



TECHNICAL SPECIFICATION



Rotating electrical machines – Part 32: Measurement of stator end-winding vibration at form-wound windings

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.160.01

ISBN 978-2-8322-3714-4

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	10
2 Normative references	10
3 Terms, definitions and abbreviated terms	11
3.1 Terms and definitions.....	11
3.2 Abbreviated terms.....	13
4 Causes and effects of stator end-winding vibrations	14
5 Measurement of stator end-winding structural dynamics at standstill	15
5.1 General.....	15
5.2 Experimental modal analysis.....	15
5.2.1 General	15
5.2.2 Measurement equipment	16
5.2.3 Measurement procedure	17
5.2.4 Evaluation of measured frequency response functions, identification of modes	20
5.2.5 Elements of test report	20
5.2.6 Interpretation of results.....	21
5.3 Driving point analysis.....	22
5.3.1 General	22
5.3.2 Measurement equipment	23
5.3.3 Measurement procedure	23
5.3.4 Evaluation of measured FRFs, identification of modes	23
5.3.5 Elements of test report	24
5.3.6 Interpretation of results.....	24
6 Measurement of end-winding vibration during operation	25
6.1 General.....	25
6.2 Measurement equipment.....	25
6.2.1 General	25
6.2.2 Vibration transducers.....	26
6.2.3 Electro-optical converters for fiber optic systems	27
6.2.4 Penetrations for hydrogen-cooled machines	27
6.2.5 Data acquisition.....	27
6.3 Sensor installation	28
6.3.1 Sensor locations	28
6.3.2 Good installation practices.....	29
6.4 Most relevant dynamic characteristics to be retrieved	30
6.5 Identification of operational deflection shapes.....	31
6.6 Elements of test report.....	31
6.7 Interpretation of results	32
7 Repeated measurements for detection of structural changes	33
7.1 General.....	33
7.2 Reference measurements, operational parameters and their comparability	33
7.3 Choice of measurement actions	35
7.4 Aspects of machine's condition and its history	36
Annex A (informative) Background causes and effects of stator end-winding vibrations	37

A.1	Stator end-winding dynamics	37
A.1.1	Vibration modes and operating deflection shape	37
A.1.2	Excitation of stator end-winding vibrations	38
A.1.3	Relevant vibration characteristics of stator end-windings	38
A.1.4	Influence of operational parameter	41
A.2	Increased stator end-winding vibrations	41
A.2.1	General aspects of increased vibration	41
A.2.2	Increase of stator end-winding vibrations levels over time and potential remedial actions	42
A.2.3	Transient conditions as cause for structural changes	43
A.2.4	Special aspects of main insulation	44
A.3	Operational deflection shape of global stator end-winding vibrations	44
A.3.1	General	44
A.3.2	Force distributions relevant for global vibrational behaviour	44
A.3.3	Idealized global vibration behaviour while in operation	45
A.3.4	General vibration behaviour of stator end-windings	47
A.3.5	Positioning of sensors for the measurement of global vibration level	49
A.4	Operational deflection shape of local stator end-winding vibrations	51
Annex B (informative)	Data visualization	52
B.1	General	52
B.2	Standstill measurements	53
B.3	Measurements during operation	56
Bibliography	62
Figure 1	– Stator end-winding of a turbogenerator (left) and a large motor (right) at connection end with parallel rings	7
Figure 2	– Example for an end-winding structure of an indirect cooled machine	8
Figure 3	– Measurement structure with point numbering and indication of excitation	19
Figure 4	– Simplified cause effect chain of stator end-winding vibration and influencing operational parameters	35
Figure A.1	– Illustration of global vibration modes	40
Figure A.2	– Example of rotational force distribution for $p = 1$	45
Figure A.3	– Example of rotating operational vibration deflection wave for $p = 1$	46
Figure A.4	– Illustration of two vibration modes with different orientation in space (example for $p = 1$)	47
Figure A.5	– on-rotational operational vibration deflection wave (example for $p = 1$)	48
Figure A.6	– Amplitude and phase distribution for a general case.	49
Figure A.7	– Sensors for the measurement of global vibration level centred in the winding zones	50
Figure A.8	– Measurement of global vibration level with 6 equidistantly distributed sensors in the centre of winding zones	50
Figure A.9	– Example – Sensor positions for the measurement of local vibration level of the winding connection relative to global vibration level	51
Figure B.1	– Measurement structure with point numbering and indication of excitation	52
Figure B.2	– Example for linearity test – Force signal and variance of related FRFs	53
Figure B.3	– Example for reciprocity test – FRFs in comparison	53
Figure B.4	– Example – Two overlay-plots of the same transfer functions but different dimensions	54

