



Method to Measure the Dynamic Stiffness of High Voltage Electric Cable and Cable Bundles

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. This procedure describes a method to measure the dynamic stiffness of electric wire bundles typically used to carry high voltage electrical current in electric and hybrid vehicles.

1.2 Applicability. This procedure may be used to measure the dynamic stiffness of high voltage electrical cable or bundles of cables.

1.3 Remarks. As the demand for vehicle refinement has increased and the time allotted for design/development has decreased, the need for more accurate modeling is critical. The task of modeling multi-strand copper cables is too time consuming and difficult to do at the current level of understanding. To bridge this gap, an accurate method to measure the cable's dynamic stiffness is required. This procedure details the method to measure cable and cable bundle dynamic stiffness.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

IEC 651

2.2 GM Standards/Specifications.

None

2.3 Additional References. None

3 Resources

3.1 Facilities. This testing shall be performed on a bedplate or equivalent. The bedplate shall be isolated from the local environment to prevent/minimize external vibration.

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.2 Equipment.

3.2.1 Large Inertial Mass. This mass may be the inertial mass of an air bearing calibration system or a large inertial mass with hardware that allows the mass to be suspended as the mass of a pendulum. Its design must also have the ability to attach clamp mechanisms that hold one end of a cable or cable bundle.

3.2.2 Shakers. One (1) electrodynamic shaker that is capable of an output of up to 200 N.

3.2.3 Metal Cable. If using an independent inertial mass, a minimum of 10 m of wire rope or metal cable with a working load in excess of 2000 N.

3.2.4 Force Transducers. One (1) force transducer with a flat sensitivity between 2 Hz and 2000 Hz and a temperature range of 10 °C to 50 °C.

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3.2.5 Accelerometers. Four (4) tri-axial low mass accelerometers with flat response from 2 Hz to 2000 Hz and an operating range of 10 °C to 50 °C.

3.3 Data Acquisition Equipment. Data acquisition hardware capable of calculating frequency domain results between 2 kHz and 10 kHz, with a minimum of 80 dB dynamic range. This hardware shall meet class 1 accuracy corresponding to IEC 651 or be equivalent for the application (precision ± 0.7 dB or $\pm 8\%$). The preferred data acquisition system consists of a personal computer running Leuven Measurement System (LMS) Test.Lab software with Step Sine Testing module, connected to a Scadas III frontend.

3.3.1 Cable. High Voltage Electrical cable bundle and/or single cables.

3.3.2 Cable Clamps. This procedure requires that each cable in the bundle is held in the correct design position relative to the other cables in the bundle; X, Y, Z, XX, YY, and ZZ at both ends, (see 3.5.1.3). Each end of the cable bundle is to be clamped in the correct design position and orientation as in the vehicle (X, Y, Z, XX, YY and ZZ). These clamps will need to be designed and fabricated for each cable bundle design being tested. One (1) cable clamp will be attached to the inertial mass, and the other cable clamp will be attached to ground. See Appendix A, Figures A1 and A2 for examples.

3.4 Test Time.

Calendar time: 7 to 21 days

Test hours: 8 to 32 hours

Coordination hours: 32 hours

3.5 Test Required Information. The following information is required to run this procedure.

3.5.1 Design Information.

3.5.1.1 Cable Specification. Physical dimensions of the cable:

- Outside Diameter
- Cross Sectional Area of the conductor

3.5.1.2 Cable Bundle Construction. The physical location of each cable relative to each other at both ends.

3.5.1.3 Routing. The exact routing of the wire bundle:

- Correct X, Y and Z position of each end of the bundle
- Correct angle that each end of the bundle terminated (XX, YY and ZZ)
- Correct path that the bundle follows

See examples of the required information in Appendix A, Figures A3 thru A7.

3.5.1.4 Length. The correct length of each cable in the bundle.

3.6 Personnel/Skills. One (1) qualified engineer or technician trained in the use of data acquisition and recording equipment and having basic knowledge of digital signal processing of acoustic or vibration signals. Knowledge of LMS's Structural Testing Module, LMS's Step Sine Test module, LMS's Swept Sine Test module and Microsoft Excel is also helpful.

4 Procedure

4.1 Preparation.

4.1.1 Cable Bundle Design Information. The first step is to collect the design information of the cable bundle, its routing and any additional bundle retainers that are included in the design.

4.1.2 Design and Fabrication.

4.1.2.1 Cable End Clamp Design. Once the design of the cable bundle and its routing information is gathered, the Engineer conducting the test must design a clamp for each end of the cable bundle. The clamps must be designed to hold a minimum length of cable equal to three (3) times its diameter. One of the clamps must be designed so that it can be attached to the inertial mass perpendicular to each of the three (3) principal axes of the cable end. The other clamp design must allow the clamp to be grounded to a bedplate in each of the attachment positions of the opposite end of the bundle. See Appendix A, Figure A8.

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4.1.2.2 Cable Bundle Retainer. If a cable bundle retainer is included in the design, it must also be included in the testing of the cable. If testing is to happen before the retainer exists in hardware, then the design will need to be fabricated, or fixturing that duplicates the retainer's function must be fabricated.

4.1.3 Acquire the Cable and Retainer. To ensure that the correct materials are used, acquire the cable to be tested from the design engineer or the development engineer. If there is a bundle retainer in the design and it exists in hardware, acquire it from the design engineer or development engineer.

4.1.3.1 Cut the Cable. Cut each cable that will make up the bundle to the correct length. Be aware that each cable may have a unique length. The correct length is the design length (length from connector to connector) plus the lengths to be held by each cable clamp.

