G15B
Intro (1)

17.12 Cycloconverter Method of Speed Control

The cycloconverter method of controlling speed relies on the ability of the converter to accept current from the switchboard at constant frequency and voltage. The controller also passes this current to the a.c. motor at a reduced frequency, with its voltage adjusted. The cycloconverter is different; it operates without an intermediate d.c. stage in the conversion.

The fixed-frequency supply from the a.c. generators simultaneously goes to the three pairs of thyristor bridges of the cycloconverter (Refer Figure 17.11). The upper and lower bridges of each pair are arranged to operate alternately so that a number of triggering pulses develop in the top set of thyristors - followed by an equal number from the bottom set, to deliver an output with a lower frequency (Refer Figure 17.12). The two bridges for each phase are required to supply both the positive and negative half-cycles.

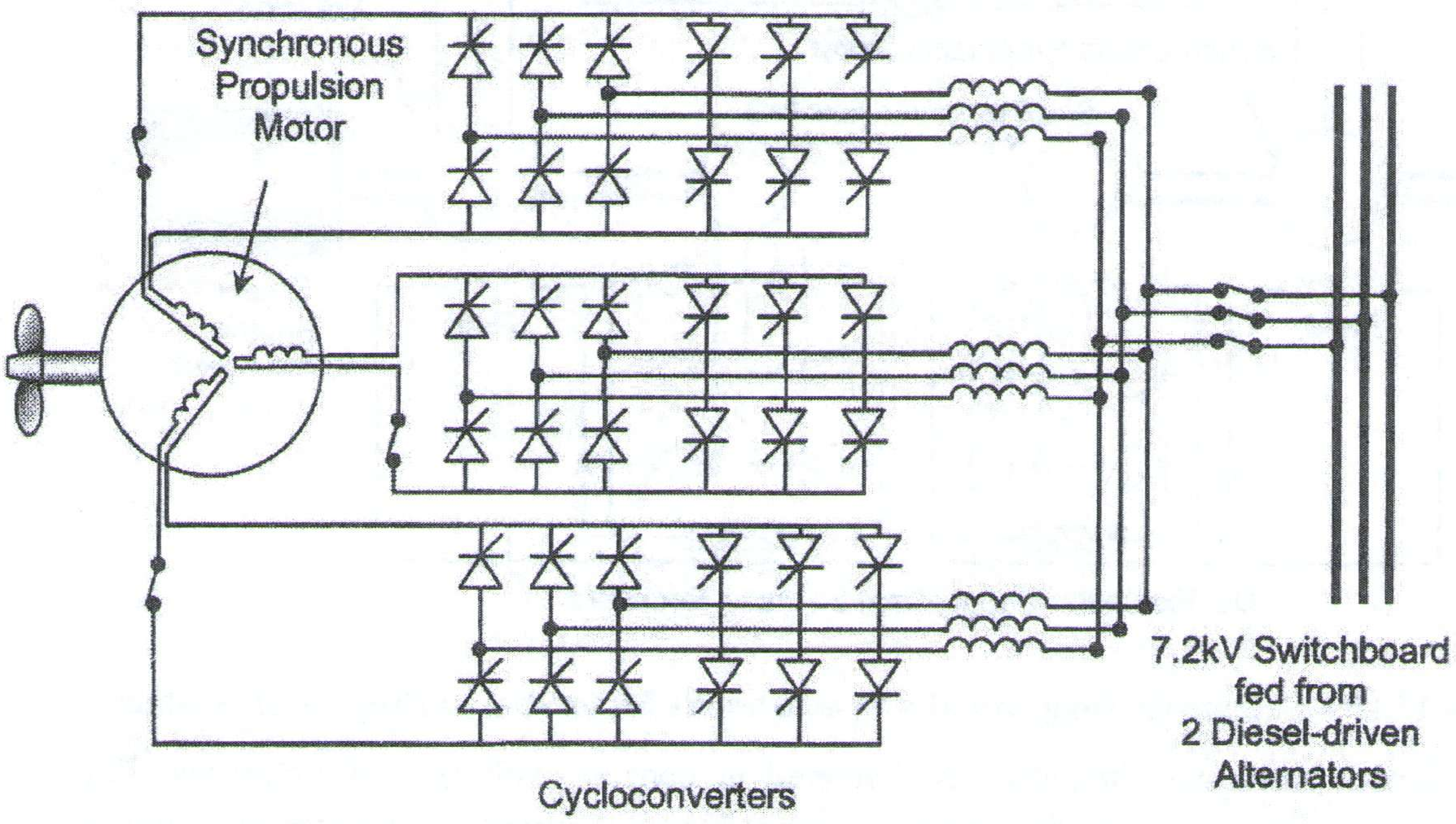


Figure 17.11 – Schematic Diagram of a Cycloconverter-based Propulsion System

The frequency pattern is shown very simply to illustrate the principle. There is greater variation in reality, because the triggering of the thyristors is continually changed relative to the three-phase supply so that the output can be customised to provide the exact frequency and amplitude of the voltage required. Frequency is variable from 0 to 60 Hz.

G15B Intro 2

17.11 Fixed-Speed Alternators with Variable-Speed Synchronous Motors

The potential for using static electronic equipment to convert an electrical supply can be seen from the description of an a.c. drive for a d.c. propulsion motor in this chapter. Static frequency converters are used in a number of ship's installations as the controlling intermediary between fixed-speed alternators and variable-speed synchronous propulsion motors (Refer Figure 17.10).

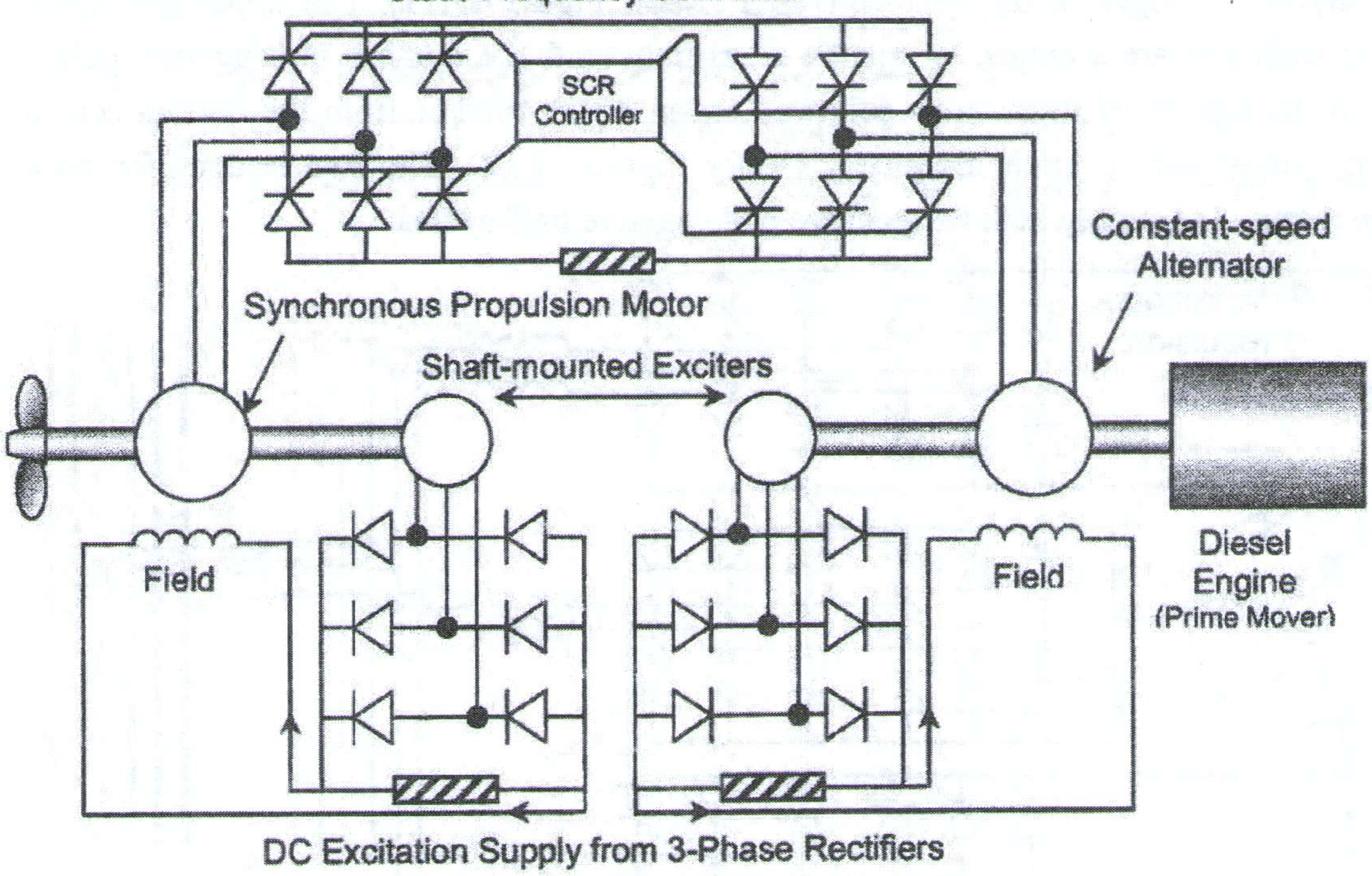


Figure 17.10 – Schematic Diagram of a Synchronous Motor-based Propulsion System

The output from the alternators is delivered at constant voltage and frequency. For manoeuvring or slow speeds, the output is passed on to propulsion motors at a lower frequency and with its voltage adjusted. The speed of a synchronous motor is governed by the frequency of the current supplied. Many synchronous drives are based on conversion of the output (from fixed-speed alternators), first to direct current and then back to a.c. at a lower frequency (the opposite of the converter scheme for variable-speed shaft generators). The vessel, when operating at full speed, will receive power at normal frequency and voltage straight from the switchboard.

G1E6 Intro 3

The one-line diagram identifies the main feeder and branch circuits which will be explained later on in this chapter. Major loads and controls are also identified. This provides an overview of the main electrical system. This information, although useful in certain applications, falls short of revealing the complete picture.

1.9.2 Block Diagram

A block diagram shows in simplified form, the main inter-relationships of the elements in a system, and how the system works or may be operated. Such diagrams are often used to depict control systems and other complex relationships (Refer Figure 1.9). These diagrams state the function of each block but usually give no information of the components therein, or how the blocks are interconnected.

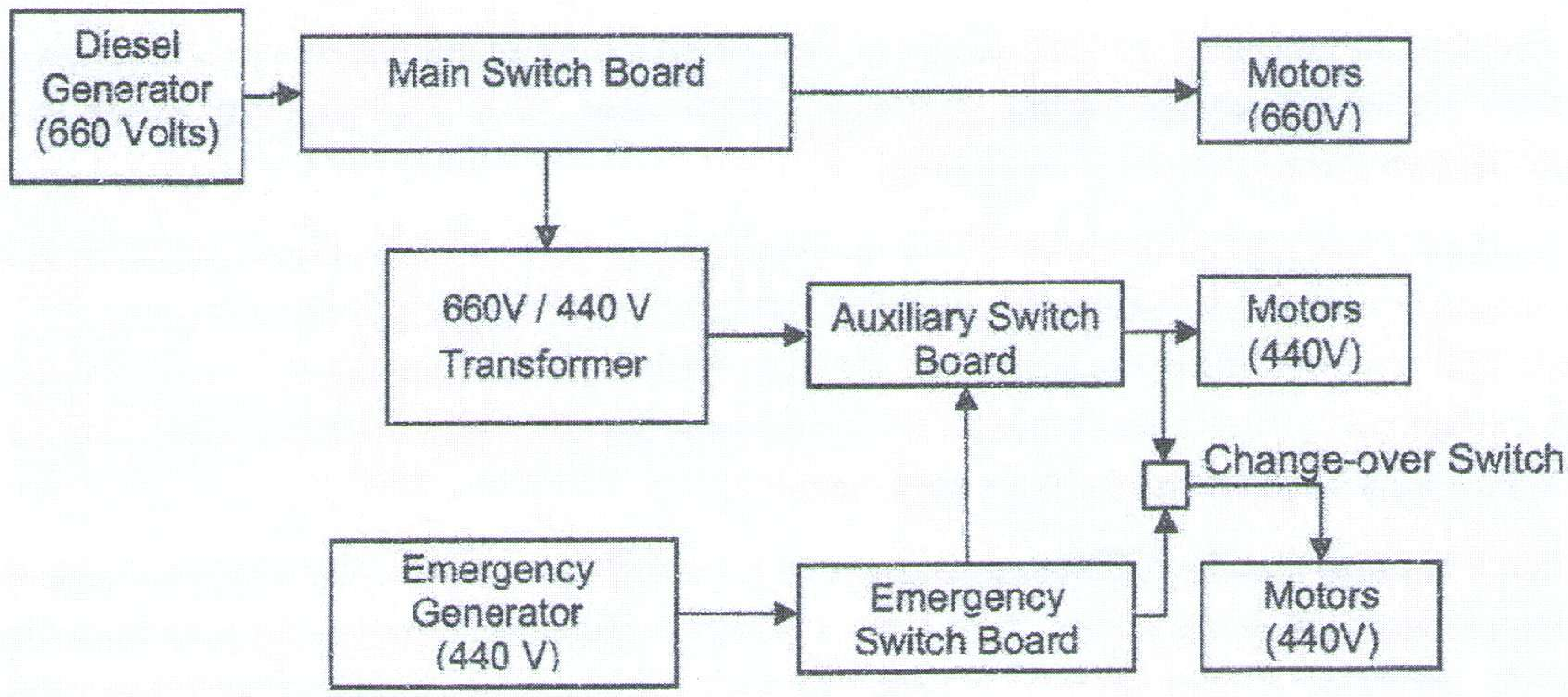


Figure 1.9 - Block Diagram of a Ship's Electrical System

1.9.3 System Diagram

A system diagram shows the main features of a system and its bounds, without necessarily showing cause-to-effect. Its main use is to illustrate the ways of operating the system. Detail is omitted in order to make the diagram as clear as possible, and so easily understood (Refer Figure 1.10).