Figure B.5 – Shapes of the 4, 6 and 8-node modes with natural frequencies, measurement in one plane.....	55
Figure B.6 – Mode shape of a typical 4-node mode with different viewing directions (stator end-winding and outer support ring).....	55
Figure B.7 – Example – Amplitude and phase of dynamic compliance and coherence.....	56
Figure B.8 – 2-pole, 60 Hz generator – Trend in displacement over time for 10 stator end-winding accelerometers, as well as one accelerometer mounted on the stator core.....	56
Figure B.9 – 2-pole, 60 Hz generator – End-winding vibration, winding temperature trends over time, constant stator current.....	57
Figure B.10 – 2-pole, 60 Hz generator – End-winding vibration, stator current trends over time, constant winding temperature.....	57
Figure B.11 – 2-pole, 60 Hz generator – Example of variation in vibration levels at comparable operating conditions.....	58
Figure B.12 – 2-pole, 60 Hz generator – Raw vibration signal, acceleration waveform	59
Figure B.13 – 2-pole, 60 Hz generator – FFT and double integrated vibration signal, displacement spectrum	59
Figure B.14 – 2-pole, 60 Hz generator – Displacement spectrum	60
Figure B.15 – 2-pole, 60 Hz generator – Velocity spectrum.....	60
Figure B.16 – 2-pole, 60 Hz generator – Acceleration spectrum	61
Table 1 – Node number of highest mode shape in relevant frequency range and minimum number of measurement locations	20
Table 2 – Possible measurement actions to gain insight into various aspects of the cause-effect chain.	36

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ROTATING ELECTRICAL MACHINES –

Part 32: Measurement of stator end-winding vibration at form-wound windings

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a Technical Specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 60034-32, which is a Technical Specification, has been prepared by IEC technical committee 2: Rotating machinery.

The text of this Technical Specification is based on the following documents:

Enquiry draft	Report on voting
2/1810/DTS	2/1849/RVC

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

NOTE A table of cross-references of all IEC TC 2 publications can be found on the IEC TC 2 dashboard on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

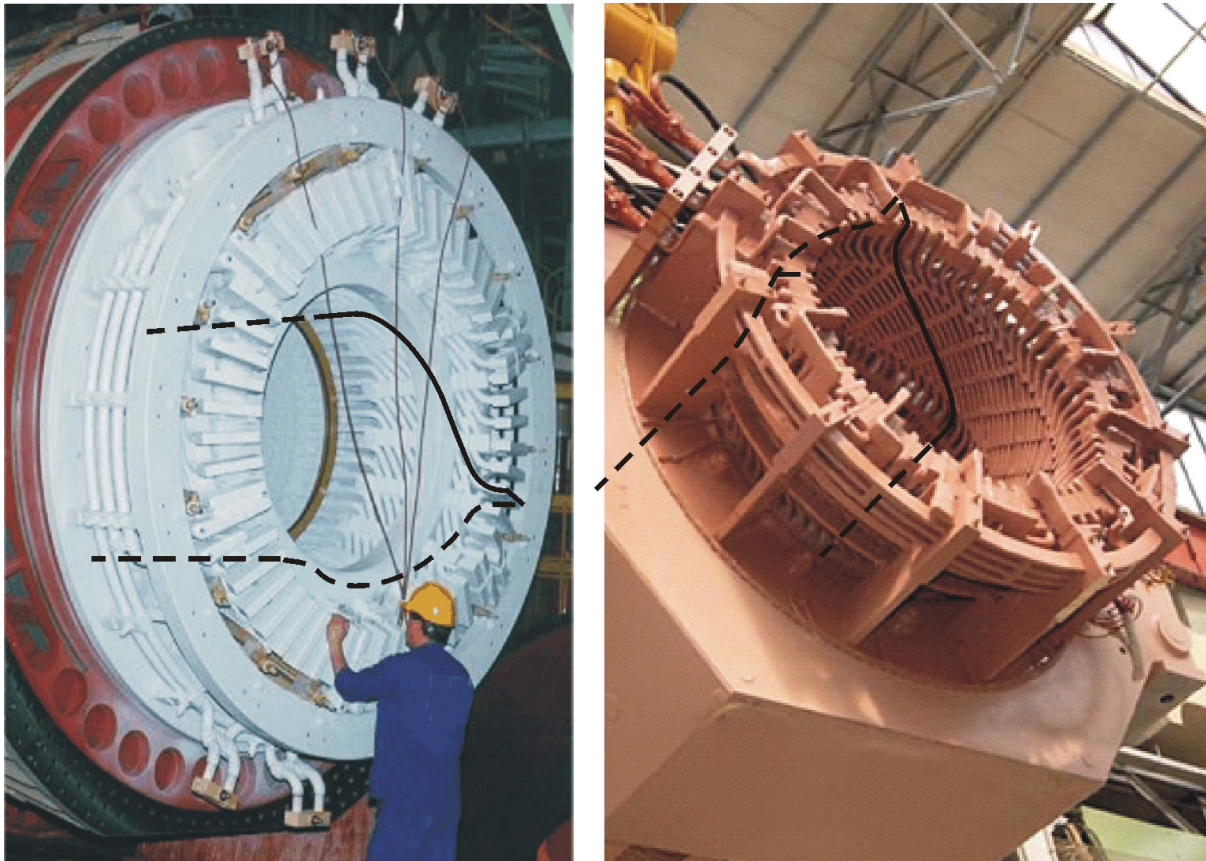
IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Large alternating current (AC) machines are equipped with multiphase stator windings. The information in this document is based on a dual-layer design. Such windings are connected to a multiphase voltage system (multiphase current system), which establishes a rotating magnetic field in the air gap between the rotor surface and stator bore. The voltage and current can vary during operation in order to adapt to varying mechanical load. Electrical machines are normally designed for motor or generator operating mode. The majority of AC machines are equipped with symmetrical three-phase windings, consisting of three, electrically isolated, spatially distributed winding parts that are intended for common operation.

