

# IEEE Recommended Practice for Thermal Cycle Testing of Form-Wound Stator Bars and Coils for Large Rotating Machines

IEEE Power & Energy Society

Sponsored by the  
Electric Machinery Committee

---

IEEE  
3 Park Avenue  
New York, NY 10016-5997  
USA

**IEEE Std 1310™-2012**  
(Revision of  
IEEE Std 1310-1996)

21 May 2012



# **IEEE Recommended Practice for Thermal Cycle Testing of Form-Wound Stator Bars and Coils for Large Rotating Machines**

Sponsor

**Electric Machinery Committee  
of the  
IEEE Power & Energy Society**

Approved 29 March 2012

**IEEE-SA Standards Board**

**Abstract:** This procedure is intended for form-wound bars/coils for rotating machines rated 10 kV or more at 50 Hz or 60 Hz that are subjected to many transitions from no-load to full-load current during normal operations, and where rapid load variations are typical. Only the thermal cyclic degradation within the groundwall insulation and/or the conductor package and delamination of the groundwall insulation from the conductor are addressed by this test. The procedure is applicable to indirectly-cooled machine types such as:

- combustion turbine generators
- pumped storage or peaking duty hydrogenerators
- synchronous condensers
- cyclic duty water pump motors

Various pass/fail criteria are presented, and the ones that apply in a specific circumstance must be agreed between user and manufacturer prior to commencement of testing.

**Keywords:** cyclic duty, delamination, groundwall degradation, IEEE 1310, indirectly cooled machines, peaking duty, stator winding, thermal cycling

---

The Institute of Electrical and Electronics Engineers, Inc.  
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2012 by The Institute of Electrical and Electronics Engineers, Inc.  
All rights reserved. Published 21 May 2012. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-0-7381-7270-5      STD97245  
Print: ISBN 978-0-7381-7376-4      STDPD97245

*IEEE prohibits discrimination, harassment, and bullying. For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>. No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.*

**Notice and Disclaimer of Liability Concerning the Use of IEEE Documents:** IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

Use of an IEEE Standard is wholly voluntary. IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon any IEEE Standard document.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained in its standards is free from patent infringement. IEEE Standards documents are supplied "AS IS."

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE standard is subjected to review at least every ten years. When a document is more than ten years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

**Translations:** The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

**Official Statements:** A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

**Comments on Standards:** Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important to ensure that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. Any person who would like to participate in evaluating comments or revisions to an IEEE standard is welcome to join the relevant IEEE working group at <http://standards.ieee.org/develop/wg/>.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board  
445 Hoes Lane  
Piscataway, NJ 08854  
USA

**Photocopies:** Authorization to photocopy portions of any individual standard for internal or personal use is granted by The Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

## Notice to users

### Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

### Copyrights

This document is copyrighted by the IEEE. It is made available for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making this document available for use and adoption by public authorities and private users, the IEEE does not waive any rights in copyright to this document.

### Updating of IEEE documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect. In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE-SA Website at <http://standards.ieee.org/index.html> or contact the IEEE at the address listed previously. For more information about the IEEE Standards Association or the IEEE standards development process, visit IEEE-SA Website at <http://standards.ieee.org/index.html>.

### Errata

Errata, if any, for this and all other standards can be accessed at the following URL: <http://standards.ieee.org/findstds/errata/index.html>. Users are encouraged to check this URL for errata periodically.

### Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at <http://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

## Participants

At the time this IEEE recommended practice was completed, the Materials Subcommittee Working Group had the following membership:

**Gregory Stone, *Chair***  
**Richard Huber, *Vice Chair***

Ray Bartnikas  
Stefano Bomben  
Andrew Brown  
Don Campbell  
Doug Conley  
Ian Culbert  
S. N. Fernando  
Nancy Frost  
Paul Gaberson

George Gao  
Bal Gupta  
Gary Heuston  
Aleksandra Jeremic  
Thomas Klamt  
Laurent Lamarre  
Gerhard Lemesch  
William McDermid  
Charles Millet

Glen Mottershead  
Sophie Noel  
Jeffrey Sheaffer  
Meredith Stranges  
Joe Williams  
Chuck Wilson  
Hugh Zhu

The following members of the individual balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

