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IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines

Sponsor

Electric Machinery Committee
of the
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Abstract: Suggestions are made for testing the dielectric strength of the insulation separating the various turns from each other within multiturn form-wound coils to determine their acceptability. Typical ratings of machines employing such coils normally lie within the range of 200 kW to 100 MW. The test voltage levels described do not evaluate the ability of the turn insulation to withstand abnormal voltage surges, as contrasted to surges associated with normal operation. The suggestions apply to: (1) individual stator coils after manufacture; (2) coils in completely wound stators of original manufacture; (3) coils and windings for rewinds of used machinery; and (4) windings of machines in service to determine their suitability for further service (preventive-maintenance testing). Coil service conditions, test devices, and test sequence are discussed. High-frequency test levels for new coils during winding, and for applying surge tests to complete windings, are given.
Keywords: ac machines, power system transients, rotating-machine insulation testing

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Foreword

(This foreword is not a part of IEEE Std 522-1992, IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines.)

This revision of IEEE Std 522-1977 was initiated by the Insulation Subcommittee (now Materials Subcommittee) of the Rotating Machinery Committee of the IEEE Power Engineering Society. At the time that this standard was completed, the working group had the following membership:

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IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines

1. Introduction

1.1 Many alternating-current rotating electric machines are designed to have multiturn form-wound stator coils. In these cases, the winding has two separate but interrelated insulating barriers:

(1) between the various turns (turn insulation)
(2) between the turns and ground (ground insulation)

Failure of either of these barriers will prematurely terminate the service life of the machine. A test level, twice rated voltage plus 1 kV, for the ground insulation has been in existence for many years. This guide suggests methods and test levels for the turn insulation.

1.2 Experience has shown that turn-insulation failures can be precipitated by abnormal steep-front surges caused by factors such as lightning strokes, faulty breaker closures, or the malfunction of various types of switching devices. However, turn-insulation failures can also be caused by surges during normal breaker operations when the circuit conditions are such that the rise time of the surge at the machine terminals is less than a few microseconds. A measure of protection from such surges may be provided by installation of devices such as wave-sloping capacitors at the machine terminals and surge arrestors, or by increasing turn-to-turn insulation. When used for this purpose, capacitor ratings are usually chosen to extend the rise time of voltage surges to 5 µs or longer.

1.3 References are given for determining surge environment and strength of electric machines in the Bibliography (Section 8).

2. Scope and Reference

2.1 Scope. The purpose of this guide is to make suggestions on testing the dielectric strength of the insulation separating the various turns from each other within multiturn form-wound coils to determine the acceptability of the coils. Typical ratings of machines employing such coils normally lie within the range of 200 kW to 100 MW. Test voltage levels described herein do not evaluate the ability of the turn insulation to withstand abnormal voltage surges, as contrasted to surges associated with normal operation. These suggestions apply to:

(1) Individual stator coils after manufacture
(2) Coils in completely wound stators of original manufacture
(3) Coils and windings for rewinds of used machinery
(4) Windings of machines in service to determine their suitability for further service (preventive-maintenance testing)

2.2 Reference. This guide shall be used in conjunction with the following publication:

[1] IEEE Std 43-1974 (1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery (ANSI).[1]

3. Service Conditions

3.1. The maximum operating (line frequency) voltage difference between turns in a coil depends upon the voltage between coil terminals and the internal construction of the coil.

3.2. A second and less predictable voltage difference between turns can be caused by transients. Additional information on the nature of such transients and the associated turn voltage distribution may be found in a number of articles cited in the Bibliography. Steep-front waves due to arcing in the associated circuit can be damaging to turn insulation since a substantial portion of the wave can appear across the turn insulation of the coils near the line terminals.

The voltage difference that turn insulation must withstand, therefore, covers a broad range from less than 100 V in normal operation to as much as several thousand volts under transient conditions. At the one end of this range, all that is needed is physical separation; whereas at the other, insulation having considerable dielectric strength is desirable.

4. Suggested Test Devices

4.1. Individual form-wound multiturn coils have a low series impedance at power frequencies, particularly so prior to insertion in the stator core. Because of this, connection across the leads of any power-frequency test source of adequate voltage to test the insulation will result in high current. This, of course, will also be the case with dc and very-low frequency sources. Therefore, to apply a voltage of reasonable magnitude across the coil leads without excessive current, a test voltage having an equivalent frequency several orders of magnitude above power frequency would be desirable (examples are given in Appendix A, A1.2).

4.2. A suitable testing device should provide voltage control, accurate indication of voltage level, and a means of detecting turn-to-turn insulation failure. A single-stage “Marx” generator with a storage oscilloscope is an example of such a device. A schematic diagram of the generator is given in the Appendix. Both conduction- and induction-type testing devices have been developed and applied satisfactorily. In either type, a steep-front voltage wave is applied to the test coil. In each cycle, a capacitor is charged to an appropriate voltage, then discharged by means of a suitable switch (such as a spark gap, thyratron, or a solid-state device) into a circuit that includes the test coil. Voltage and current then oscillate at the natural frequency of the circuit.

