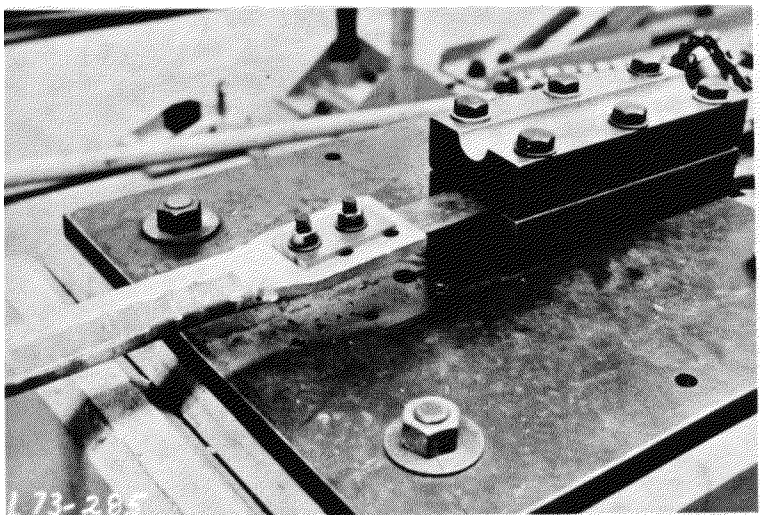

Figure 4 — Flexure Termination

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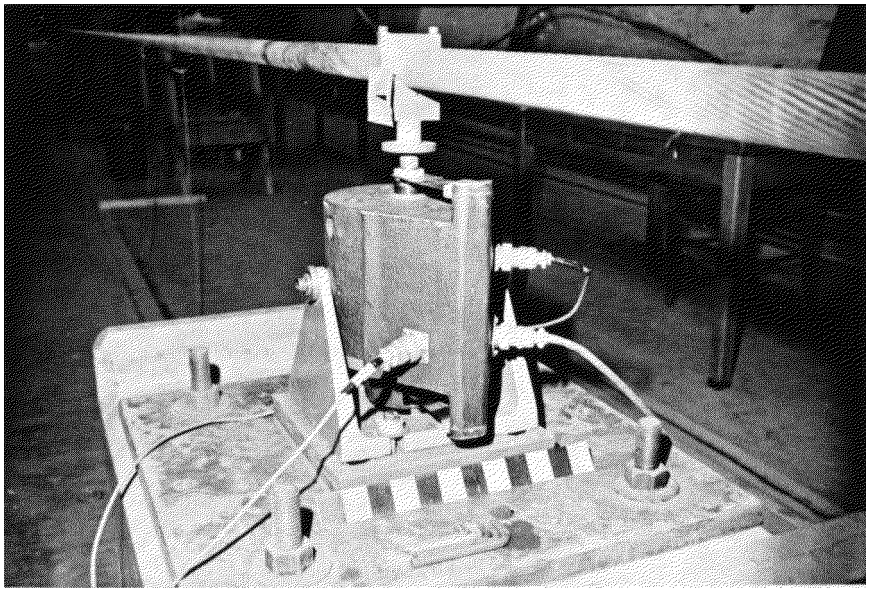

Figure 5 — Electro-dynamic Vibration Generator

the driver, should be corrected so that it is equivalent to the antinode velocity. Excessive generator mass changes the length of the loop to which it is attached and is indicative of localized damping. The effect of attaching the vibration generator to the conductor should not change the loop length in which the attachment is made by more than 10 percent. Otherwise, it should be accounted for in the determination of the self-damping of the conductor. A generator mass of less than 10 percent of the mass per unit length of conductor is normally satisfactory. The method of attachment of the driver to the conductor should be noted in the table of results.

The alternating force provided by the generator should be simple harmonic with a distortion level of less than 5 percent.

6. Test Method

The method used to drive the conductor to vibrate at resonance in one of its principal modes should be briefly described. Information should be given on the type of driving device and on the mechanical connections between the device and the conductor.

The method used to assess resonance conditions and the accuracy of frequency, force, displacement or velocity measurements, etc., should be stated.

The motion of the conductor must be simple harmonic. The amount of distortion can be determined directly from either the displacement or velocity signal. Alternatively, the distortion is acceptable if the difference between the maximum and minimum antinode amplitudes, compared with the average throughout the span, is equal or less than 5 percent.