Michael Adams  
Thomas Bishop  
William Bloethe  
Stefano Bomben  
Steven Brockschink  
Andrew Brown  
Gustavo Brunello  
Weijen Chen  
Jerry Corkran  
Ian Culbert  
Jorge Fernandez Daher  
Matthew Davis  
Gary Donner  
Donald Dunn  
James Dymond  
Gary Engmann  
Rostyslaw Fostiak  
Ron Greenthaler  
J. Travis Griffith

Randall Groves  
Bal Gupta  
Gary Heuston  
David Horvath  
Richard Huber  
Innocent Kamwa  
Joseph L. Koepfinger  
Chung-Yiu Lam  
Gerhard Lemesch  
William Lockley  
Greg Luri  
William McBride  
William McCown  
William McDermid  
Don McLaren  
James Michalec  
Gary Michel  
G. Harold Miller  
Charles Millet

Jerry Murphy  
Michael S. Newman  
William Newman  
Lorraine Padden  
Christopher Petrola  
Alvaro Portillo  
Bartien Sayogo  
Jeffrey Sheaffer  
Gil Shultz  
James Smith  
Gary Stoedter  
Gregory Stone  
Meredith Stranges  
James Timperley  
Remi Tremblay  
John Vergis  
John Yale  
Hugh Zhu



When the IEEE-SA Standards Board approved this recommended practice on 29 March 2012, it had the following membership:

**Richard H. Hulett**, *Chair*  
**John Kulick**, *Vice Chair*  
**Robert M. Grow**, *Past President*  
**Judith Gorman**, *Secretary*

Satish Aggarwal  
Masayuki Ariyoshi  
Peter Balma  
William Bartley  
Ted Burse  
Clint Chaplin  
Wael Diab  
Jean-Philippe Faure  
Alexander Gelman

Paul Houzé  
Jim Hughes  
Young Kyun Kim  
Joseph L. Koepfinger\*  
John Kulick  
David J. Law  
Thomas Lee  
Hung Ling  
Oleg Logvinov

Ted Olsen  
Gary Robinson  
Jon Walter Rosdahl  
Mike Seavey  
Yatin Trivedi  
Phil Winston  
Yu Yuan

\*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Richard DeBlasio, *DOE Representative*  
Michael Janezic, *NIST Representative*

Julie Alessi  
*IEEE Standards Program Manager, Document Development*

Malia Zaman  
*IEEE Standards Program Manager, Technical Program Development*

## Introduction

This introduction is not part of IEEE Std 1310-2012, IEEE Recommended Practice for Thermal Cycle Testing of Form-Wound Stator Bars and Coils for Large Rotating Machines.

In some applications, large rotating machines are subjected to rapid transitions from low power to full power, and vice versa. For example, hydrogenerators (peaking duty and pumped storage), synchronous condensers, and gas turbine generators are often raised from idle to full power in a matter of minutes, are operated at full power for hours, and are then rapidly reduced to zero output. This load cycling leads to rapid temperature changes within the stator winding. As a result, an alternating shear stress develops within the ground insulation system.

If the bond between the copper and the insulation is not adequate, the copper may separate from the insulation. This results in the formation of voids between the insulation and the copper that may permit relative movement of the copper strands/turns, leading to abrasion of the insulation. Also, voids can develop between the layers of the groundwall insulation as a result of delamination. In high-voltage bars/coils, these voids can lead to partial discharges, and, under certain circumstances, to puncture of the insulation.

The test procedure described in this recommended practice is intended to simulate this thermal cyclic aging mechanism under controlled conditions. To give meaningful results in a reasonable time, acceleration is achieved by repeatedly applying heating and cooling cycles to the test samples without any hold time at the maximum or minimum temperatures. The test is performed on production, prototype, or similar design bars/coils that are not planned for subsequent use in a winding since the test produces aging of the insulation.

Note that this test procedure is not intended to evaluate the relative performance of the end-winding or the methods used to support the end-winding or the effects on the thermal cyclic aging mechanism, if any, caused by the methods used to support the end-winding. Other thermal cyclic aging mechanisms of abrasion of the coil by the core iron and cracking of insulation at the slot exit are not addressed. This recommended practice is not appropriate for direct liquid cooled machines since it is not likely that rapid winding temperature swings will occur even if the load changes rapidly. This recommended practice is not intended for direct gas cooled machines, but this may change in future revisions. This recommended practice does not apply to windings processed by the global vacuum pressure impregnation (GVPI) method.