4.2.1. In conduction-type devices, the test voltage is applied directly to the coil leads. Failure detection is by visual inspection of either test voltage or current on a cathode-ray oscilloscope. Coils may be tested singly, or two nominally similar coils may be tested simultaneously, thereby facilitating comparison of the wave shape. In testing a single coil, the wave shape at a sufficiently low voltage should be recorded and used to compare with wave shapes at high voltages. A significant difference, approximately 10% or more, in magnitude or frequency of the waves indicates probable insulation failure.

[1]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

4.2.2. In induction-type devices, the test voltage is induced in the coil under test, which constitutes the secondary of the transformer, the primary of which is excited by a steep-front wave from the capacitor. Failure is indicated by dissymmetry of either current in the test coil or voltage at its terminals. See Fig A3 in Appendix A.

5. Test Sequence

5.1. Coils can be tested at one or more of the following steps of manufacture:

(1) Prior to insertion into the stator core. This is appropriate when the coils are to be installed at a location remote from the coil-manufacturing plant. If the coils have too low an impedance in air, they may be assembled into a simulated core for testing purposes. Each coil should be tested.

(2) After assembly into the stator core, after wedging and bracing of the end turns, but before insulating the series connections and before connecting between phase groups. Again, each coil should be tested.

(3) After connecting into phase groups, but before insulating the series connections and before connecting between phase groups.

(4) After all connections are made and the insulation is applied. All maintenance tests are normally made under such conditions. If the test voltage is applied at the machine terminals, the electrical impulse voltage level should be selected so as to avoid overstressing ground insulation. In this case, the test may disclose only existing short circuits and not incipient weaknesses of the turn insulation. Otherwise, the test voltage can be induced into the stator coils by means of a surge-inducing coil. The test method given in Appendix A will stress incipient weaknesses and may cause them to fail.

(5) Extra coils (if specified in agreement between the manufacturer and the user) that are not used in winding the machine can be tested to destruction to determine the turn-to-turn capability of the electrical insulation system design.

5.2. The ambient conditions should be acceptable for insulation testing. Prior to turn-to-turn testing, the insulation resistance should be tested in accordance with IEEE Std 43-1974 [1].[2] The insulation surface should be clean and dry. The coil temperature should be at least a few degrees above the dew point, as a minimum, to avoid condensation of moisture on the coil insulation. The turn-to-turn testing should not proceed until the insulation resistance tests have been conducted successfully.

6. High-Frequency Test Levels for New Coils

6.1. The minimum turn-to-turn test voltage should be no less than 350 V peak, which is the minimum sparking voltage for a uniform field in air (Paschen's Law) (see [B7]). Beyond this, no generally accepted approach to the selection of turn-to-turn test voltage has evolved. Manufacturers have used coil and machine design parameters, such as size and weight of coil, length of turn, arrangement of turns within the coil, operating volts per turn or per coil, system voltage, inter-turn and turn-to-ground capacitance, and others, to determine turn-voltage test levels for their products. These procedures have not been described explicitly in the literature, and it is not feasible to describe them here. Agreement should be reached between the manufacturer and the user as to what testing technique and level should be applied to the machine coils and at what stage of manufacture the tests should be run.

[2]The numbers in brackets correspond to those of the references in 2.2. When preceded by the letter B, they correspond to those of the Bibliography in Section 8.

6.2. Whatever test technique is used, it is suggested that for testing the turn insulation, impulses with fast rise time 0.1 µs (with a tolerance of –0.0 µs and +0.1 µs) should be used. In general the coils should have sufficient groundwall and turn insulation to withstand an electrical impulse voltage within the envelope defined in Fig 1.

$$V_1 = (\sqrt{2}/\sqrt{3})V_L = 1 \text{ per unit (pu) at front rise time } 0.0\ \mu s \quad \text{(Eq 1)}$$

$$V_2 = 3.5 \text{ pu at front rise time } 0.1\ \mu s \quad \text{(Eq 2)}$$

$$V_3 = 5 \text{ pu at front rise time } \geq 1.2\ \mu s \quad \text{(Eq 3)}$$

where

V_n (n = 1, 2, 3) = Momentary peak electrical impulse capability across the coil.

V_L = Rated rms line-to-line voltage in kV.