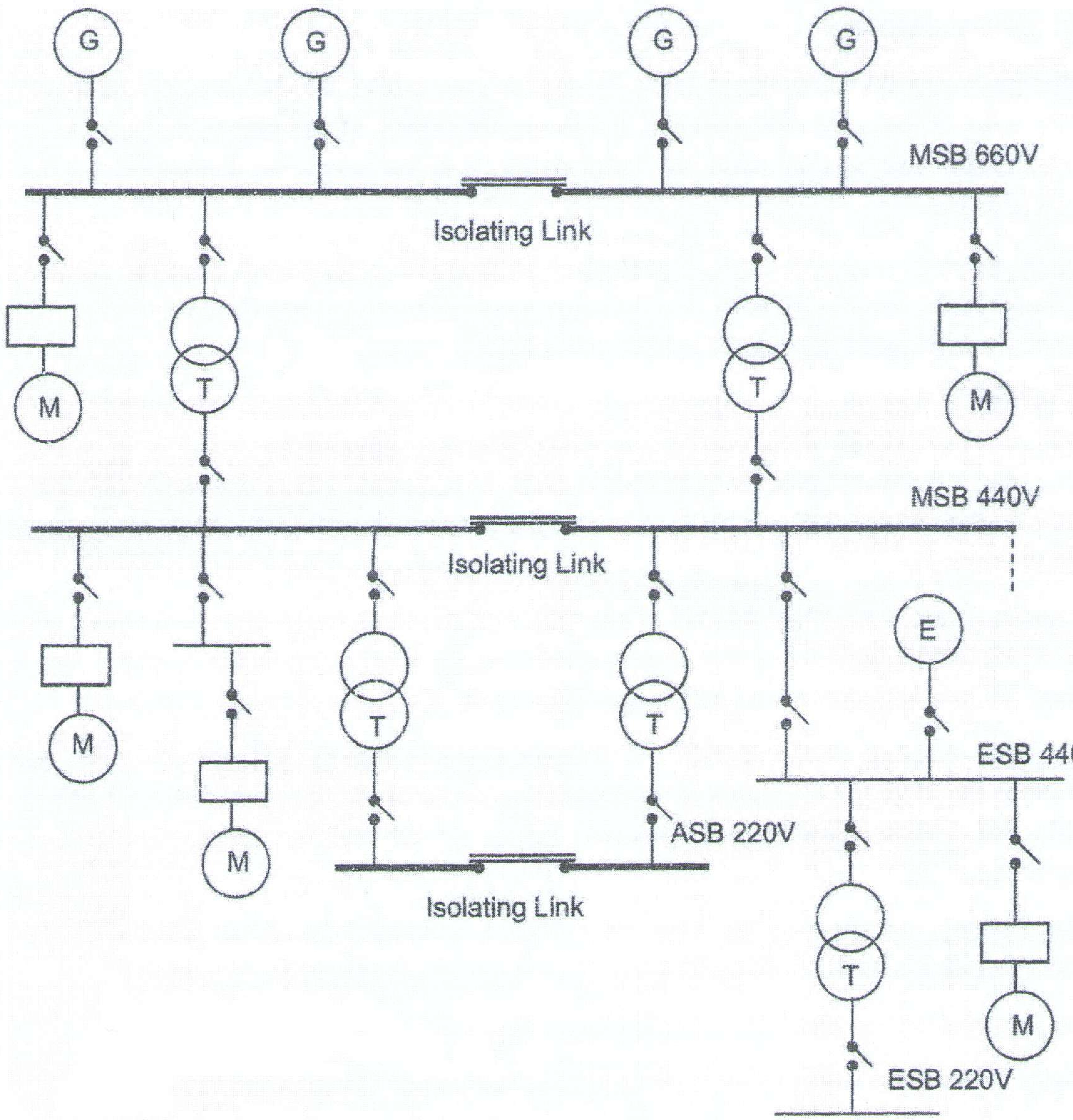


Figure 1.10 – A Typical Electrical System Diagram

G158(1) G158 1

Proc. of the 5th WSEAS/IASME Int. Conf. on Electric Power Systems, High Voltages, Electric Machines, Tenerife, Spain, December 16-18, 2005 (pp136-142)

Performance testing of high voltage generator- and motor insulation systems

RUBEN VOGELSANG
ABB Switzerland Ltd., High Voltage Products*
Brown Boveri-Str. 5, 8050 Zurich, SWITZERLAND

BERNHARD FRUTH, OLIVER DUCRY
PD Tech Power Engineering AG
Seestrasse 14b, 5432 Neuenhof, SWITZERLAND

Abstract: - High voltage rotating machines remain to play a significant role in generating electrical energy. One of the main causes for down times of these machines is related to problems in the winding insulation. The deregulated energy market leads to cost pressure on the producers of the insulations and the utilities. While manufacturers built insulations with increased electric field, utilities want to reduce costs through longer maintenance intervals and a higher lifetime of the machines. Improvements of insulations and a long failure-free lifetime can only be achieved when a complex mix of measures is applied. This paper describes a mix of techniques that are all suited to achieve a long lifetime of the insulations. Among them is a new method that allows testing of manufacturing quality of the insulation with only few material efforts, visual inspections, the measurement of loss factor and PD measurements.

Key-Words: - Winding, Insulation, Generator, Motor, Partial discharges, Lifetime, Aeging, Treeing, Monitoring

1 Introduction

Owners of electrical machines expect a high reliability and a long lifetime of its equipment. This can only be achieved by a consistent quality assurance throughout the whole product life cycle on both, the product- and process level. The product level includes design, the raw materials itself and its combination to the final insulation system. The process level includes research and development, production, quality, in-factory testing, commissioning as well as on- and off-line testing in service.

Winding insulations for high voltage rotating machines consists of three basic components, which is mica that is resistant against partial discharges and tree growth, a support material that gives mechanical strength and a binder resin that fills voids between the mica and the support material. The single components are produced as tapes that are wrapped around the conductor to form the insulation [1, 2]. In order to avoid air inclusions, the latter between the mica tapes are filled with binder resin (bitumen in older insulations). For this purpose, two technologies, resin rich and vacuum pressure impregnation (VPI) are used [1]. After having formed the insulation, the bar is finished with a corona protection for the slot and end winding [1].

Whereas there are some experiences for different raw materials of winding insulations [2–6], the influence of the processing on lifetime has still not been conclusively described. In particular, the influence of different manufacturing qualities and type of manufacturing on the material properties and on time to breakdown is not fully understood [7].

Manufacturers reduce design margins to cut cost and to increase equipment performance. Eventually, the stresses to the insulation systems are increased. Some sources report that more than 30% of motor breakdowns are caused by insulating problems [8–10]. To avoid costs, which are especially high at outages of the power station, testing of the insulations becomes more and more important. Since the insulation system of high voltage rotating machines are of a very complex nature, a high reliability of the machines can only be achieved by applying a complex number of measures.

This paper describes very new and experienced test- and analysis methods, which are all suited to increase lifetime and availability of the insulations. In detail, methods are described for verification of performance of new materials and manufacturing processes as well as diagnosis methods for operating equipment, suited to achieve life extension and/or to reach an early identification of pending problems.

*The work has been carried out during the time at the Swiss Federal Institute of Technology Zurich

2 Verification of performance of new materials

2.1 Standard test method according to IEEE 1043

Current test procedures for electrical insulation systems include electrical, thermal, mechanical and environmental factors as single- sequential- or multifactor load [11, 12]. The test specimens are representative for the bars as used in the machines. They are therefore prepared with outer conductive- and stress grading coating, such as shown in Fig.1.

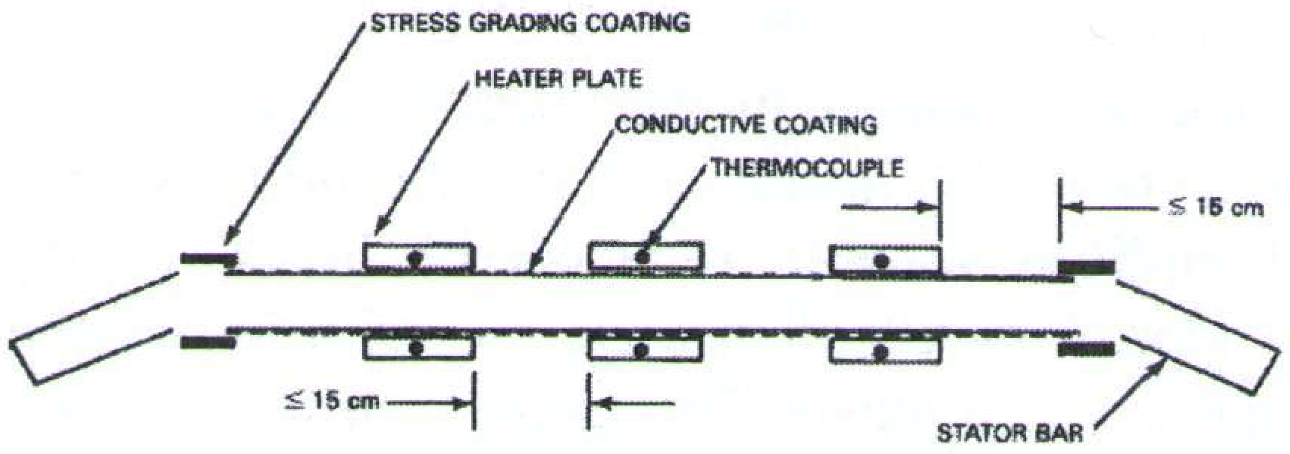


Fig.1: Specification of a test of form wound bars and coils according to IEEE 1043 Std [12]

The advantage of the test is that it is well accepted, it is standardised and covers the whole insulation, including outer- and endwinding protection. It can so far not been replaced when it comes to customer acceptance tests. However, since it requires an insulation bar for each result, much material is needed to achieve an acceptable statistical evaluation, which limitates that test to be used to assess insulation quality in the production process.

2.2 New test with embedded electrode

As seen in Section 2.1, standard ageing tests require much effort. Therefore, newest research results were applied to develop a test method, requiring significantly less material and testing effort [7, 13]. It is based on the result that the main electrical degradation mechanism of winding insulations is electrical tree propagation [7, 13]. In the following, the basic structure, scientific assessment and application of the test method at industrial manufactured winding insulations is described.

2.2.1 Basic structure

When tree growth is the main electrical degradation mechanism, insulation properties can be determined by merely measuring the time interval a tree needs to propagate through the material. In order to determine that value, an arrangement with an embedded electrode was developed that causes tree inception immediately after voltage application. That electrode is a copper sheet of 20 x 20 mm^2, with a thickness of 0.2 mm. It was embedded into the material by the manufacturer of the insulation. The edges of the embedded copper sheet have a radius of < 10 µm. It can therefore be ensured that the tree incepts immediately (< 30 s) after voltage application. Since time interval for tree inception is practically zero, the total measured time to breakdown interval is the time interval for tree propagation through the material. From here on, such tests are therefore referred to as *"Electrical treeing tests"*. A cross section of a winding insulation with embedded electrode is shown in Fig.2, a detailed description of the arrangement is given in [7, 13].