Large AC rotating electrical machines are typically equipped with form-wound windings consisting of form wound coils (as defined in IEC 60034-15:2009, 2.3), single winding coils (single winding bars) which are given their shape before being assembled into the machine.

The winding overhang, or end-winding, is the portion of the stator winding that extends beyond the end of the magnetic core and is, in most cases, formed as a circular cone, see some examples in Figure 1 below.



IEC

NOTE Individual coil end marked with black line.

Figure 1 – Stator end-winding of a turbogenerator (left) and a large motor (right) at connection end with parallel rings

The majority of large AC machines with form-wound stator windings are equipped with a stator end-winding support structure. Among other functions it is expected to withstand the high electromagnetic force loading when the machine is exposed to an electrical fault in the electrical supply system. This includes a fault in the supply lines of an electrical grid or in an electronic supply device. In many cases the stator end-winding support structure is not only designed to increase the structural strength, but also provide appropriate structural stiffness and inertia to systematically influence structural dynamics and thus the vibration level during operation.

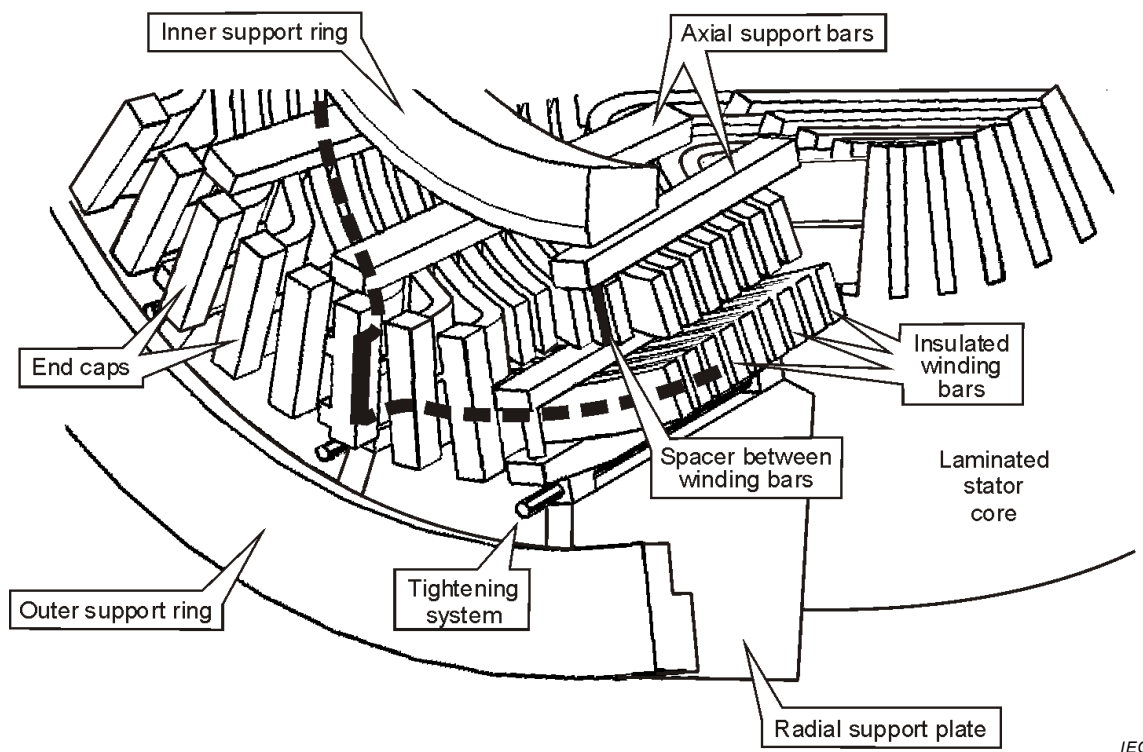


Figure 2 – Example for an end-winding structure of an indirect cooled machine

Typical support elements are plates and rings, which support the end-winding cone as a whole. Moreover, the distance between coils (or bars) of the end-winding are defined by spacing elements and their positions are fixed by fastening components. The typical materials used for support elements, spacers and fasteners are composites containing glass fibre materials as well as resin impregnated felts, cords and bandings (see Figure 2). Also, high electrical fields surrounding metal parts could produce electrical discharges compromising long term electrical strength.

Until now there existed no general Technical Specification to get reliable and comparable results for the identification of natural frequencies during stand-still and for vibration behaviour of stator end-windings during operation.

The experimental modal analysis of stator end-windings is a well-established tool which has also been used for the verification of natural frequencies and mode shapes of large electrical machines worldwide. The goal is to avoid operation of the machine with increased end-winding vibration levels under the influence of natural frequencies. Measurement of transfer functions and identification of structural dynamic properties (e.g. natural frequencies, mode shapes and other modal parameters) with an impact test is a common testing procedure. It is applied to new machines by the manufacturer and also used as a maintenance tool by the user or contractor during a major overhaul of large rotating machines.