6.3. The rise time of applied impulses should be between 0.1 and 0.2 µs.

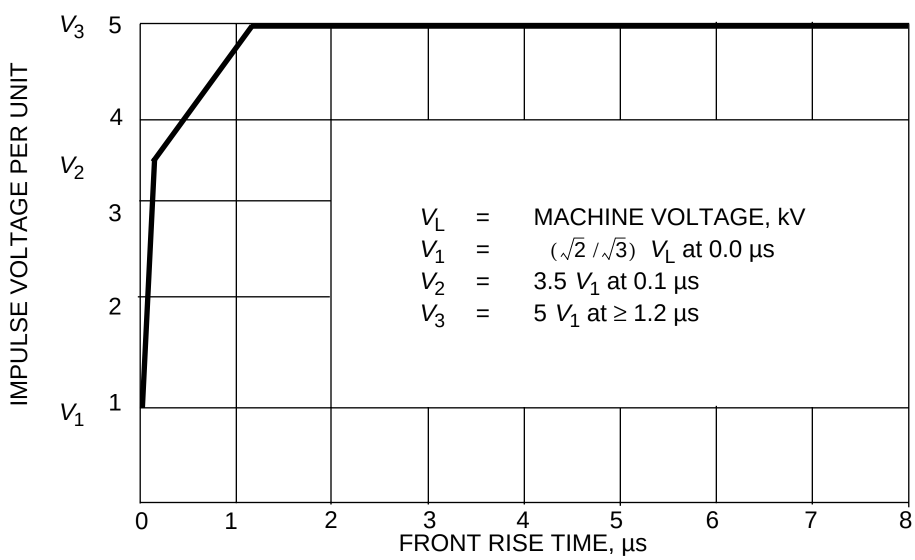


Fig 1
Coil Electrical Impulse Withstand Envelope

6.4. In the event that the machine is likely to be subjected to voltage surges during its service life and protective devices are not used as mentioned in 1.2, turn insulation having higher-than-normal electric strength may be used in the coils. In this case, the turn-to-turn test voltage may be appropriately adjusted upwards.

6.5. If agreed between the manufacturer and the user, the impulse withstand envelope given in Fig 2 (from [B20]) may be used for testing coils designed for machines that are not likely to see high-magnitude fast-fronted surges.

6.6. For unimpregnated or green coils, the test voltage may be 60–80% of the value specified in 6.2. or 6.5., as agreed between the manufacturer and the user.

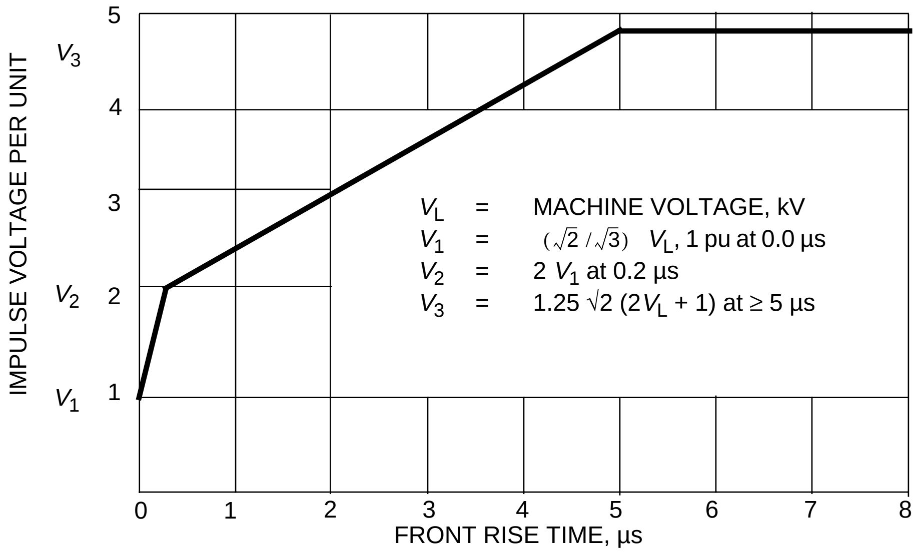


Fig 2
Alternative Coil Impulse Voltage Withstand Envelope

7. Maintenance Tests or Tests After Installation of Machines

7.1. Turn-to-turn voltage for tests made in the field is suggested to be approximately 75% of V_n as defined in Section 6. It is good practice to obtain approval from the manufacturer of the coils on any test program.

7.2. In many cases, particularly in maintenance testing, it is desirable to make the test with a minimum of disassembly of the machine (for example, with the rotor in place). In the case of salient-pole synchronous machines, this can sometimes be done by removing a single pole and field-coil assembly and rotating the rotor and testing fixtures. For nonsalient pole machines, the rotor may have to be removed.

7.3. The test may be performed using a surge-inducing coil (Appendix A) to apply the test voltage to the coil under test. The degree of coupling that can be achieved by this method varies rather widely, and in some cases it may not be possible to reach the 75% voltage level in the coils being tested. Therefore, the 75% figure should be considered a general guideline.

7.4. Other methods of detecting turn-insulation failures and means of minimizing damage due to faults are included in the Bibliography ([B4], [B16], [B27], [B30], [B44], [B46], [B49], and [B51]).

8. Bibliography

[B1] Acosta, J. and Cornick, K. J., "Field investigations into the factors governing the severity of prestriking transients," *IEEE Transactions on Energy Conversion,* EC-2, no. 4, pp. 638–645, Dec. 1987.

[B2] Bacvarov, D. C. and Sharma, D. K., "Risk of winding insulation breakdown in large ac motors caused by steep switching surges, part I: computed switching surges, and part II: probabilistic risk assessment," *IEEE Transactions on Energy Conversion*, EC-1, pp. 130–152, Mar. 1986.