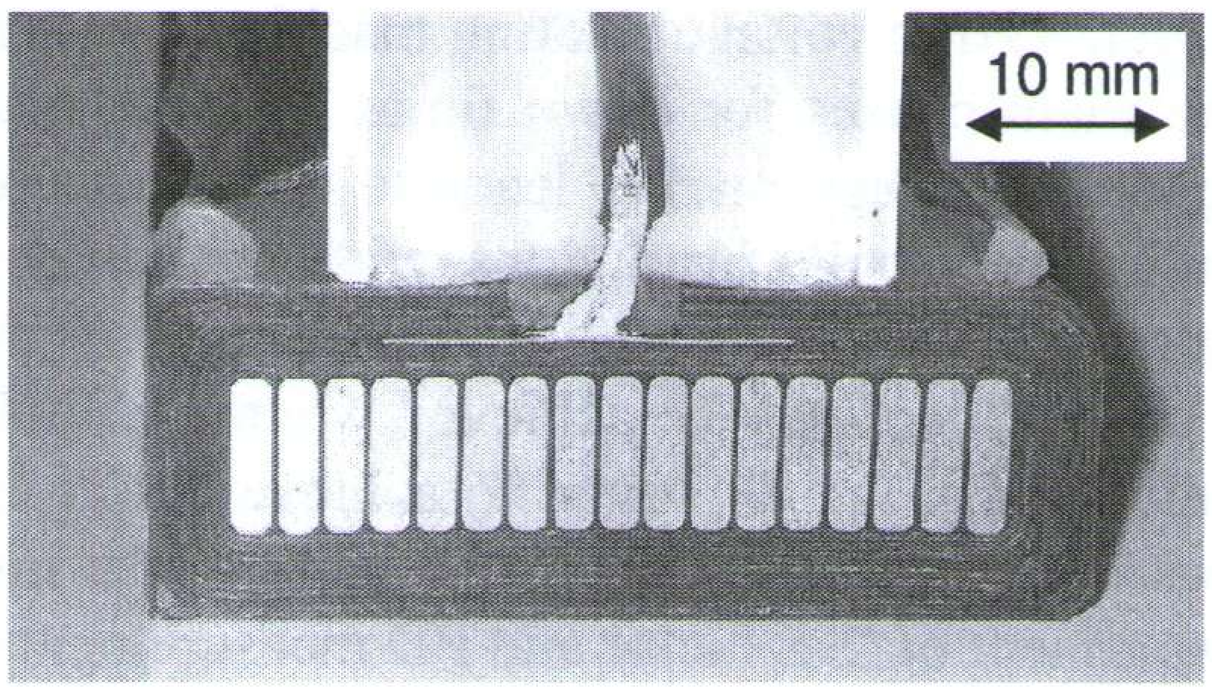


Fig.2: Insulation with the embedded high voltage electrode

In each insulation bar, 4 electrodes were uniformly embedded into the material. Therefore, the main advantages of the arrangement are that much less material is required since fewer bars are needed, a material test is presented since tree propagation through the insulation is measured and that certain regions of the bar can be investigated separately [7].

2.2.2 Similarities and differences to the standard tests, application of the new test method

In order to give a reference to the standard test method, the results of the electrical treeing tests were compared to results with the same type of bars prepared according that as specified in the standards [11, 12, 14]. In the tests with three different insulation systems and constant test conditions, such as the same insulation thickness of 2 mm, the same temperature of 20 ± 5 °C and the same voltage level of 32 kV rms, the results show for all materials that time to breakdown for electrical treeing- and standard tests are not significantly different [7].

Since there are no significantly differences in the results and electrical treeing tests require much less material, they are recommended to extend standard tests for random tests in the production line, determination of residual dielectric strength of bars after service, investigating the tendency of some influencing factors in research laboratories and fingerprint-tests for newly developed material compositions. In addition, they can be used to

G158(37)

Proc. of the 5th WSEAS/IASME Int. Conf. on Electric Power Systems, High Voltages, Electric Machines, Tenerife, Spain, December 16-18, 2005 (pp136-142)

investigate insulation properties at certain regions of the bar to find weak spots of the insulation, such as endwindings, straight sections or conductor edges.

In some cases, such as random tests in the production line, it is impossible to insert the embedded electrode during the wrapping process as described in Section 2.2.1. A method was therefore developed to place the copper sheet in the winding insulation on a completely manufactured bar. In a first step, a gap with a diameter between 10 and 20 mm has to be milled into the insulation. Then, a copper sheet of 0.2 mm thickness must be introduced on the gap surface and attached. In order to avoid surface discharges during the high voltage tests, the gap and the copper sheet must be molded in epoxy resin.

To ensure that the results with this arrangement are representative, tests with subsequent introduced electrodes were carried out and compared to that of treeing tests with a wrapped electrode. Two materials with different time to breakdown values were chosen. Voltage level, temperature and insulation thickness were chosen to be the same as in Section 2.2.2 for both materials. The results are compared in the Weibull-plot in Fig.3.

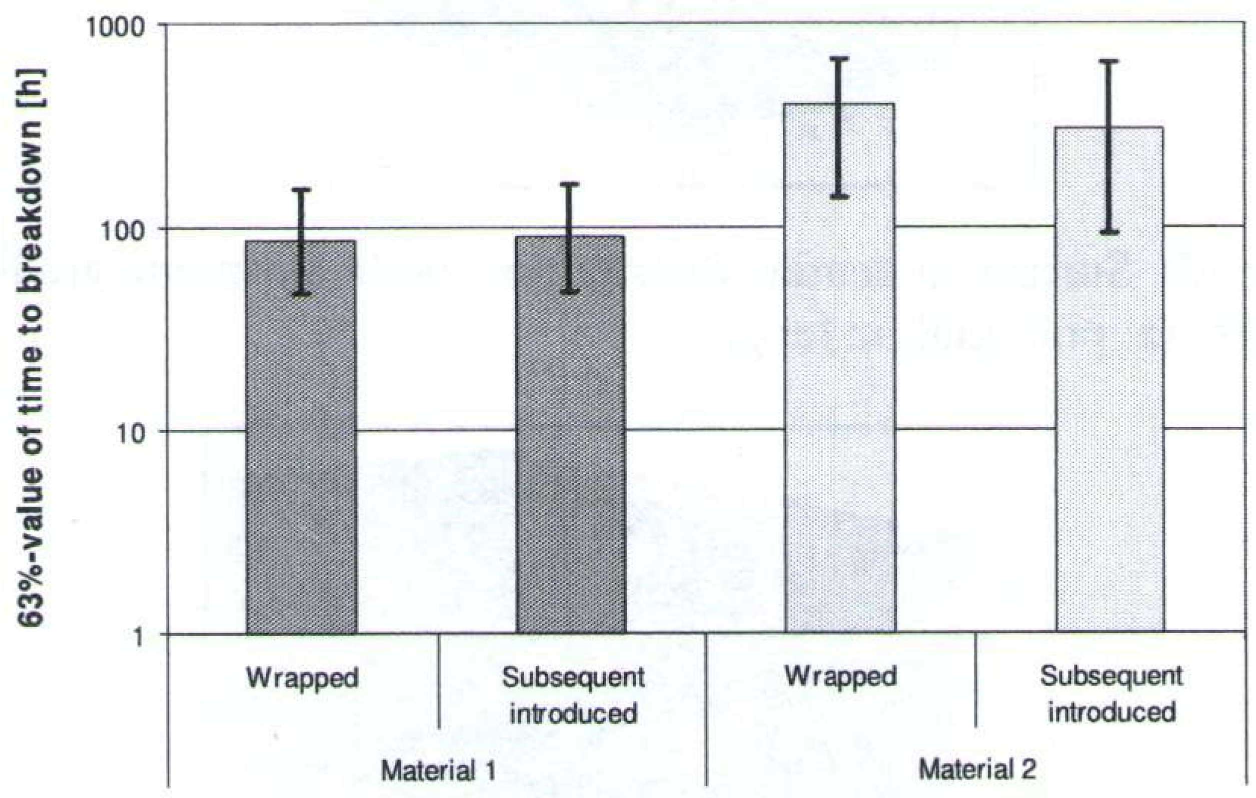


Fig.3: Time to breakdown values of treeing tests with wrapped- and subsequent introduced electrode

2.2.3 Tests at industrial manufactured winding insulations

To apply the new method, tests at industrially manufactured bars have been carried out. These bars differ in type of taping and production company. To compare the results, reference insulations were made. Fig.4 shows the Weibull-plot for the time to breakdown values for the insulations tested.

The results in Fig.4 show that there is a significant difference in the time to breakdown values for material 2 as the confidential intervals do not overlap. That proves that industrial manufacturing of company 2 is of a poor quality. In contrast, no significant difference in time to breakdown was measured for material 3 as the confidence intervals do overlap. This shows that the manufacturing of material 3, company I is of a good quality.

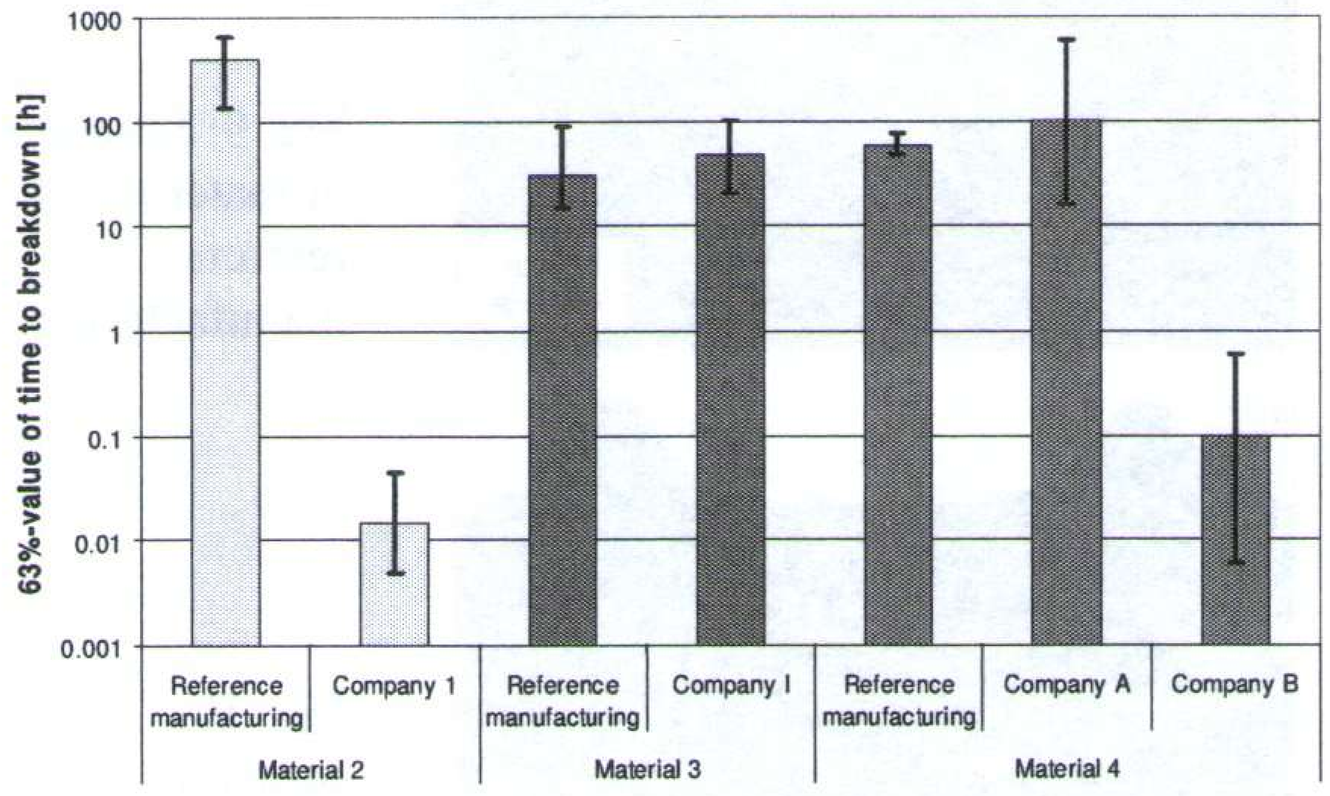


Fig.4 Time to breakdown values at winding insulations at different manufacturing

A somewhat different picture shows material 4. Whereas company A is able to produce that insulation in a similar quality than the reference insulation, is the material of company B of a rather poor quality as the time to breakdown values show. The reason for the significant different time to breakdown values can be found in the microscopic properties of the insulation. Figs.5 to 11 show a representative example of the insulation quality of the materials in the same order as given in Fig.4.