4.1.3.2 Assemble the Cable Bundle. Assemble the cable bundle according to the design. Ensure each cable is in its correct design position in each cable clamp. Also ensure that each cable has the correct length between clamps.

4.1.4 Inertial Mass Selection. After the cable bundle is assembled, the person conducting the test must select which test setup to use. The air bearing is the easiest test setup to use, however, its use is limited to cable bundles that do not produce significant side loads on the air bearing. If a cable bundle in the design position produces side loads high enough to ground out the air bearing, the results will be incorrect. In the latter case a pendulum suspension and inertial mass must be used.

4.1.4.1 Air Bearing Calibrator Setup. The air bearing calibrator is set up just as if the operator is preparing to calibrate a set of accelerometers. It is clamped to a bedplate and a shaker is attached to one end of the inertial mass with a quill and force transducer. On the other end of the inertial mass, one end of the cable bundle is securely attached.

The orientation of this bundle end in the X, Y and Z axes is the same as it would be in the vehicle the opposite end of the bundle is grounded to bedplate and the location and orientation of its three (3) principal axes must match the end attached to the inertial mass. See Appendix A, Figures A9 and A10 for an example.

4.1.4.2 Pendulum Supported Inertial Mass Setup. The inertial mass is supported by a flexible thin metal cable. The minimum requirements for the inertial mass are:

- The mass or the Inertial Mass must be much greater than that of the cable bundle.
- It must have two (2) flat parallel sides that are oriented normal to the bedplate
- One (1) surface must have a hole drilled and tapped to accept the attachment of a force transducer and it must be in line with its center of mass
- The other flat surface must have holes drilled and tapped that allow attachment of the cable clamps in all three (3) principal axis of the cable bundle's end.
- The inertial mass must have attachments allowing it to be hung in a stable orientation through the motion caused by the shaker.

An illustration of the setup can be seen in Appendix A, Figures A11 thru A13. The inertial mass must be hung from a minimum height of 2 m. this reduces the vertical acceleration to be less than 0.1% of the horizontal acceleration. Due to the horizontal load from the cable bundle stiffness, lateral restraints similar to a pendulum in the horizontal plane are also required. These too need to be a minimum of 2 m in length to minimize lateral acceleration caused by its arc. This is also illustrated in Appendix A, Figure A11.

4.1.5 Test Hardware Setup. Set up the hardware in accordance with Appendix A, Figures A9 thru A13 as appropriate, while paying attention to the following recommended principles.

4.1.5.1 Space Requirement. To efficiently conduct this procedure, a space of approximately ½ of a standard bedplate is required.

4.1.5.2 Alignment of the Shaker and the Inertial Mass. It is important that alignment of the shaker and the inertial mass in its neutral position be horizontal.

4.1.5.2.1 Air Bearing Calibrator Inertial Mass. If using the air bearing calibrator, inertial mass misalignment will cause a Direct Current (DC) offset in the force signal, reducing accuracy.

4.1.5.2.2 Suspended Inertial Mass Setup. If using an inertial mass suspended by metal cable, misalignment will cause a DC offset in the force and decrease acceleration in the direction expected proportional to the misalignment.

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4.1.6 Instrumentation.

4.1.6.1 Force Transducers. Locate the force transducers in accordance with Appendix A, Figure A14.

4.1.6.2 Accelerometers. Locate the accelerometers 1 thru 4 in accordance with Appendix A, Figure A14.

4.2 Conditions.

4.2.1 Environmental Conditions. The ambient air temperature should remain between 15 °C and 25 °C.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.3 Instructions.

4.3.1 Data Acquisition. The data acquisition portion of the procedure is a Frequency Response Function (FRF) test. The operator may choose between Random Noise, Swept Sine or Step Sine for the excitation signal. The decision criteria is which of the signal types produces the data with the least noise in the measurement and the highest coherence.

4.3.1.1 Acquisition Test Parameters. The parameters for this test are:

- Set the FRF to H1
- Set the frequency range to 512 Hz
- Set the frequency resolution to 0.5 Hz
- Set the window according to the excitation type:
 1. Random excitation requires a Hanning window
 2. Swept Sine or Step Sine excitation require a Uniform window.
- Set the averaging type to linear
- Set the number of averages to 100 for Random Excitation or Swept Sine. Set the number of averages to 3 for Step Sine.

4.3.1.2 Measurements. Each cable bundle requires a set of four (4) measurements:

4.3.1.2.1 The First Measurement. The first measurement is of just the inertial mass by itself.

4.3.1.2.2 The Next Three (3) Measurements. The next three (3) measurements are made with the cable bundle attached to the end of the inertial mass. Each of these measurements is taken with the cable bundle end attached once in each axis, X, Y and Z. The grounded end of the cable bundle must be in the correct design position relative to the end attached to the inertial mass.

5 Data

5.1 Calculations. When all four (4) measurements have been completed and the data stored, the data is ready for processing.

5.1.1 LMS Processing. Within LMS, move to the Navigator module. Inside this module select the data calculator screen.

Select the measurements of just the inertial mass. From this data set, select all the FRF's that are in the direction of the shaker. Load those measurements into the calculator and average them.

Now calculate the reciprocal of the averaged results. This yields:

$$\left(\frac{\ddot{x}_{cal}}{f_{cal}}\right)^{-1}$$

Store it for later calculations.

Now, with each set of measurements made when the cable bundle was attached, select all the FRF's that are in the direction of the shaker. Load those measurements into the calculator and average them. This result is the calculation below:

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