[B3] Baltensperger, P. and Meyer, H., "Overvoltages resulting from the disconnection of high voltage motors," *Brown Boveri Rev*iew, vol. 40, no. 9, pp. 342–350, 1953.

[B4] Chowdhuri, P., "Fault detection in three-phase rotating machines," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-91, pp. 160–167, Jan./Feb. 1972.

[B5] Christiansen, K. A. and Pedersen, A., "An experimental study of impulse voltage phenomena in a large ac motor," IEEE Publication 68C6-E1-87, pp. 148–150, 1968.

[B6] Cornick, K. J. and Thompson, T. R., "Steep-fronted switching voltage transients and their distribution in motor windings, part I: system measurements of steep-fronted switching voltage transients, part II: distribution of steep-fronted switching voltage transients in motor windings," *Proceedings of the IEE,* part B, pp. 45–63, Mar. 1982.

[B7] Dakin, T. W. and Berg, D., "Progress in dielectrics," *Theory of Gas Breakdowns*, vol. 4, Academic Press, pp. 167–168, 1962.

[B8] Dick, E. P., Gupta, B. K., Pillai, P., Narang, A., and Sharma, D. K., "Equivalent circuits for simulating switching surges at motor terminals," *IEEE Transactions on Energy Conversion*, EC-3, no. 3, pp. 696–704, Sept. 1988.

[B9] Dick, E. P., Gupta, B. K., Pillai, P., Narang, A., and Sharma, D. K., "Practical calculations of switching surges at motor terminals," *IEEE Transactions on Energy Conversion,* EC-3, no. 4, pp. 864–872, Dec. 1988.

[B10] Dick, E. P, Gupta, B. K., Pillai, P., Narang, A., Lauber, T. S., and Sharma, D. K., "Prestriking voltages associated with motor breaker closing," *IEEE Transactions on Energy Conversion*, EC-3, no. 4, pp. 855–863, Dec. 1988.

[B11] Electricity Supply Industry, "Testing the insulation systems of stator coils for rotating electrical machines," ESI Std 44-5, Issue 3, Sept. 1982.

[B12] Foust, C. M. and Rohats, N., "Insulation testing of electrical windings," *Transactions of the AIEE*, vol. 62, pp. 203–206, 1943.

[B13] Greenwood, A. and Glinkowski, M., "Voltage escalation in vacuum switching operations," *IEEE Transactions on Power Delivery*, PWRD vol. 3, no. 4, pp. 1698–1706, Oct. 1988.

[B14] Gupta, B. K., Lloyd, B. A., Dick, E. P., Narang, A., Greenwood, A. N., and Sharma, D. K., "Switching surges at large ac motors," Paper 11-07, 1988 Session of CIGRE, International Conference on Large High Voltage Electric Systems, Paris, France.

[B15] Gupta, B .K., Lloyd, B. A., Stone, G. C., Campbell, S. R., Sharma, D. K., and Nilsson, N. E., "Turn insulation capability of large ac motors, part 1-surge monitoring," *IEEE Transactions on Energy Conversion*, EC-2, no.4, pp. 658–665, Dec. 1987.

[B16] Gupta, B. K., Lloyd, B. A., Stone, G. C., Sharma, D. K., and Fitzgerald, J. P., "Turn insulation capability of large ac motors, part 2—impulse strength," *IEEE Transsctions on Energy Conversion*, EC-2, No. 4, pp. 666–673, Dec. 1987.

[B17] Gupta, B. K., Lloyd, B. A., Stone, G. C., Sharma, D. K., Nilsson, N. E., and Fitzgerald, J. P., "Turn insulation capability of large ac motors, part 3—insulation coordination," *IEEE Transactions on Energy Conversion*, EC-2, no.4, pp. 674–679, Dec. 1987.

[B18] Heller, B. and Veverka, A., "Surge phenomena in electrical machines," London, England: Iliffe Books, Ltd., 1968.

[B19] "Impulse testing of rotating a-c machines," AIEE Committee Report, *AIEE Transactions*, vol. 79, part III, pp. 182–188, 1960.

[B20] "Impulse voltage strength of ac rotating machines," IEEE Working Group Report, *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-100, pp. 4041–4053, 1981.

[B21] International Electrotechnical Commission, Document 2 (Secretariat) 658, Dec. 1984.

[B22] Jackson, D. W., "Surge protection of rotating machines," Chapter 8 of IEEE Course on Surges, IEEE Publication No. 79E0144-6-PWR, 1978.

[B23] Jackson, D. W., "Survey of failures of surge protective capacitors and arresters on ac rotating machines," Report by Working Group 3.4.9 of Surge Protective Devices Committee, *IEEE Transactions on Power Delivery*, PWRD vol. 4, no. 3, pp. 1725–1730, July 1989.

[B24] Kaufmann, R. H., "Recommendations for surge voltage protection of motors in industrial power systems," *Industrial Power Systems*, vol. 9, no. 2, pp. 4–6, June 1966.