Tests should be performed to check that the conductor test arrangement is stable and the results are repeatable, such as by making measurements twice with both increasing and decreasing amplitudes. Steady-state condition stability is acceptable if four or five readings of the energy dissipated per cycle or of power, performed at a few seconds intervals, do not show a definite increase or decrease of value and the variations are

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kept within 10 percent. These conditions can be obtained only if, in the same length of time, frequency variations are kept below 0.1 percent and amplitude variations are practically nil.

7. Power Measurements

The parameters which are actually measured to obtain the power dissipated should be clearly stated.

Preference should be given to the simpler and more direct methods, such as velocity and displacement measurements by means of transducers directly connected to the cable and force measurements by means of suitable dynamometers or transducers placed between the drive unit and the conductor.

If the harmonic force applied to the conductor is being measured, together with the displacement of the conductor at its connecting point to the drive unit, the energy dissipated per cycle should be obtained from the hysteresis loops which can be photographed from an oscilloscope or tape recorded and subsequently displayed on an x-y recorder. Power is then calculated.

If the harmonic force and the velocity are being measured, then the power measurements can be made directly with a wattmeter or suitable instrumentation.

8. Recommended Values of T, l, f, Y

The value of tensile load T to be used in the test, if not specifically required by a particular conductor application, should be suitably chosen in order to be representative of normal conductor loadings. The following loadings, expressed as percentages of the conductor RTS[3] are preferred: 15 (17.5), 20 (22.5), 25 (27.5), 30 (35), 40 (50). (The values in brackets are optional.)

A minimum of three different tensile loads T should be used, the medium value of which should correspond to the most common conductor loading on the line.

A minimum of five different loop lengths ℓ should be tested. The maximum and minimum loop lengths should correspond to the minimum and maximum frequencies that are generated in the wind velocity range of 3 to 30 kilometres per hour for the particular conductor diameter of interest. The relationship between frequency, wind velocity and conductor diameter is as follows:

[3]Rated tensile strength.

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Table 1—Specimen Table of Results Conductor Power Dissipation

Frequency	Loop	*Y*	*V*		*F*		*P*	*Y/D*
(Hz)	Length (m)	(mm)	(m/s)	(ft/s)	N	(lb)	mW/m	D
		17	0.45	(1.47)	5.15	(1.14)	48	0.42
9.3	8	11	0.29	(0.96)	1.45	(0.32)	8.6	0.27
		4.4	0.11	(0.39)	0.56	(0.13)	1.34	0.11
		1.5	0.51	(1.66)	8.2	(1.84)	86	0.28
13.9	4.6	7.2	0.32	(1.01)	3.58	(0.8)	23	0.18
		2.4	0.1	(0.34)	1.13	(0.25)	2.4	0.06
		9.6	0.59	(1.96)	25.16	(5.6)	310	0.24
19.7	3.4	5.1	0.32	(1.01)	6.29	(1.4)	41	0.12
		2.8	0.17	(0.34)	2.78	(0.62)	10	0.07
		6.8	0.56	(1.84)	41.51	(9.3)	480	0.17
26	2.7	4.1	0.33	(1.08)	16.35	(3.7)	112	0.1
		1.7	0.14	(0.46)	3.9	(0.86)	11	0.042
		5.6	0.57	(1.9)	69.19	(15.6)	825	0.14
32.5	2.1	3.8	0.39	(1.28)	31.45	(7.1)	256	0.094
		1.7	0.17	(0.56)	13.84	(3.1)	49	0.041

NOTES

1—*Y* freeloop double amplitude (mm)

2—*F* single amplitude exciting force at vibration generator (N)

3—*P* power dissipated per unit length (mW/m)

4—*D* diameter of conductor (mm) vibration generator directly connected to conductor in center of span

5—*V* single amplitude velocity at vibration generator (m/s)

$$f(\text{Hz}) = \frac{50 \times \text{wind velocity (km/hr)}}{\text{conductor diameter (mm)}}$$

The test frequencies must be within the capability of the test span and the tension sufficiently high for the conductor to have a natural mode at the desired frequency.

A minimum of three different antinode double amplitudes for each loop length should be tested and the values should be between $\frac{25}{f}$ and $\frac{150}{f}$.

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It is recommended that the loop lengths chosen be common to all the tensile loads T used. It is also recommended that, within the previously suggested range values of Y, a number of antinode displacement amplitudes be selected that are common to all the loop lengths used.

It is recommended that the results of the tests for each tension be tabulated as shown for the "power method" in Table I and presented in diagrams as illustrated in Fig 6 showing the power dissipated per unit conductor length, as a function of the ratio of the antinode displacement amplitude y to conductor diameter, for each loop length ℓ and corresponding frequency f and tensile load T. On the same diagram, the data referring to the different loop lengths and frequencies can be shown provided different symbols are used. It is preferable to present different diagrams for each tensile load, unless required for specific comparison purposes.