The test procedure described in this document is not a multifactor aging stress as described in IEC 60505, since the only accelerating factor is the rate of change of temperature.

This is the first revision of this recommended practice. However, in most material respects, this test procedure is the same as described in the first edition. Based on experience, some changes were made to the diagnostic tests.

## Contents

1. Overview .....	1
1.1 Scope .....	2
1.2 Purpose .....	3
2. Normative references.....	3
3. Definitions .....	5
4. Thermal cycling test description.....	5
4.1 Test objects.....	5
4.2 Method of heating.....	5
4.3 Method of cooling .....	6
4.4 Temperature cycle and schedule.....	6
5. Thermal cycling test setup.....	7
5.1 Quantity of bars/coils required for testing .....	7
5.2 Positioning and setting up bars/coils for test .....	8
5.3 Temperature criteria, measurement, and control .....	10
6. Bar/coil preparation.....	11
7. Diagnostic tests preceding and during thermal cycling.....	11
7.1 Electrical proof test for the groundwall insulation.....	12
7.2 Dissipation factor and tip-up measurements.....	12
7.3 Partial discharge measurements.....	12
7.4 Physical measurements.....	12
7.5 Tap test—mechanical delamination detection .....	12
7.6 Surface resistivity .....	13
8. Post-thermal cycle tests .....	13
8.1 Proof tests .....	13
8.2 Breakdown or voltage endurance test.....	14
8.3 Dissection .....	14
9. Preparation of test report .....	15
Annex A (normative) Sample calculation for estimating current rating of test supply .....	16
A.1 Approximate method for calculation .....	16
A.2 Loss of thermal energy, practical tests.....	17
A.3 Test equipment.....	17
Annex B (informative) Decisions required by manufacturer/purchaser/testing facility .....	18
Annex C (informative) Bibliography.....	19

# IEEE Recommended Practice for Thermal Cycle Testing of Form-Wound Stator Bars and Coils for Large Rotating Machines

*IMPORTANT NOTICE: IEEE Standards documents are not intended to ensure safety, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.*

*This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.*

## 1. Overview

In some applications, large rotating machines are subjected to rapid transitions from low power to full power, and vice versa. For example, hydrogenerators (peaking duty and pumped storage), synchronous condensers, and gas turbine generators are often raised from idle to full power in a matter of minutes, are operated at full power for hours, and are then rapidly reduced to zero output. This load cycling leads to rapid temperature changes within the stator winding.

Increasing the machine output from no-load to full-load causes the stator current to increase from zero to full-load current. This current raises the temperature of the stator winding copper conductors due to  $I^2R$  (copper) losses. As the temperature increases, the copper will expand, especially in the axial direction. The longer the stator bar (or coil), the greater will be the total expansion of the copper. The high-voltage groundwall insulation operates at lower temperature than the copper and may have a lower coefficient of thermal expansion. Therefore, the thermally-induced expansion of the insulation is less than the copper. The difference in expansion is greater when the machine power level is rapidly changed since thermal inertia of the stator iron causes the insulation temperature to lag behind the copper temperature. The difference in expansion between the insulation and the copper creates a shear stress within the insulated bar/coil. In particular, during the manufacturing process, a shear stress between the copper and the insulation of the bar/coil is formed as the bar/coil cools from its groundwall curing temperature. In general, when the bar/coil is heated, the shear stress relaxes; when it cools, the shear stress increases. If the glass

transition temperature is exceeded during the test, this general rule may not apply. For more information, refer to [B11].

If the bond between the copper and the insulation is not adequate, the copper may separate from the insulation. This results in the formation of voids between the insulation and the copper that may permit relative movement of the copper strands/turns, leading to abrasion of the insulation. Also, voids can develop between the layers of the groundwall insulation as a result of delamination. In high-voltage bars/coils, these voids can lead to partial discharges, and, under certain circumstances, to puncture of the insulation.