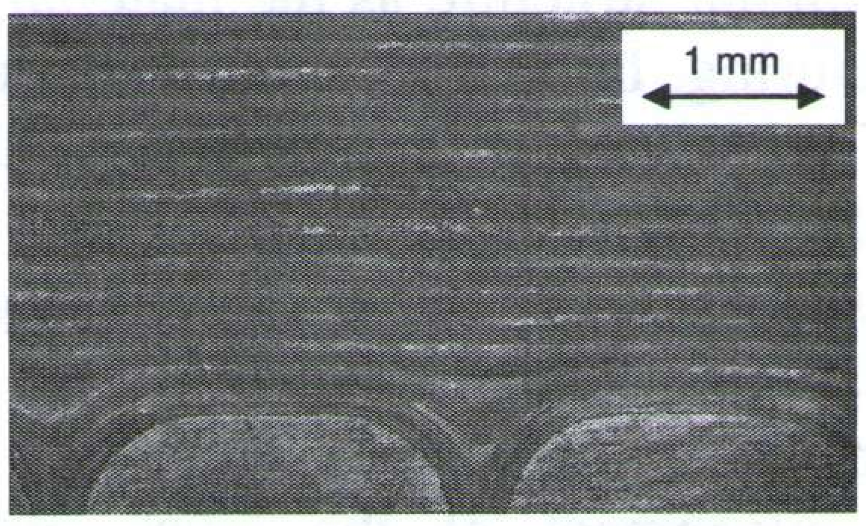


Fig. 5: Structure of material 2 at reference manufacturing

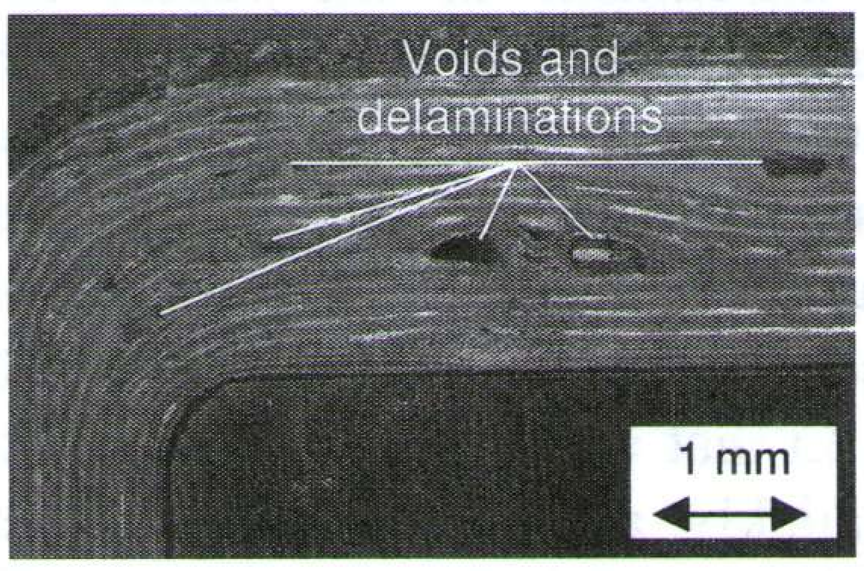


Fig. 6: Structure of material 2 at manufacturing of company 1

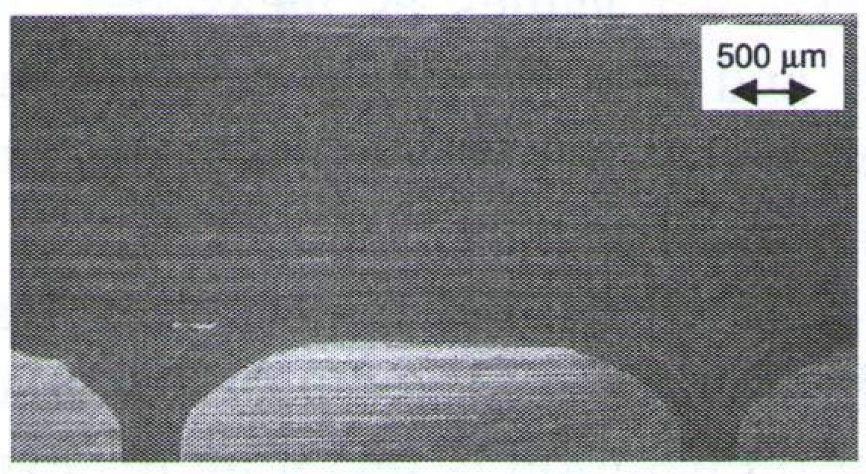


Fig. 7: Structure of material 3 at reference manufacturing

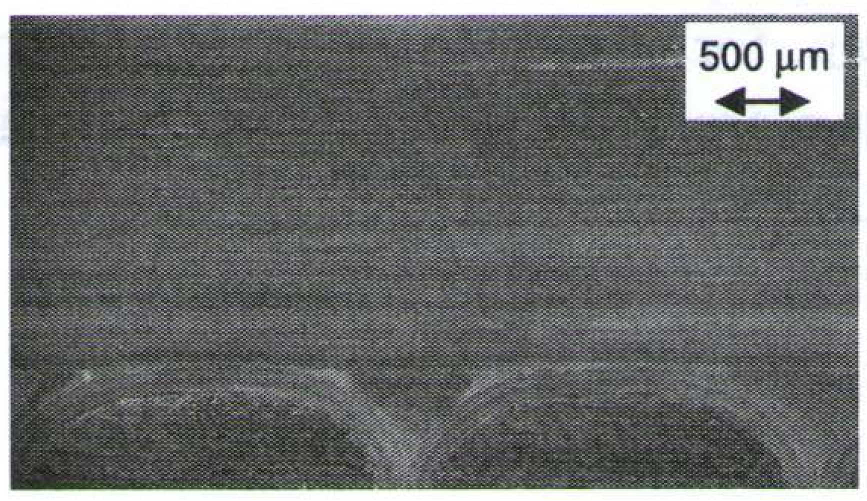


Fig. 8: Structure of material 3 at manufacturing of company I

G1S3(4)

Proc. of the 5th WSEAS/IASME Int. Conf. on Electric Power Systems, High Voltages, Electric Machines, Tenerife, Spain, December 16-18, 2005 (pp136-142)

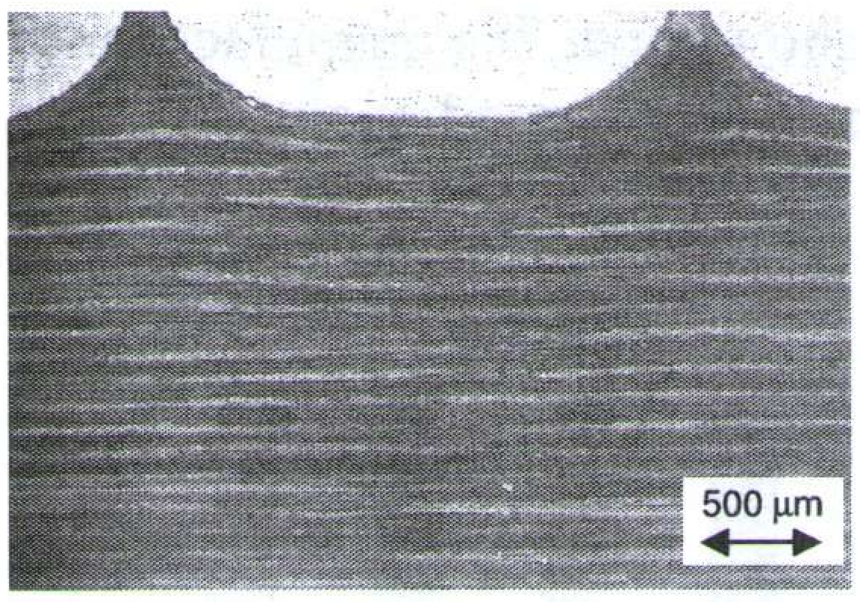


Fig. 9: Structure of material 4 at reference manufacturing

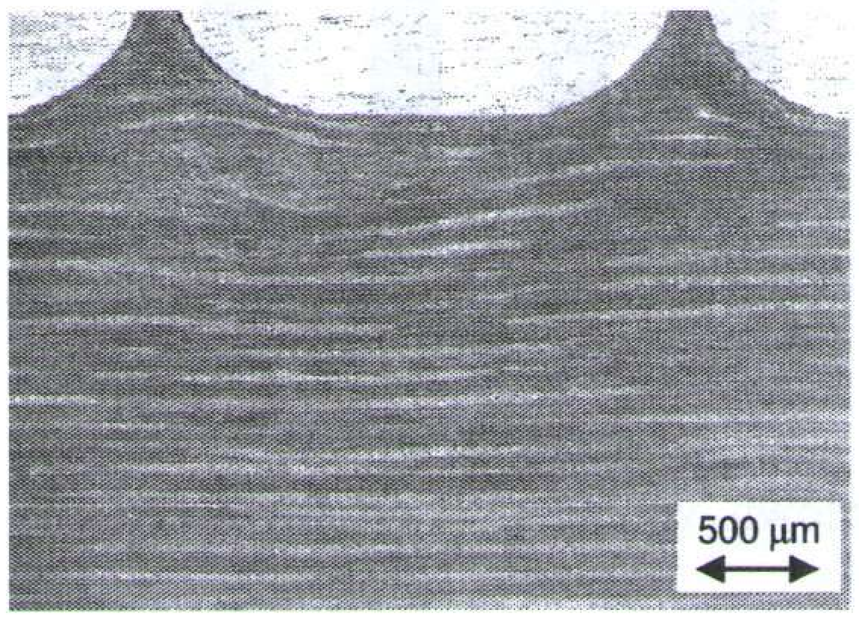


Fig. 10: Structure of material 4 at manufacturing of company A

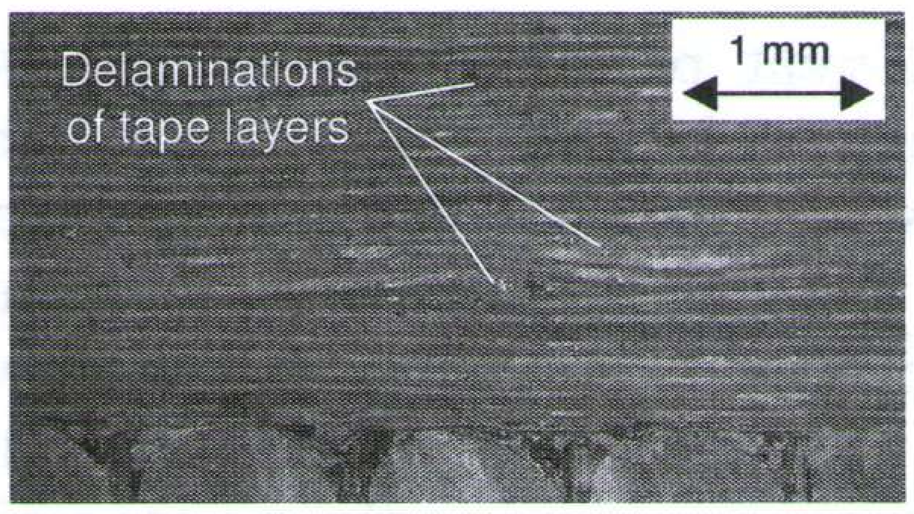


Fig. 11: Structure of material 4 at manufacturing of company B

The micrographs clearly show that all reference materials are without any voids or imperfections. Also, material 3, company I and material 4, company A have similar structure as the material at reference manufacturing. In contrast, both materials that show many voids and delaminations in the insulation have the significantly reduced time to breakdown values, such as material 2, company 1 (Fig.6) and material 4, company B (Fig.11).

The reason for such a difference is supposed to be the different attachment of the tapes. Both systems were taped by hand and it is supposed that at hand taping, it is not possible to have such a constant taping strength as with machine taping. This can lead to a loose attachment of the tapes and the binder resin cannot fill the regions between the tapes sufficiently. In that area, an electrical tree can propagate very quickly along, thus causing very short time to breakdown values as measured. The breakdown values and the micrographs confirm a significant influence of the taping on potential lifetime of winding insulations.

Since material 4 is a VPI and material 2 a resin rich insulation, the results of Fig.4 show that the sensibility for poor preparation is much more severe for resin rich than for VPI-insulations and those tolerances in taping are more critical for resin rich insulations than for VPI-materials.

3 Diagnosis and life extension of operating equipment in service

3.1 Visual inspection of endwindings

One of the most commonly discharge sources in rotating machines is the so called endwinding discharge. This surface discharge generally occurs on the field grading varnishes and is caused by different reasons, such as surface contamination, inadequate coating properties or degradation of conducting properties of the field grading material. The task of field grading is to minimise the surface field strength by establishing a practically constant potential gradient. In comparison to conductivity measurements, surface potential distribution mapping represents an effective way to compare different materials. An appropriate field grading substance may avoid long-term corrosion or damage produced by discharges. Fig.12 and Fig.13 compare two commercial grading materials.