[B25] Koutsoukas, A., "A re-evaluation of motor insulation surge withstand capability," Presented at Edison Electric Institute, ESE Committee, San Diego, CA, Feb. 15, 1983.

[B26] Koutsoukos, A. and Hadad, S. Z., "Vacuum circuit breaker and motor insulation surge withstand," Presented at American Power Conference, April 24–26, 1984.

[B27] Krankel, D. and Schuler, R. A., "Method for checking the turn insulation of form wound coil windings for high-voltage rotating machines," *Brown Boveri Review*, vol. 57, no. 4, pp. 191–196, 1970.

[B28] Laforte, J. T., McCoy, R. M. and Sharma, D. K., "Impulse voltage capability of rotating machine insulation as determined from model specimens," *IEEE Transactions on Energy Conversion*, EC-3, no. 1, pp. 149–157, Mar. 1988.

[B29] McLaren, P. G. and Abdel-Rahman, M. H., "Steep-fronted surges applied to large ac motors—effect of surge capacitor value and lead length," *IEEE Transactions on Power Delivery*, PWRD-3, pp. 990–997, July 1988.

[B30] Moses, G. L, and Harter, E. F., "Winding-fault detection and location by surge comparison testing," *Transactions of the AIEE*, vol. 64, pp. 499–503, 1945.

[B31] Musil, R. J., Wenger, S., and Scherer, K., "Practical considerations concerning impulse voltage testing of formwound coils for rotating machines," *IEEE Transactions on Energy Conversion*, EC-3, pp. 111–115, Mar. 1988.

[B32] Narang, A., Gupta, B. K., Dick, E. P., and Sharma, D. K., "Measurement and analysis of surge distribution in motor stator windings," *IEEE Transactions on Energy Conversion*, EC-4, no. 1, pp. 126–134, Mar. 1989.

[B33] Nassar, O. M., "Effect of surge wave reflection inside a motor on voltage distribution across stator windings," *IEEE Transaction on Power Apparatus and Systems*, PAS-104, no. 4, pp. 882–889, April 1985.

[B34] Nassar, O. M., "Effects of system parameters and circuit breaker characteristics on large synchronous motors," *IEEE Transaction on Energy Conversion*, EC-3, no. 1, pp. 95–101, Mar. 1988.

[B35] Nassar, O. M., "Motor insulation degradation due to switching surges and surge protection requirements," *IEEE Transactions on Energy Conversion*, EC-1, no. 3, pp. 182–189, Sept. 1986.

[B36] Nassar, O. M., "The use of partial discharge testing in the evaluation of interturn insulation failure of large motors," *IEEE Transactions on Energy Conversion*, EC-2, no. 4, pp. 615–621, Dec. 1987.

[B37] Oil Companies Materials Association (OCMA), Specification No. Elec. 1, "Three-phase induction Motors," July 1981.

[B38] Oliver, J. A., Woodson, H. H., and Johnson, J. S., "A turn insulation test for stator coils," *IEEE Transactions on Power Apparatus and Systems*, PAS-87, no. 3, pp. 669–678, 1968.

[B39] Petrov, G. N. and Abramov, A. I., "Impulse voltages between turns in the windings of electric machines under surge conditions," *Elektrichestvo*, no. 7, pp. 24–31, 1954.

[B40] Reckleff, J. G., Nelson, J. K., Musil, R. J., and Wenger, S., "Characterization of fast rise-time transients when energizing large 13.2 kV motors," *IEEE Transactions on Power Delivery*, PWRD-3, pp. 627–636, April 1988.

[B41] Rhudy, R. G., Owen, E. L., and Sharma, D. K., "Voltage distribution among the coils and turns of a form wound ac rotating machine exposed to impulse voltage," *IEEE Transactions on Energy Conversion*, EC-1, pp. 50–60. June 1986.

[B42] Rudge, W. J. Jr., Hunter, E. M., and Wieseman, R. W., "Protection of rotating ac machines against travelling wave voltages," *General Electric Review*, Feb./Mar. 1938.

[B43] Rudge, W. J., Jr., Wieseman, R. W., and Lewis, W. W., "Protection of rotating ac machines against travelling wave voltages due to lightning," *Transactions of the AIEE*, 1938.

[B44] Rylander, J. L., "High frequency voltage test for insulation of rotating electrical apparatus," *Transactions of the AIEE*, vol. 45, pp. 459–465, 1962.

[B45] Sexton, R. M., "A survey of turn insulation on large ac motors," Proc. 1967 Seventh Electrical Insulation Conference, IEEE Publication 32C79, pp. 71–73.

[B46] Sexton, R. M. and Alke, R. J., "Detection of turn-to-turn faults in large high-voltage turbine generators," *Transactions of the AIEE*, vol. 70, pt 1, pp. 270–274, 1951.

[B47] Shankle, D. F., Edwards, R. F., and Moses, G. L., "Surge protection for pipeline motors," *IEEE Transactions on Industry and General Applications*, IGA-4, no. 2, pp. 171–176, 1968.