The test procedure described in this recommended practice is intended to simulate this thermal cyclic aging mechanism under controlled conditions. To give meaningful results in a reasonable time, acceleration is achieved by repeatedly applying heating and cooling cycles to the test samples without any hold time at the maximum or minimum temperatures. The test is performed on production, prototype, or similar design bars/coils that are not planned for subsequent use in a winding since the test produces aging of the insulation.

Interpretation of test results depends on the analysis of the diagnostic and post-thermal cycle test data and/or comparison of the data to past results on the same insulation system. The slot sections of stator bars/coils similar to those that have performed well under diagnostic and post-thermal cycle tests are expected to withstand load cycling duty better than slot sections similar to those that have tested poorly.

Note that this test procedure is not intended to evaluate the relative performance of the end-winding, or the methods used to support the end-winding, or the effects on the thermal cyclic aging mechanism, if any, caused by the methods used to support the end-winding. Also, there is no hold period at the maximum or minimum temperature as exists in a generator since this would greatly complicate the temperature-control scheme. Other thermal cyclic aging mechanisms of abrasion of the coil by the core iron and cracking of insulation at the slot exit are not addressed. Including a core model, slot filler materials, and the end-winding support structure would greatly increase the cost and complexity of the test. IEC 60034, Part 18, Section 34 describes a test procedure that includes a core model for thermal cycling testing. Those interested may refer to this IEC document. This recommended practice is not appropriate for direct liquid cooled machines since it is not likely that rapid winding temperature swings will occur even if the load changes rapidly. This recommended practice is not intended for direct gas cooled machines, but this may change in future revisions. This recommended practice does not apply to windings processed by the global vacuum pressure impregnation (GVPI) method.

The test procedure described in this document is not a multifactor aging stress as described in IEC 60505 since the only accelerating factor is the rate of change of temperature. A multifactor aging test may also have mechanical and electrical stresses as aging factors. Although a multifactor aging test method may simulate more accurately the stresses encountered in service, it is very expensive to perform and is not in common use.

## 1.1 Scope

This procedure is intended for form-wound bars/coils for rotating machines rated 10 kV or more at 50 Hz or 60 Hz that are subjected to many transitions from no-load to full-load current during normal operations, and where rapid load variations are typical. Only the thermal cyclic degradation within the groundwall insulation and/or the conductor package and delamination of the groundwall insulation from the conductor are addressed by this test. Examples of machine types that typically exhibit rapid load transitions include:

- Combustion turbine generators
- Pumped storage or peaking duty hydrogenerators

- Synchronous condensers
- Cyclic duty water pump motors

Various pass/fail criteria are presented, and the ones that apply in a specific circumstance must be agreed between the user and the manufacturer prior to commencement of testing. Whether a particular bar or coil has passed or failed is best determined by comparing the test results from a number of stator bars or coils.

## 1.2 Purpose

A test method to determine the relative ability of high-voltage form-wound stator bars and coils of large rotating machines to resist deterioration due to rapid heating and cooling resulting from machine load cycling is described. The test procedure is primarily intended for machines where the stator windings are indirectly cooled by air or hydrogen. This procedure provides a recommended practice for performing thermal cycle testing of form-wound stator bars and coils without the use of a simulated core. To ensure the results of the thermal cycling test accurately represent the insulation deterioration expected in service, the bars or coils used in the test should represent in every way the characteristics of the production lot. Thermal cycle testing of bars and coils confined in a simulated core would require different parameters and therefore is not covered by this procedure.

## 2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM D 149, Standard Test Methods for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies.<sup>1</sup>

ASTM D 229, Standard Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation.

ASTM D 352, Standard Test Methods for Pasted Mica Used in Electrical Insulation.

ASTM D 494, Standard Test Method for Acetone Extraction of Phenolic Molded or Laminated Products.

ASTM D 619, Standard Test Methods for Vulcanized Fiber Used for Electrical Insulation.

ASTM D 790, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.

ASTM D 1868, Standard Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems.

ASTM D 2344, Standard Test Method for Apparent Interlaminar Shear Strength of Parallel Fiber Composites by Short-Beam Method.

ASTM D 3846, Standard Test Method for In-Plane Shear Strength of Reinforced Plastics.

---

<sup>1</sup>ASTM International publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.