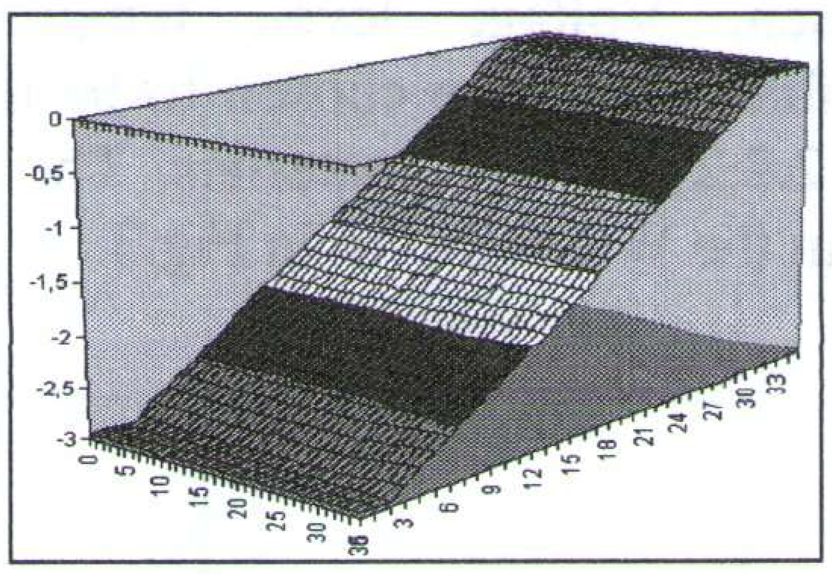


Fig.12: Surface potential distribution with optimum grading effect (z: potential, x: length)

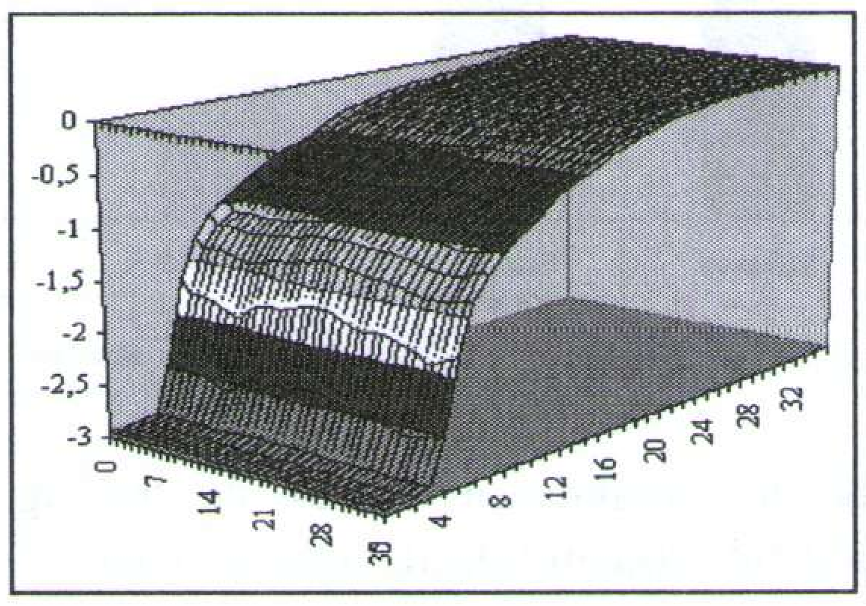


Fig.13: Surface potential distribution with insufficient grading effect (z: potential, x: length)

An insufficient grading leads to a material corrosion by continuous partial discharge activity. In a latter stage, the surface may strongly be eroded and the electrical field distribution may completely deviate from its original state, thus causing discharges parallel to the insulator surface and in a vertical direction to metal parts. In order to identify endwinding problems, it has to be looked for white traces, such as shown in Figs. 14 and 15. In addition to an off-line visual inspection, on-line ultrasonic detection is a standard technique to localise surface discharges, where UV sensitive camera systems can

Proc. of the 5th WSEAS/IASME Int. Conf. on Electric Power Systems, High Voltages, Electric Machines, Tenerife, Spain, December 16-18, 2005 (pp136-142)

help to rapidly pin-point the location of discharge during high voltage tests and to precisely locate and analyse the origin of a discharge in order to help to define confined defect oriented repair measures.

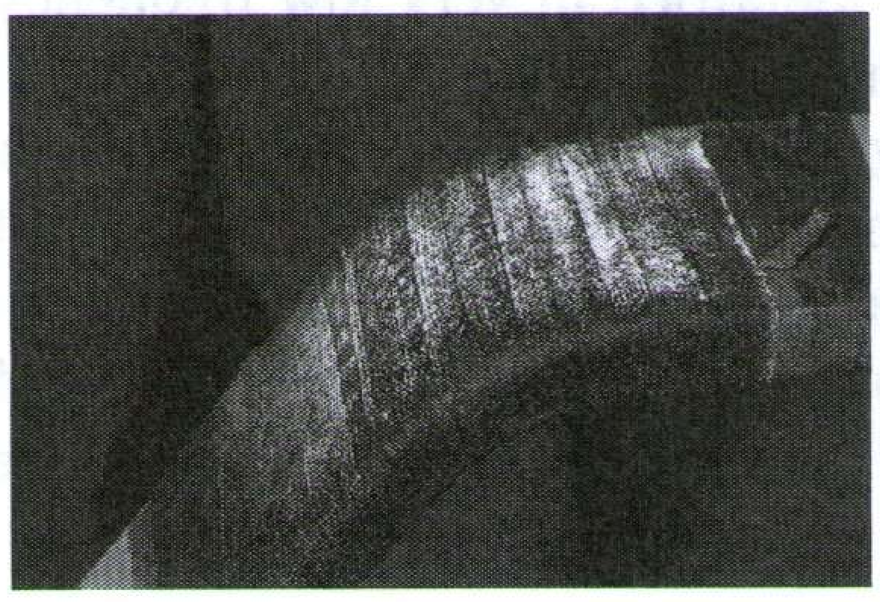


Fig.14: White traces at endwinding due to corona degradation

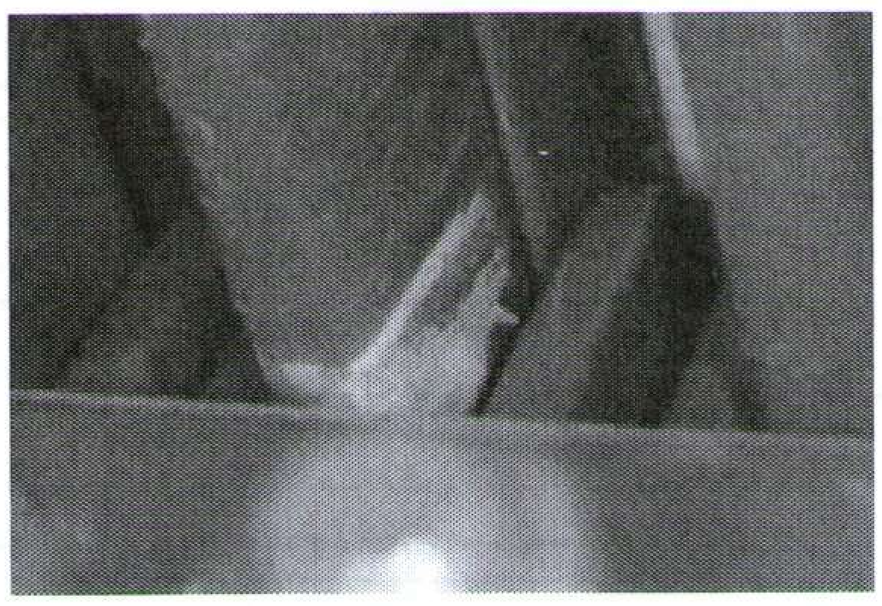


Fig.15: Severe degradation due to spark discharges caused by ageing of the semi-conducting coating at an endwinding

3.2 AC loss factor

The dielectric loss of a high voltage rotating machine insulation may have different independent physical origins that are also depending on the dielectric properties of the material and the partial discharges (PD). The individual contribution of each different dissipation mechanism to the dielectric loss depends on the nature, the severity and the time of operation of a machine but also on the structural state of the insulation and especially the impregnating resin. The loss of dipolar origin hardly varies with voltage (the dipolar loss mainly depends on the structural state of the resin, e.g. age or polymerisation). The losses due to partial discharge activity and field grading materials are field dependent.

3.3 Partial discharges

2.2.1 Off-line PD measurements

Off-line Partial discharge activity is detected in conjunction with tan δ measurements by using the phase resolving partial discharge acquisition technique (PRPDA). The core data acquisition of the PRPD is based on an event recording concept, where the PRPD generates patterns that represent a three-dimensional distribution function with the coordinates high voltage phase angle, signal amplitude and event number. These patterns are represented as colour-pictured fingerprints or so called "partial discharge patterns" [15–17].

Other than the dielectric loss factor, PD patterns are direct measures of the PD activity. In the first place, PD indicates defects and stresses in the rotating machine, e.g. defects created by abrasion of insulating materials or surface contamination. In addition, PD measurements reveal locally confined defects, which would otherwise get lost in the bulk signal. Since the shape of a pattern is usually related to a defect and its geometry, PD patterns allow in most situations to identify the most prominent defects, recognise superimposed of defects and distinguish noise from disturbance. Some examples of PD patterns are shown in Figs.16 and 17. Typically, the internal discharge in Fig.16 (triangular shape) dominates at lower voltages and its level is hardly voltage dependent. At higher voltages the surface discharge, Fig.17, dominates. Whereas in Figs.16 and 17 the single effect is shown, illustrate Figs. 18 and 19 typical superimpositions of both effects.

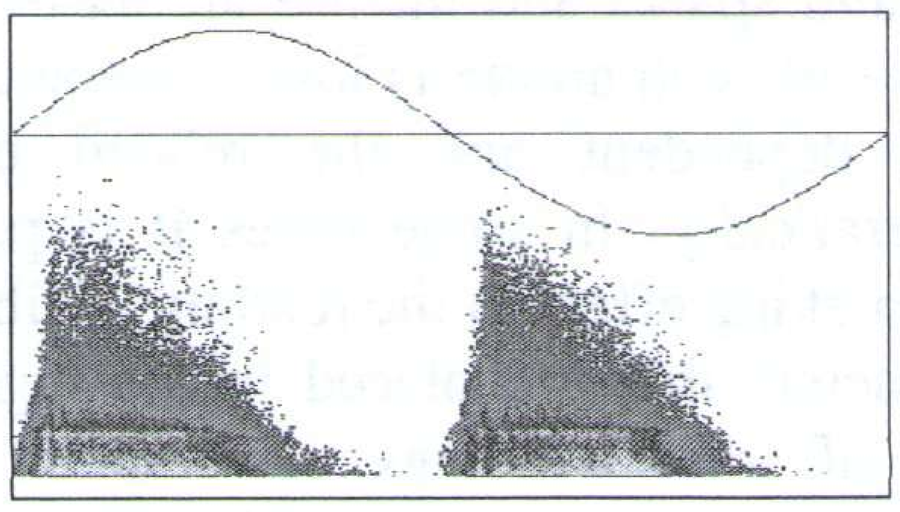


Fig.16: PD-pattern of a discharge in a delamination

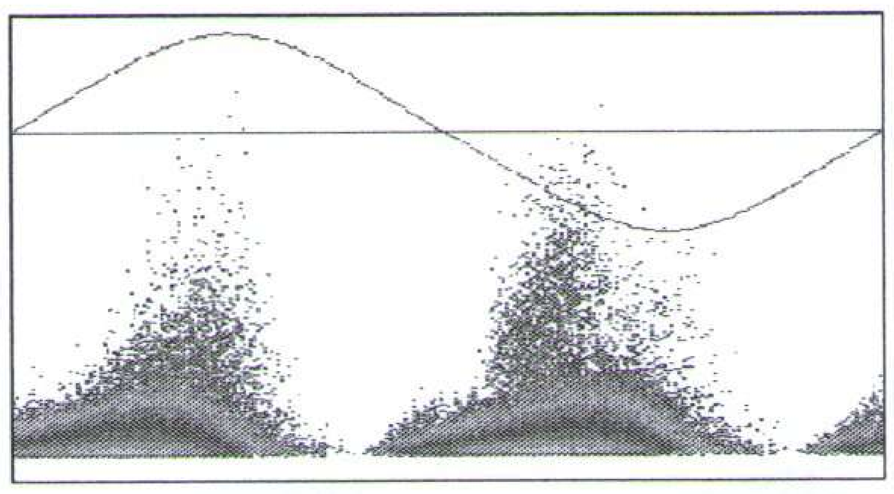


Fig.17: PD-Pattern of a surface discharge in an endwinding

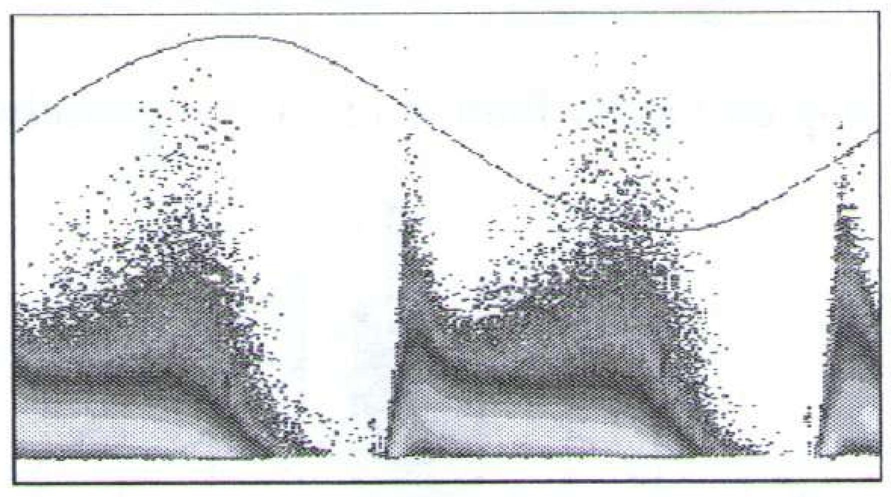


Fig.18: Superimposed internal and surface discharge pattern I

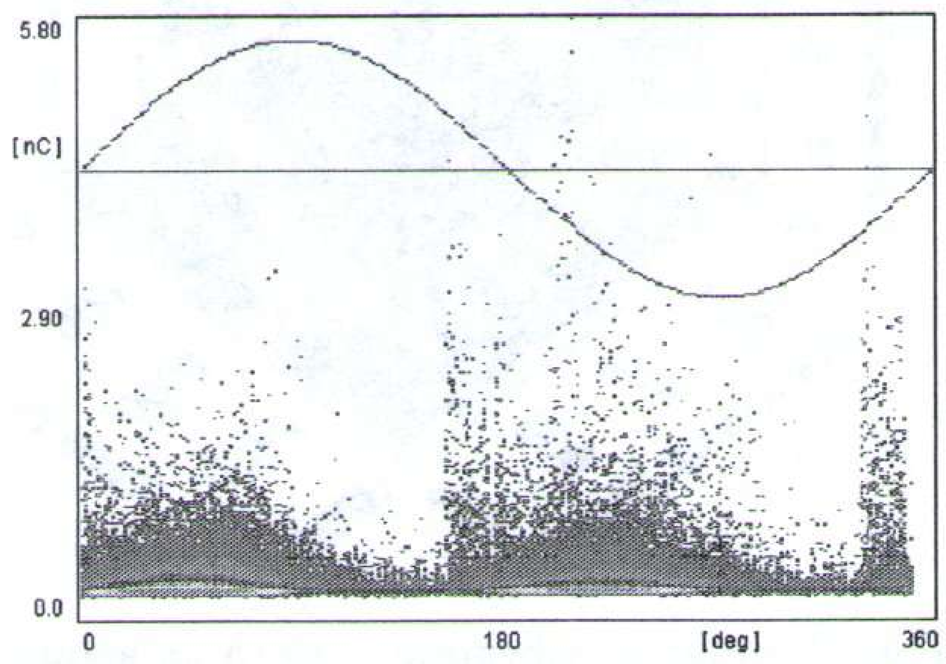


Fig.19: Superimposed internal and surface discharge pattern II

For off-line PD measurements, the effort and costs are rather high since the machines must go out of service and the testing personal has to go on site. Therefore, off-line PD measurements are made in regular time intervals. A disadvantage of that is, that rapidly occurring property changes in the insulation may not be detected.