[B48] Sills, H. R. and McKeever, J. L., "Characteristics of split-phase currents as a source of generator protection," *AIEE Transactions* (Power Apparatus and Systems), vol. 72, pp. 1005–1014, Oct. 1953.

[B49] Simmons, E., "Turn testing of rotating machinery," *Double Client Conference*, Jan. 1964.

[B50] Tempelaar, H. G., "Determination of transient overvoltages caused by switching of high voltage motors," *IEEE Transactions on Energy Conversion*, EC-3, no. 4, pp. 806–814, Dec. 1988.

[B51] "Turn insulation capability of large ac motors," EPRI Project RP 2307-1, Final Report, EPRI EL-5862, vol. 1 and 2, July 1988.

[B52] Wellaner, M. A., "New arrangement for testing the insulation of the turns of machine coils," *Bulletin Oerlikon*, vol. 251, pp. 1624–1626, 1944.

[B53] Wright, M. T., Yang, S. J., and McLeay, K., "General theory of fast-fronted interturn voltage distribution in electrical machine windings," *Proceedings of the IEE*, vol. 130, pt. B., no. 4, pp. 245–256, July 1983.

[B54] Wright, M. T., Yang, S. J., and McLeay, K., "The influence of coil and surge parameters on transient interturn voltage distribution in stator windings," *Proceedings of the IEE*, vol. 130, pt. B, no. 4, pp. 257–264, July 1983.

Appendixes

(These appendixes are not part of IEEE Std 522-1992, IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines, but are included for information only.)

Appendix A
Test Procedures and Methods

A1. Method for Applying Surge Tests to Complete Windings

A1.1 General. The arrangement of the surge-inducing coil and laminated-iron sections in the bore of the machine is shown in Fig A1. The voltage waveform is measured with a one-turn search coil placed in the laminated-iron sections. The search-coil voltage is observed on an oscilloscope through a resistive voltage divider. A consistent pattern for both short-circuited and normal coils is obtained regardless of the electrical position of the coil in the winding since the search coil is affected only to the extent of the reduction of flux resulting from a short-circuited coil. A short-circuited coil generally shows a reduction of the peak amplitude of the wave in the order of 20% when compared to the normal coil. There is also a very slight increase in frequency of the short-circuited-coil waveform, but this is not always sufficiently great to use as a test criterion. It is necessary to utilize wire with multiple, fine, insulated strands in the surge-inducing coil to obtain minimum impedance. One hundred strands of enameled wire, 0.010 in (0.25 mm) diameter, have proven satisfactory for this purpose. It is suggested that the surge-inducing and search coils be insulated to ground for the maximum voltage to appear in each coil. It will be necessary to remove the machine rotor, or for salient-pole machines a pole on the rotor, to provide space for the coils and laminated-iron sections in the bore area. To assure consistent results, it is good practice to fit the laminated iron sections against the bore with uniform tightness.

A1.2. The test circuit (Fig A2) used consists principally of concentrated inductance (L) (the surge-inducing coil) and capacitance (C), with minimum resistance (R). The frequency of oscillation of the surge voltage can, therefore, be calculated from the formula:

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} \qquad \text{(Eq A1)}$$

which, when the second term under the radical is small compared to the first, reduces to:

$$f_o = \frac{1}{2\pi\sqrt{LC}} \qquad \text{(Eq A2)}$$

For example:

(1) A 200 hp motor tested with a 2-turn surge-inducing coil of 20 μH inductance and a 16 μF capacitor will have an oscillation frequency of 8900 Hz.

(2) A 69 500 kVA hydrogenerator tested with a 2-turn surge-inducing coil of 130 μH inductance and a 2 μF capacitor will have an oscillation frequency of 9800 Hz.