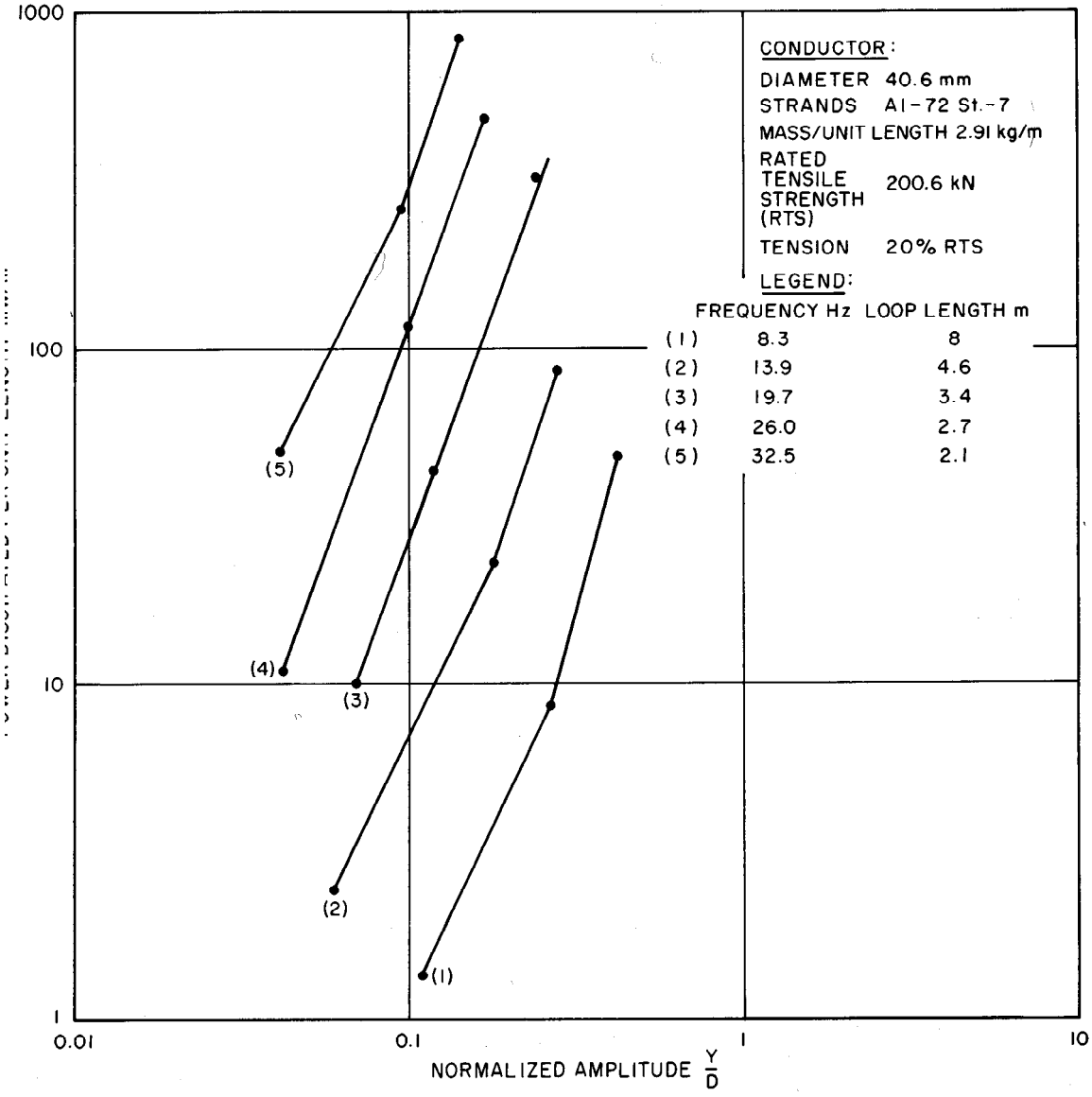

Figure 6 — Conductor Power Dissipation Characteristics

Diagrams should clearly show, for each value of T, ℓ, f, Y, all the actually measured values of P. The units shall be as indicated in the list of symbols.

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9. References

[1] CLAREN, R. and DIANA, G. Mathematical Analysis of Transmission Line Vibration. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-88, no 12, pp 1741–1767.