2.2.2 On-line PD measurements

Property changes are a result of operating stresses that may induce insulation failure and may not have let to a change of insulation properties at the time of intervention. The stresses are not present when a machine is tested at standstill. Therefore, on-line measurements are additionally recommended for detecting other damages. As an example, excessive vibration of the winding in the slot may cause so-called spark discharges. Magnetic and electrical fields induce currents in the semiconductive coatings and sparks and intense arcing occurs. The occurrence of such arcing is load-, temperature- and vibration dependent and the related discharges appear erratically. In some cases it is possible to relate a sparking effect to the reading of fibre optical accelerometers that are placed in the high voltage sections of the windings. Examples of such measurements are shown in the Figs.20 and 21.

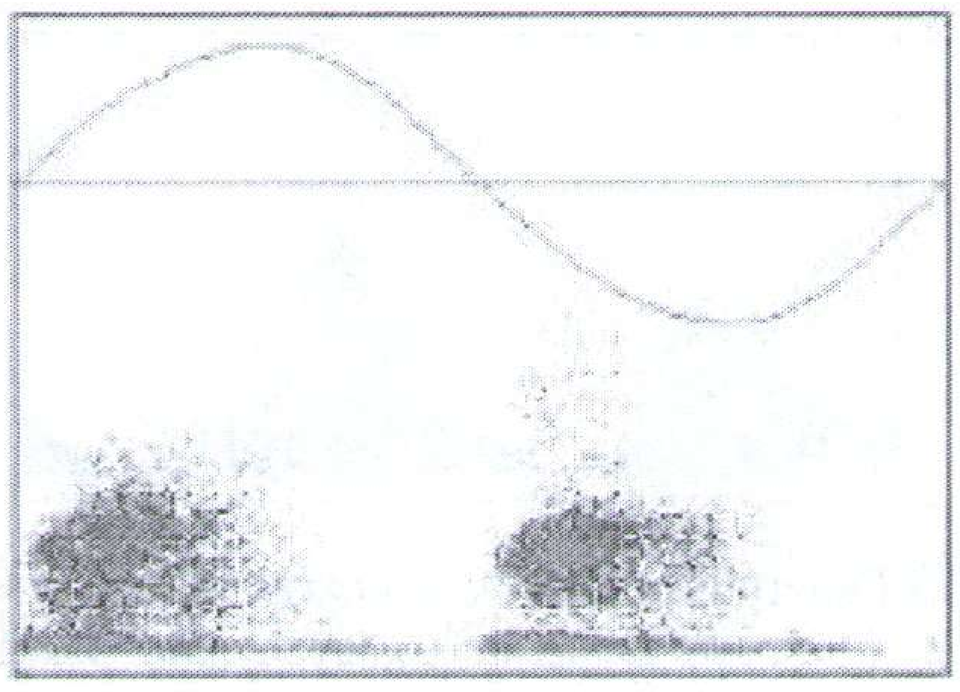


Fig.20: Example of a PD-Pattern of sparking discharges

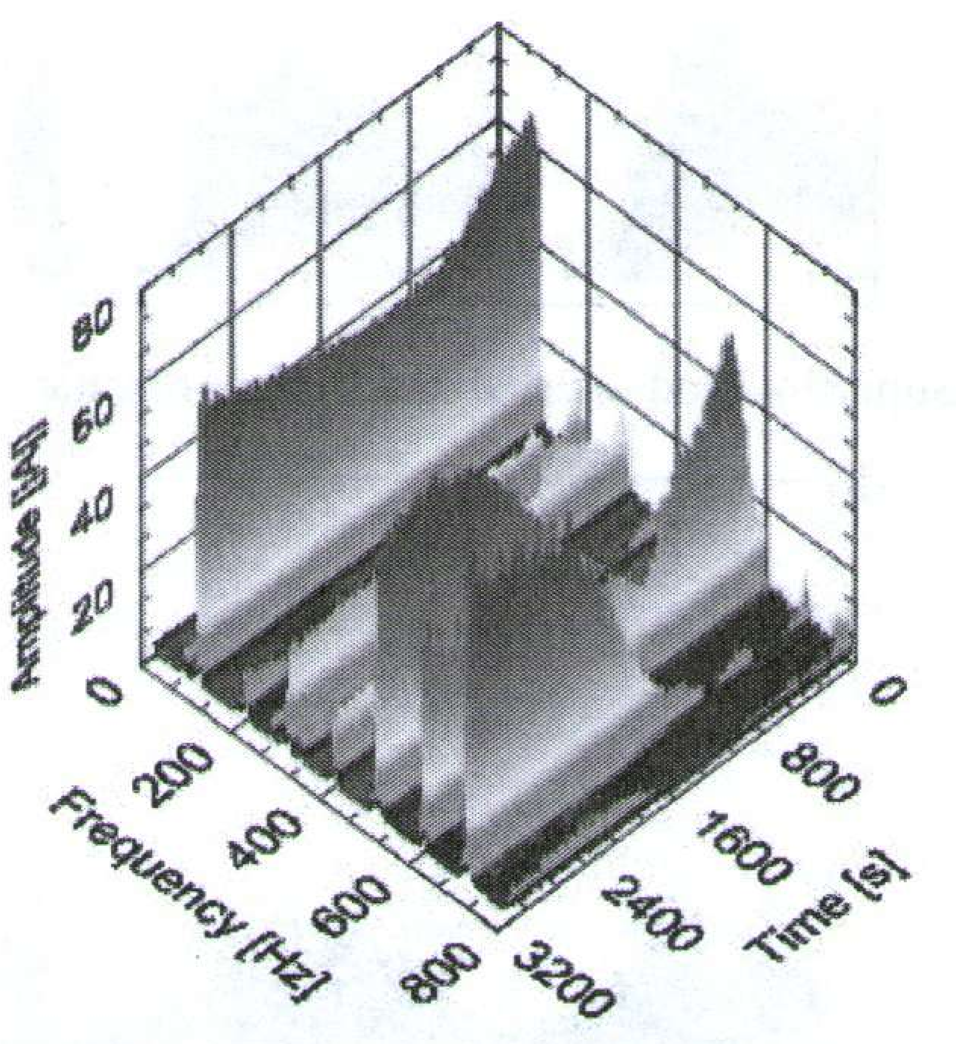


Fig.21: Time frequency vibration pattern as acquired by fibre optical sensors in the head-winding on a starting generator

2.2.2 Very low frequency tests

One of the predominant characteristic of the discharge in the insulation is its phase shift to lower phase angles with voltage. These parameters can clearly be identified in very low frequency- (VLF – 0.1 Hz) and power frequency testing. The dielectric loss is higher in VLF tests, which is a result of the higher dipolar and charge carrier mobility at low frequencies. The example in Fig.22 shows a comparison of low frequency- and power frequency testing of tan δ and capacitance at a new hydro generator.

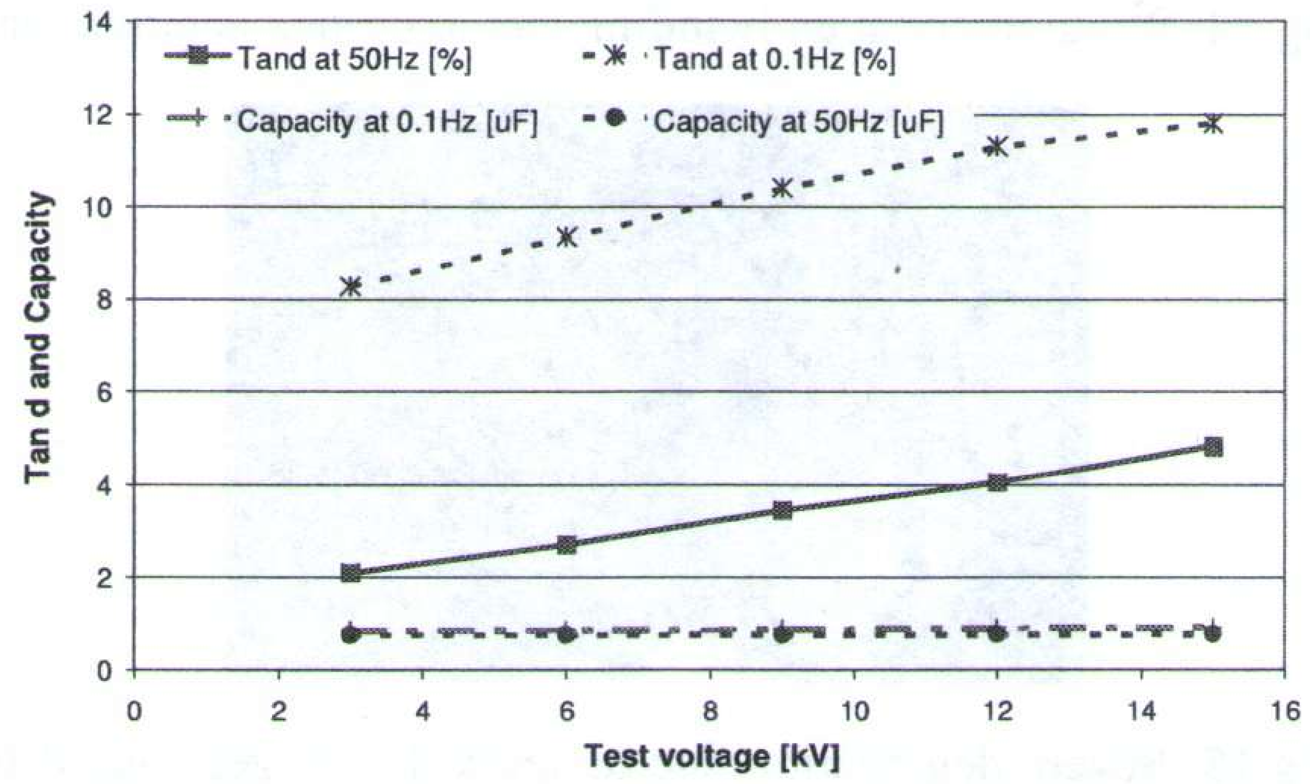


Fig.22: VLF tests of tan δ and capacitance

Since the insulation is new, the 50 Hz losses are significantly lower as the 0,1 Hz capacitance. This indicates that the polymerisation reaction is not completely finished and mobile and non polarised molecules are still available. Further on, this polarisation leads to a field independent loss component and eventually a higher loss angle [18].

4 Conclusions

Different test and diagnosis methods were presented that are all suited to achieve a long lifetime of high voltage winding insulations. From that, the following conclusions are drawn.

1. As the newly developed method with an embedded electrode allows testing of insulations with far less effort than tests according to the standards, it is recommended to be used for tests of insulation life in which only a low number of samples is accessible, which might be due to time, financial and/or material reasons.
2. Because manufacturing of different companies may reduce time to breakdown significantly, insulation quality should be surveyed in random tests in the production line. As it requires much less material, tests with the embedded electrode are recommended for this purpose and resulting time to breakdown values should be compared to reference insulations.

G158(7)

Proc. of the 5th WSEAS/IASME Int. Conf. on Electric Power Systems, High Voltages, Electric Machines, Tenerife, Spain, December 16-18, 2005 (pp136-142)

3. Since partial discharge measurements indicate the presence of locally confined defects, the results can be associated to different defect types.
4. In an off-line inspection, the combination of the procedures partial discharge (PD) measurements, AC loss factor, very low frequency tests and visual inspection allow a fairly precise determination of the machine condition and are therefore strongly recommended.
5. Since off-line tests do not show all defects, they have to be complemented by on-line PD localisation attempts using electromagnetic or ultrasonic probes.
6. In critical cases, periodic on-line PD testing or permanent PD monitoring should be applied to reassure the findings of the off-line tests in order to identify operation-caused damage scenarios or to allow an early warning in case of (sudden) defects.