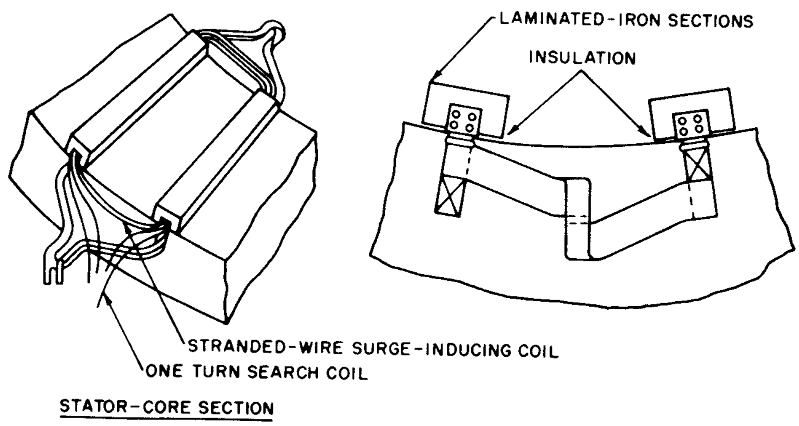


Fig A1
Surge-Inducing Coil

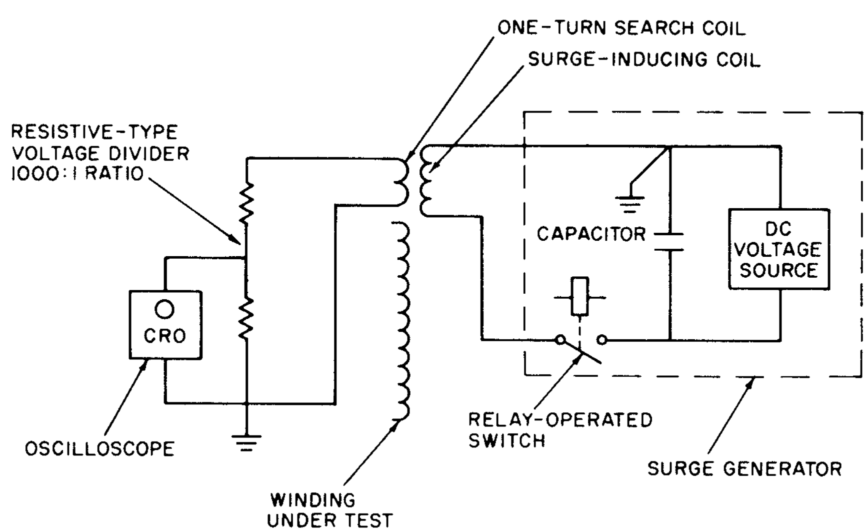


Fig A2
Suggested Arrangement of Test Equipment

A2. A Suggested Test Procedure for Wound Machines

Arrange test equipment as shown in Fig A2, being certain to connect all grounds including the frame of the machine being tested. Do not ground the windings to be tested; consider them as being energized during all testing.

Expose the leads of one stator coil in the winding by removing the insulation at the connection for calibration of the voltage wave (a line coil may be used and then it will be necessary to expose only the other lead of that coil). Place the laminated-iron sections, including the surge-inducing and search coils, in the bore to line up with the slots of the stator coil selected for calibration. The laminated-iron sections should be insulated from the core of the machine being tested with a thin insulating material, such as 0.010 in (0.25 mm) thick adhesive tape, and should be tightly fitted against the machine core. Connect the voltage-divider leads to the stator coil being used for calibration. Apply a small voltage (1000 V) to the surge-inducing coil and observe the voltage wave induced in a stator coil (this should be approximately 75% of the volts-per-turn applied to the surge-inducing coil). When a suitable waveform is established (refer to Fig A3 for the expected pattern of the voltage wave), increase the applied voltage to obtain first-peak-amplitude equivalent to the voltage desired for test. This should be based on a minimum of 350 volts-per-turn peak with maximum voltage of 75% of the coil test voltage specified in Section 6.

To determine the effect of a short-circuited turn, apply a deliberate short circuit across the exposed leads of the stator coil and apply the same voltage level used to obtain the desired volts- per-turn stress. This will establish the criteria for the test of the remaining coils in the winding and the waveforms of the short-circuited and normal coils should be generally proportional to those shown in Fig A3. Proceed to test the winding by moving the laminated-iron sections sequentially so they are positioned over each of the coils in the machine. Record the oscilloscope settings, the voltage level applied to the surge-inducing coil, and the amplitude of the first full peak of the voltage wave observed on the oscilloscope, identifying the top-slot number of each coil as it is tested. Since the waveform observed on an oscilloscope screen for any set of conditions can generally be determined more accurately by repetitive sweeps, perform at least three capacitor discharges to establish the form. The accuracy of this test in determining a short-circuited coil can be ascertained by exposing the leads of a stator coil found to be short-circuited, and retesting it with a deliberate short circuit applied across the leads. There should be no significant change from the waveform obtained during the previous test.

A3. A Suggested Test Procedure for Coils During Winding

This test can be applied to a set of new coils, completely assembled in the slots and with slot wedges in place, by applying the surge directly to the stator coil before insulating the connections. In this arrangement, the voltage-divider leads are connected in parallel with the surge-generator leads to the stator coil. The effect of a short-circuited turn under this test condition will be as indicated in Fig A4. Calibration of the voltage waveform is performed as previously described and the peak voltage is recorded by top-coil-slot number with the voltages applied steps of 0.2, 0.4, 0.6, 0.8, and 1.0 of the peak test voltage. Three impulses should be applied at each level. With the directly applied test technique, a short-circuited stator coil will provide a flat response (Fig A4) to the applied voltage and, therefore, the step voltages are of value in approximating the voltage level at which a short circuit may develop in the stator coil.