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Annex

(informative)

Appendix

(This Appendix is not a part of IEEE Std 563-1978, Guide on Conductor Self-Damping Measurements.)

In addition to the information given in IEEE Std 563-1978, it may be useful to present the results as a plot of conductor velocity against force per unit length for different frequencies and associated loop lengths, for each tension, as illustrated in Fig A1 Fig A1 from the results in Table 1 . This presentation allows, by simple calculation, the determination of the power dissipated, conductor amplitude, and the mechanical resistance of the conductor, that is, the ratio of the force to the conductor velocity, for a wide variety of conditions. The test arrangement with the vibration generator located at the center of the span provides information in the most suitable form for this type presentation since it is a requirement that the conductor be excited at an anti-node, that is, the center of a loop.

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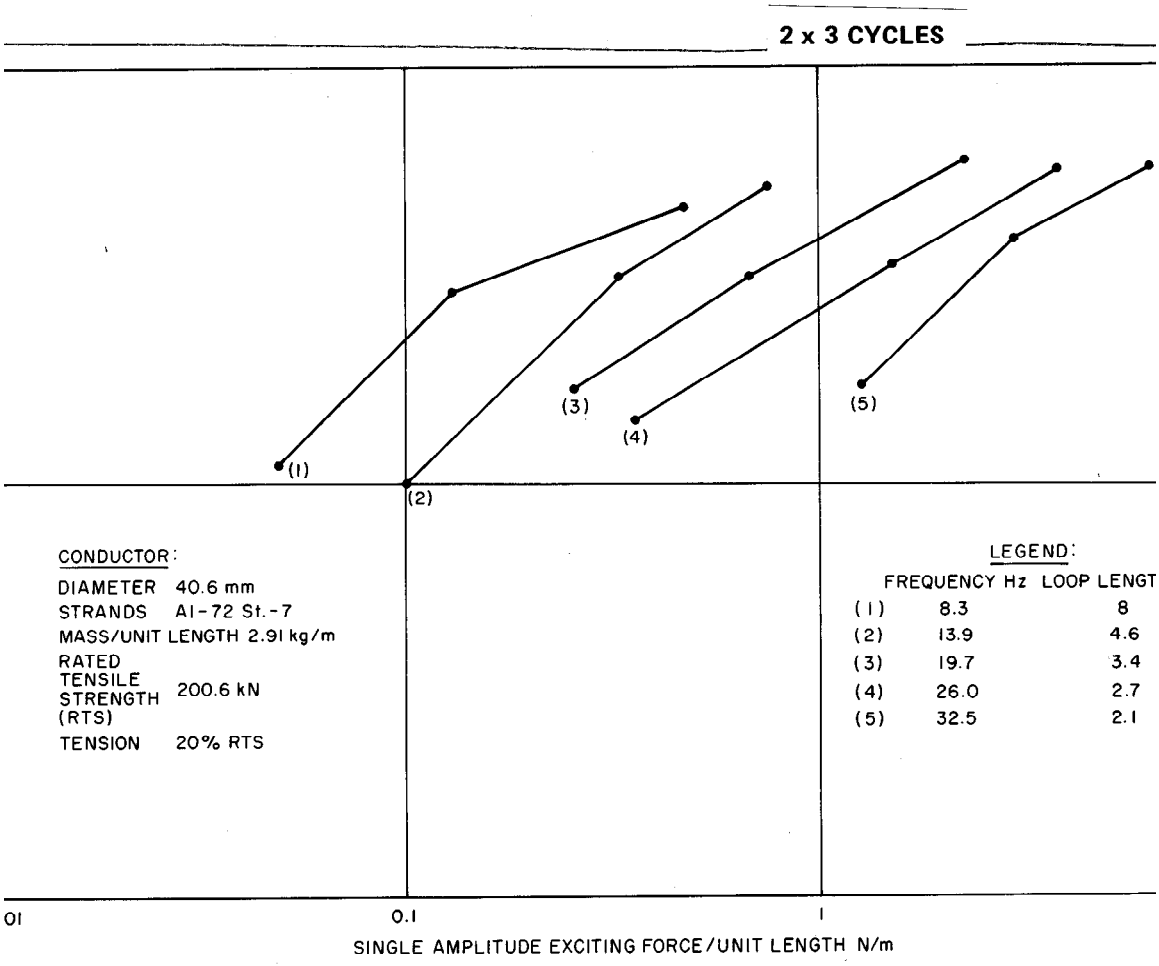

Figure A1 — Conductor Velocity vs. Exciting Force

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