Operational measurement of vibrational behaviour of stator end-windings can be performed by the installation of special vibration transducers at selected end-winding locations for periodic measurements or permanent on-line monitoring.

Although measurements of natural frequencies and vibration levels of stator end-windings are well established techniques, the interpretation of results is still a matter of further improvement and development. Therefore this first edition is a Technical Specification and not an International Standard.

ROTATING ELECTRICAL MACHINES –

Part 32: Measurement of stator end-winding vibration at form-wound windings

1 Scope

This part of IEC 60034 is intended to provide consistent guidelines for measuring and reporting end-winding vibration behaviour during operation and at standstill. It

- defines terms for measuring, analysis and evaluation of stator end-winding vibration and related structural dynamics,
- gives guidelines for measuring dynamic / structural characteristics offline and stator end-winding vibrations online,
- describes instrumentation and installation practices for end-winding vibration measurement equipment,
- establishes general principles for documentation of test results,
- describes the theoretical background of stator end-winding vibrations.

This part of IEC 60034 is applicable to:

- three-phase synchronous generators, having rated outputs of 150 MVA and above driven by steam turbines or combustion turbines;
- three-phase synchronous direct online (DOL) motors, having rated output of 30 MW and above.

This document is limited to the description of measurement procedures for 2-pole and 4-pole machines. For smaller ratings of machines than defined in this document, agreement can be made between the vendor and the purchaser for the selection of measurements in this document to be applied.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-15, *Rotating electrical machines – Part 15: Impulse voltage withstand levels of form-wound stator coils for rotating a.c. machines*

IEC 60079 (all parts), *Explosive atmospheres*

ISO 7626-5:1994, *Vibration and shock – Experimental determination of mechanical mobility – Part 5: Measurements using impact excitation with an exciter which is not attached to the structure*

ISO 18431-1, *Mechanical vibration and shock – Signal processing – Part 1: General introduction*

ISO 18431-2, *Mechanical vibration and shock – Signal processing – Part 2: Time domain windows for Fourier Transform analysis*