References

[1] H. Schaumburg, *„Werkstoffe und Bauelemente der Elektrotechnik: Polymere“*, Verlag B.G. Teubner, Stuttgart, Germany, ISBN: 3-519-06145-7, 1997

[2] K. Kimura, Y. Kaneda, “The Role of Microscopic Defects in Multistress Aging of Micaceous Insulation”, *IEEE Trans. on DEI,* vol. 2, no. 3, pp. 426–432, Jun. 1995

[3] L. A. Dissado, G. C. Fothergill, *“Electrical degradation and breakdown in polymers”,* Peter Peregrinus Ltd., London, UK, ISBN: 0 86341 196 7, 1992

[4] K. Hee Dong, J. Young Ho, R. Hong Woo, “Effect of aging on the microstructure evolution, thermal and mechanical properties of mica/epoxy composite”, *IEEE Conf. on El. Insul. and Diel. Phen., CEIDP,* Austin, USA, pp. 537–541, Oct. 1999

[5] M. R. Naghashan, “Untersuchungen zur Teilentladungsaktivität von maschinentypischen Hochspannungsisolierungen”, *Doctoral Thesis*, University of Dortmund, Germany, Shaker Verlag Aachen, 1996

[6] H. Mitsui, Y. Inoue, “Statistical analysis on the electrical failure properties of the form-wound insulations systems for rotating machines”, *IEEE Trans. on EI*, vol. EI-8, no.3, pp. 109–113, 1977

[7] R. Vogelsang, R. Brütsch, K. Fröhlich, “Effect of electrical tree propagation on breakdown in mica insulations” *13th Int. Symposium on High Voltage Engineering, ISH,* Delft, The Netherlands, Conf. Proc., pp. 1–4, Aug. 2003

[8] O. V. Thorsen, M. Dalva, “A survey of faults on induction motors in offshore oil industry, petrochemical industry, gas terminals and oil refineries”, *IEEE Trans. on Ind. Appl.*, vol. 31, no. 5, pp. 1186–1196, Sep./Oct. 1995

[9] IEEE Motor Reliability Working Group, “Report of large motor reliability survey of Industrial and commercial installations, Part I and Part II”, Committee report, *IEEE Trans. on Ind. Appl.*, vol. IA-21, no.4, pp. 853–872, Jul./Aug. 1985

[10] N. Srb, “Erfahrungen mit Stossspannungsprüfungen an elektrischen Maschinen”, *Allianz Report 70*, Heft 2, pp. 58–62, Apr. 1997

[11] IEC Std 60505, “Evaluation and qualification of electrical insulation systems”, *IEC International Standard 60505*, Second Edition, 1999

[12] IEEE Std 1043-1996, “IEEE Recommended Practice for Voltage-Endurance Testing of Form-Wound Bars and Coils”, Voltage Endurance Committee of the Dielectrics and Electrical Insulation Soc., Sep. 1996

[13] R. Vogelsang, “Time to breakdown of high voltage winding insulations with respect to microscopic properties and manufacturing qualities”, *Doctoral Thesis*, Swiss Federal Institute of Technology Zurich, Hartung-Gorre Verlag Konstanz, Germany, ISBN: 3-89649-965-3, 2004

[14] IEEE Std 1553™-2002, “IEEE Trial-Use Standard for Voltage-Endurance Testing of Form-Wound Coils and Bars for Hydro-generators” IEEE Power Engin. Society 2002

[15] B. Fruth, J. Fuhr, “Partial Discharge Pattern Recognition - A Tool for Diagnosis and Monitoring of Aging”, *CIGRE, paper* 15/33-12, 1990

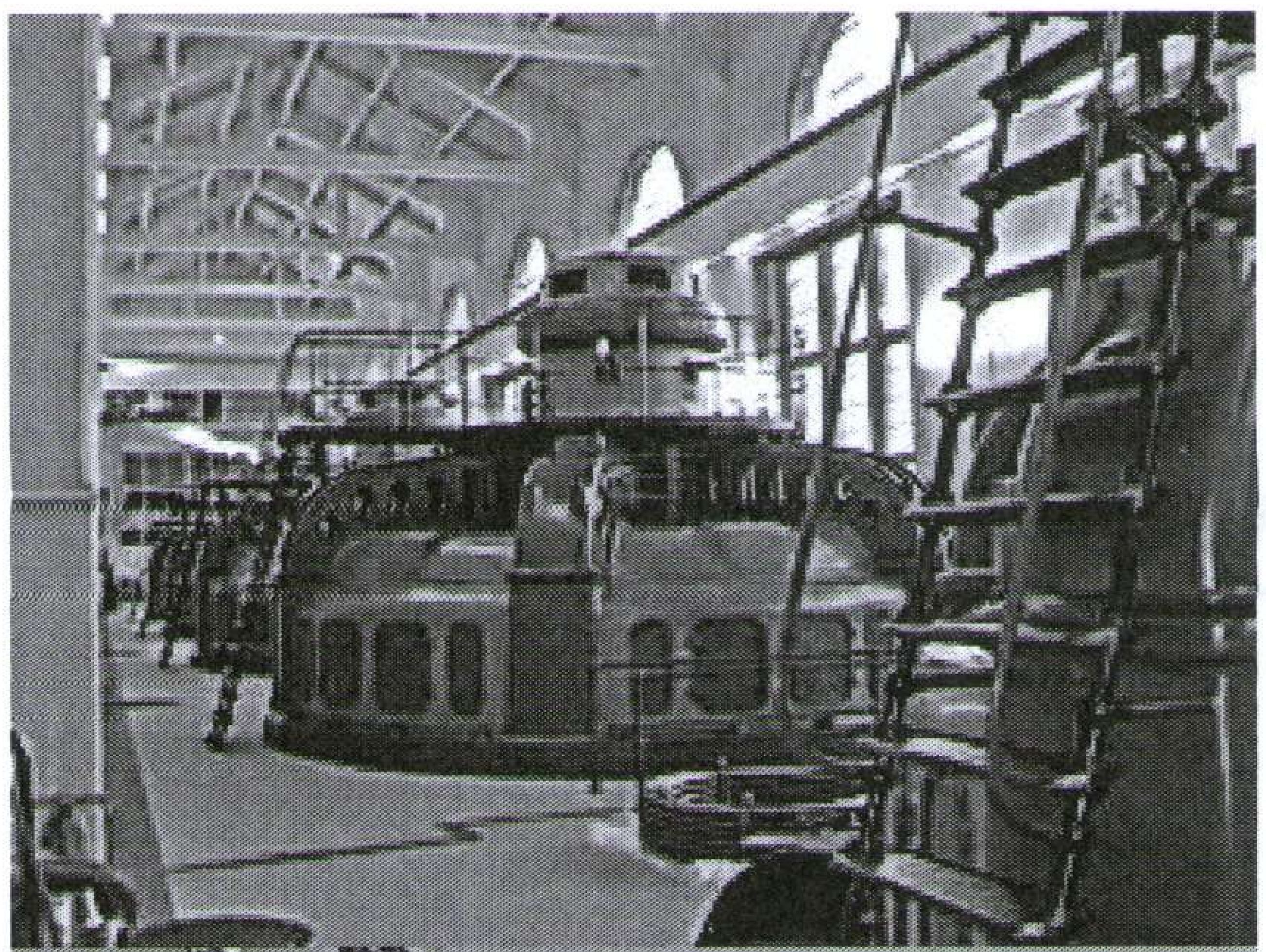
[16] L. Niemeyer, B. Fruth, F. Gutfleisch, "Simulation of Partial Discharges in Insulation Systems", Proc. *7th Int. Symp. High Voltage Engineering, ISH,* Dresden, paper 71.05, 1991

[17] R. Goffaux et al., “Dielectric Test Methods for Rotating Machine Stator Insulation Inspection”, *IEEE Conf. on El. Insul. and Diel. Phen., CEIDP,* Atlanta, USA, pp. 528 – 533, 1998

[18] B. Fruth, G. Liptak, “Dielectric Properties of Mica Epoxy Composites Subjected to Thermal and Thermoelectrical Aging”, *6th Int. Symp. High Voltage Engineering*, New Orleans, USA, paper 21.02. 1998

G153(8)

Machines Testing & Monitoring



Nearly all global energy is produced in power plants by rotating machines, such as generators, which convert mechanical energy into electrical energy. In industry, electrical motors are vital for powering mechanical drives and motion sequences. The reliable operation of rotating machines is therefore essential for a functioning power supply.

As in other high-voltage equipment, rotating machines have insulation, which is subject to aging processes. Excessive aging can lead to failure, so it is important to know the insulation state of these electrical machines over their entire service life.

Diagnostic methods which allow the reliable condition assessment of insulation include the measurement of power/dissipation factor, dielectric measurement over a large frequency range, the polarization index, and partial discharge measurements.

For all of these diagnostic methods, we offer the matching testing and monitoring solution. With this, you can perform a fast and accurate condition assessment in a variety of electrical machines to identify potential problems and risks quickly.

Commissioning & diagnosis of generators and motors

- Partial Discharge Analysis
- Dissipation/Power Factor Measurement

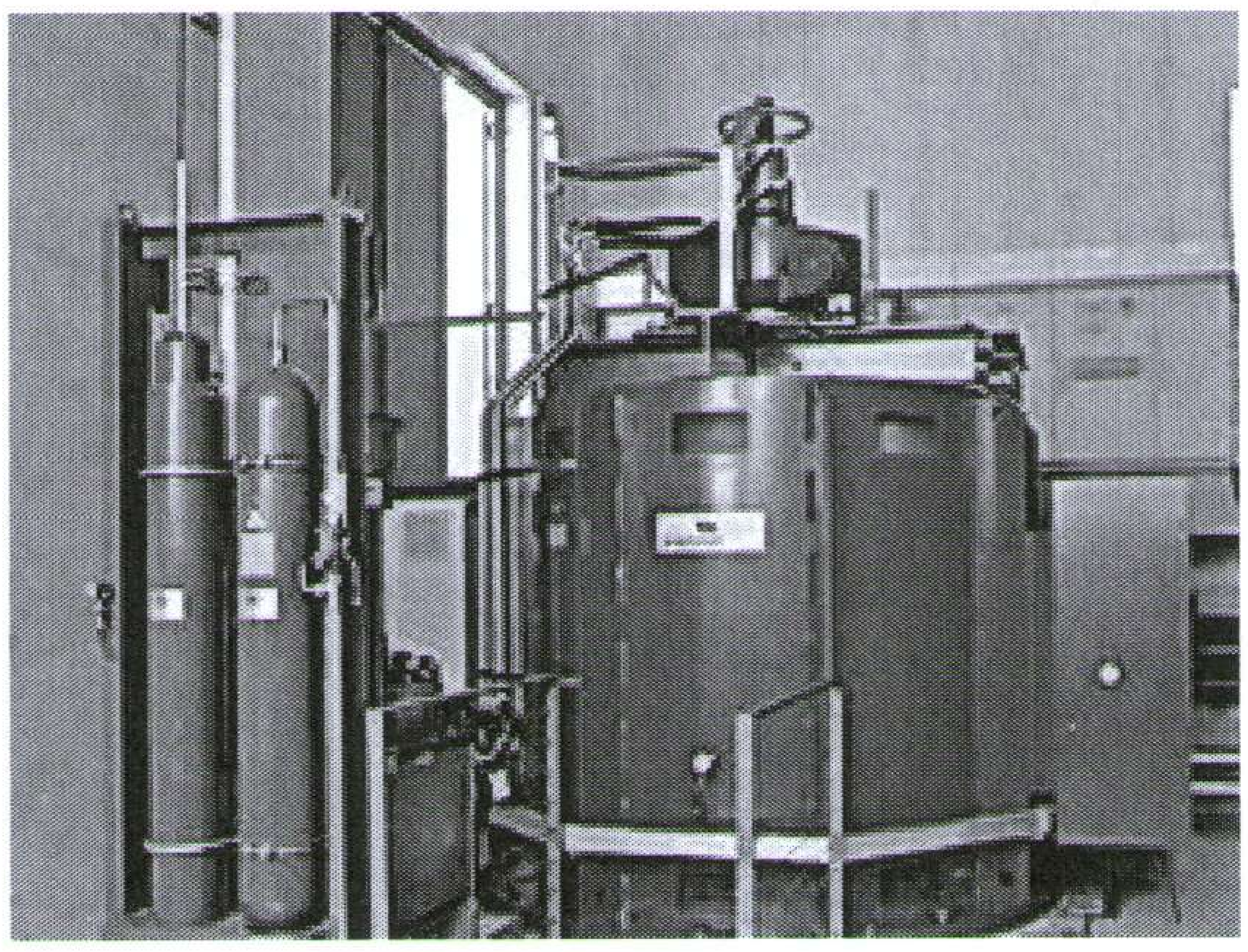
G158(91)

- [Dielectric Response Analysis]

Monitoring of generators & motors

- [Partial Discharge Monitoring]

Partial Discharge Analysis



Partial discharge (PD) occurs in the stator insulation system of rotating machines, where local electric field stress exceeds the local electrical strength. Compared with other dielectric tests, the differentiating character of partial discharge measurements allows localized weak points of the insulation to be identified.