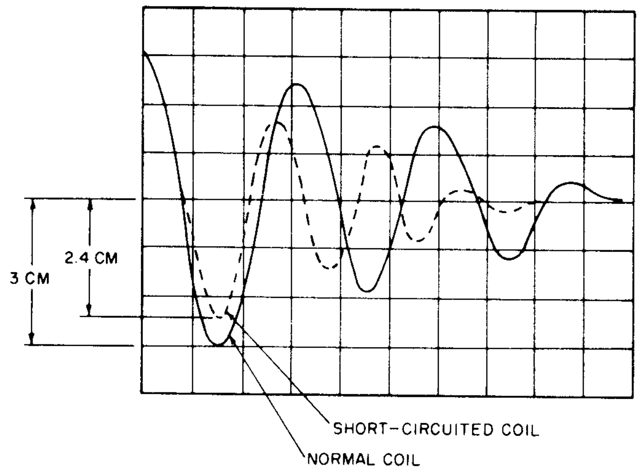


Fig A3
Voltage Waveform for Short-Circuited and Normal Coils Using Induced-Voltage Test Method

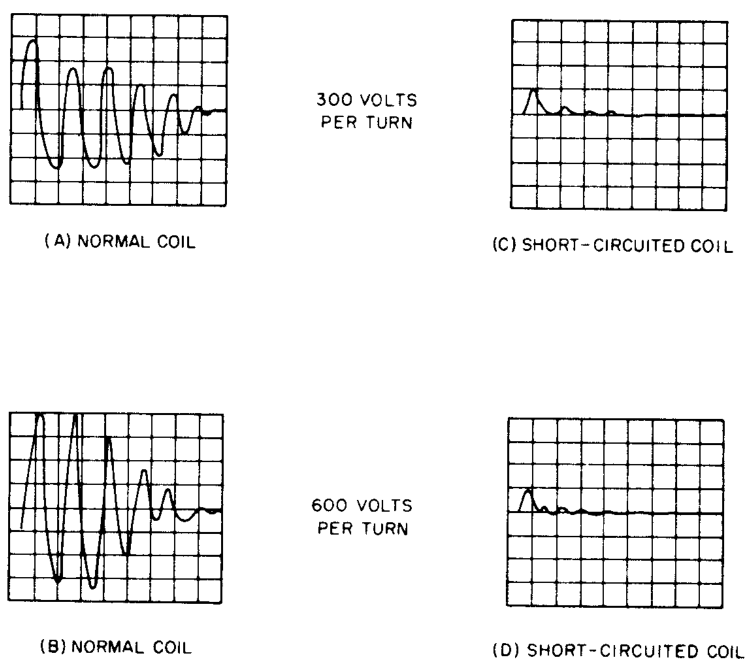
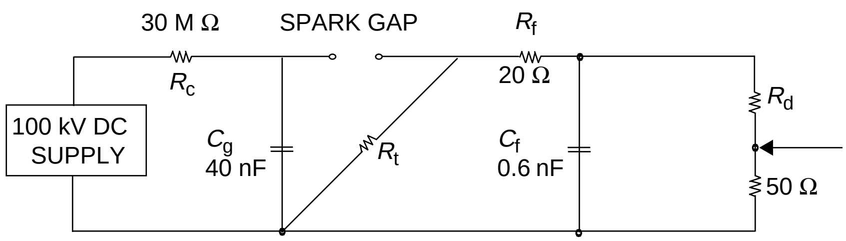


Fig A4
Waveforms of Short-Circuited and Normal Coils Tested Directly Connected, in the Iron

A4. Further Details

For further details concerning this method, such as the design of laminated-iron sections, see [B38].

A5. Marx Generator Circuit



R_c = CHARGING RESISTOR
C_g = GENERATOR STORAGE CAPACITOR
R_t = TAIL RESISTOR
R_f = FRONT RESISTOR
C_f = LOAD CAPACITOR
R_d = RESISTIVE POTENTIAL DIVIDER

Fig A5
Schematic Circuit for Marx Generator

Appendix B
Sample Test Form

Name _______________ Machine S/N _______________ Test No. _______________
Date ________________ Manufacturer ______________ Time __________________

Insulation Resistance Test

1 min ____________ 10 min __________ P.I. _______ Passed: Yes ___ No ___
1 min (40 °C) _______ 10 min (40 °C) _____ Temp. _____ Rel. Hum. ___________
Test Equipment: ____ S/N: ___________ Cal./ Date: _____ Cal. Due: ____________

Electrical Voltage Impulse Test

Coil	Impedance/ Resistance	Impulse Test		Coil	Impedance/ Resistance	Impulse Test		Coil	Impedance/ Resistance	Impulse Test	
		Passed	Failed			Passed	Failed			Passed	Failed

Test Equipment: ________ S/N: ________ Cal. Date: _______ Cal. Due: ________
Test Equipment: ________ S/N: __________ Cal. Date: _______ Cal. Due: ________
Total No. of Coils: _________ Coils Passed: __________ Coils Failed: __________

Extra Coil Destructive Test

1. Test Level (kV): _________ Test Level (PU*): ________ Failure Location: _________
2. Test Level (kV): _________ Test Level (PU*): ________ Failure Location: _________
3. Test Level (kV): _________ Test Level (PU*): ________ Failure Location: _________

Comments: ____
____
____

*per unit