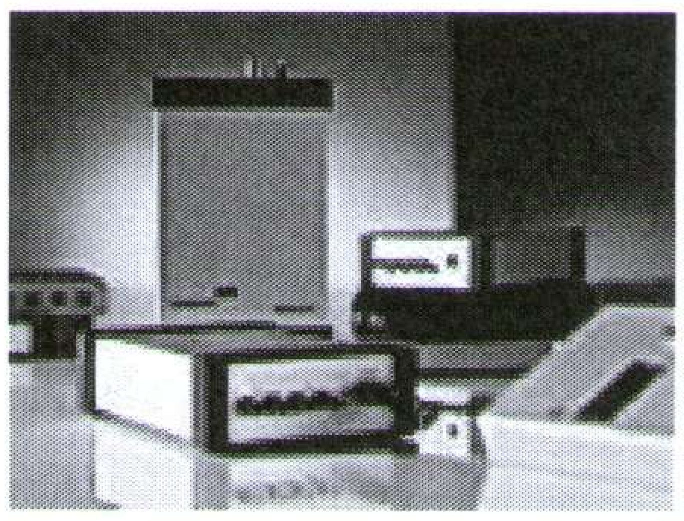
PD measurements based on IEC 60034-27 standards can be performed on motors and generators either on-line during regular load service operation or off-line by energizing each winding successively during standstill of the machine.

Generally, several different partial discharge sources are present and active within the stator winding insulation at the same time. The key to successful PD measuring in stator windings is the separation of parallel active PD sources and the distinction between harmful PD, normal PD occurrences and outer noise, inevitably present in industrial surroundings.

This is best achieved by synchronous, multi-channel partial discharge measurement. This separates internal PD sources from each other and from noise signals. PD sources are evaluated individually within the stator winding.

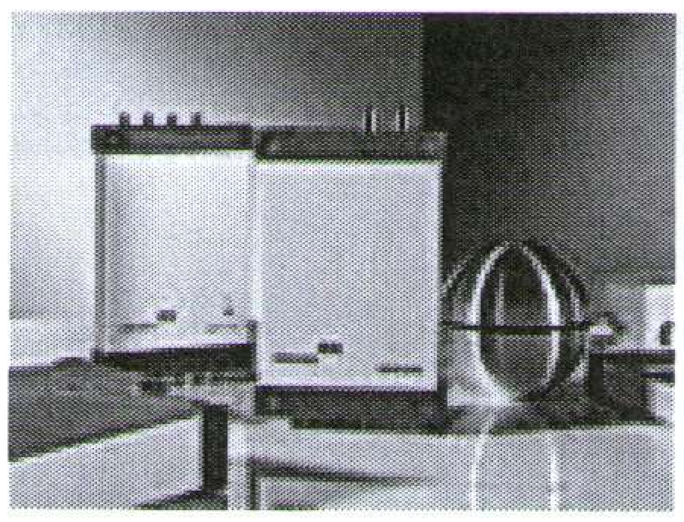
Recommended solutions for partial discharge analysis on generators and motors

a158(10)



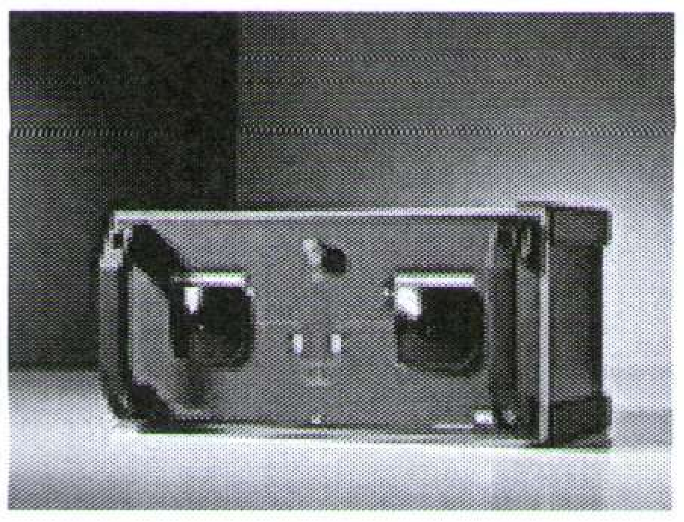
MPD 600

For high-end measuring and analysis needs



MPD 500

For routine and acceptance tests



CPC 100 + CP TD1 + CP CR500

High-voltage source for partial discharge measurements and withstand tests

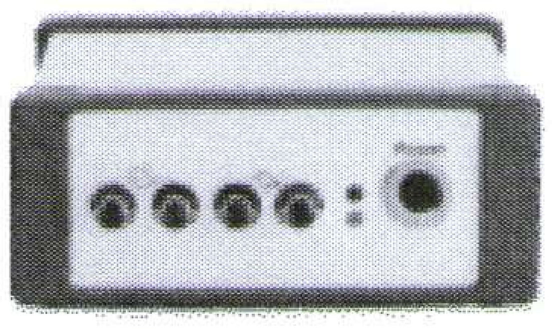
Partial discharge analysis for rotating machines testing

With our MPD 600, partial discharge (PD) can be detected and analyzed in the insulation of generators and motors. In addition to a purely single-phase test you can check all three phases synchronously thanks to the multi-channel system.

The fiber connections used and the free choice of measurement frequency and bandwidths make the MPD 600 a very robust system in environments with high interference. This makes it ideal for use both in the laboratory and on site.

The MPD 600 also offers many free features such as selectable filters to maximize the sensitivity reach. Graphical tools (e.g. 3PARD and 3FREQ) assist you in the PD analysis. And with just one click, you can also automatically create a corresponding report.

G158(11)



MPD 600

High-end measuring and analysis system for partial discharges

View Product

Related Products

- 

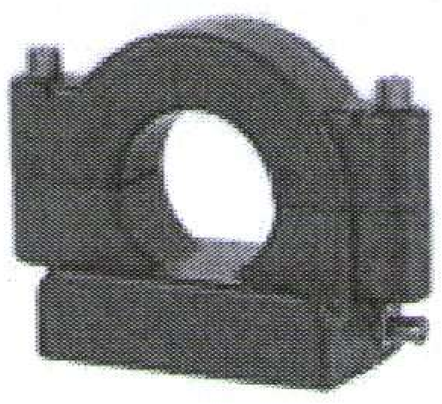
  CAL 542

  Charge calibrators are used to inject a defined charge into and verify the measurement circuit.

- 

  MCC 205/210

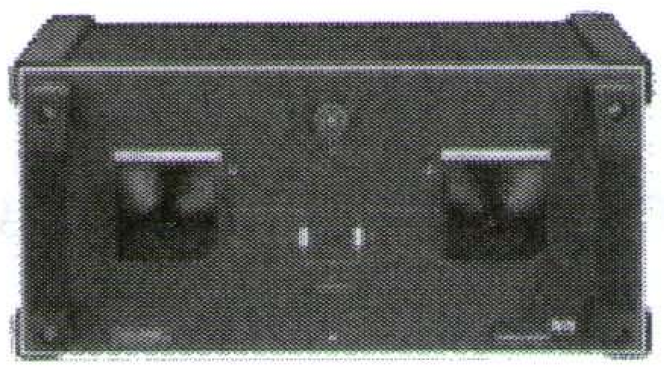
  The MCC 205 and MCC 210 coupling capacitors are designed with the quadripole measuring impedance built in and include a dedicated space for the MPD measuring unit and the MPP power pack.

- 

  MCT 120

  High frequency current transformers pick up partial discharge (PD) signals in moderate heights and in safe distance from high voltage.

G158(12)



- CPC 100 + CP TD1 + CP CR500

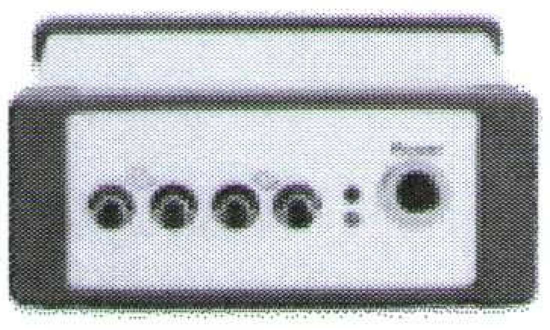
Dissipation factor/power factor measurement including source, capacitor and compensation reacto

Partial discharge analysis for routine and acceptance testing on rotating machines

The MPD 500 is ideal for routine tests, such as acceptance tests and the testing of bars, segments and individual phases of motors and generators.

The MPD 500 allows you to reliably identify and analyze partial discharge (PD) in real-time. Its low electricity consumption makes a continuous operation of up to 20 hours possible. The use of fiber-optic technology ensures an optimal level of safety and highly accurate measurements.

Our MPD 500 makes routines tests easier than ever before: with just a single click, you can perform automatic measurements in accordance with IEC 60270, and a "pass/fail" evaluation is integrated into the system as well. You can then create test reports according to your own requirements without the need for additional assistance.



MPD 500

Partial discharge measuring system for routine and acceptance tests

View Product

Related Products

-

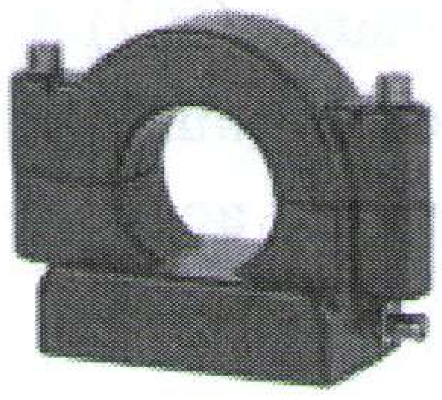
G458(13)

CAL 542

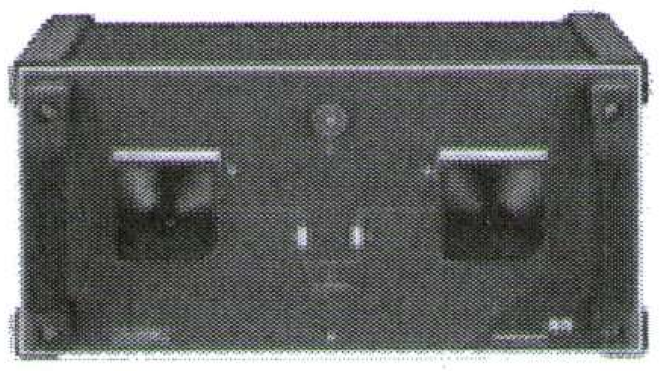
Charge calibrators are used to inject a defined charge into and verify the measurement circuit.

- 
  MCC 205/210

The MCC 205 and MCC 210 coupling capacitors are designed with the quadripole measuring impedance built in and include a dedicated space for the MPD measuring unit and the MPP power pack.

- 
  MCT 120

High frequency current transformers pick up partial discharge (PD) signals in moderate heights and in safe distance from high voltage.

- 
  CPC 100 + CP TD1 + CP CR500

Dissipation factor/power factor measurement including source, capacitor and compensation reactor

HV source for partial discharge measurement and withstand tests

The CPC 100 can be used together with the CP TD1 and the CP CR500 compensating reactor (used as a high-voltage source) to perform tests on generators and motors. This system is ideal for use in the field thanks to its modular design and the easily transportable CP CR500 reactor.

This powerful system can deliver test voltages of up to 12 kV and can compensate capacitances of up to 2µF. The flexible connection of each reactor ensures that an optimum compensation at nominal frequency will be reached. Long test cycles are possible for partial discharge measurements and voltage withstand tests.

G15B(14)

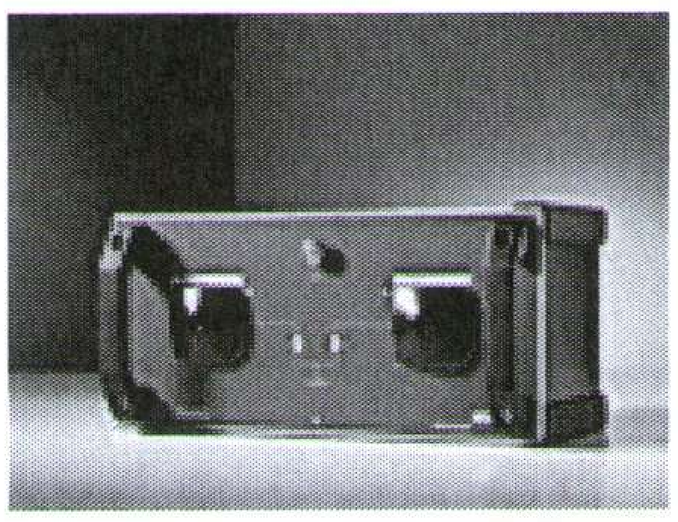
The insulation is the most sensitive part of rotating machines. The lifetime of a stator winding depends on how effectively the electrical insulation can prevent any occurrence of winding faults.

Weak spots can already occur in the insulation during manufacture or impregnation with cast resin, through the stresses of daily operation (for example in the form of soiling) or general aging.

With capacitance and dissipation factor measurements, also known as tan-delta measurements, changes in the insulation can be diagnosed. Aging processes, changes in the structure of the insulation or moisture ingress can, for example, increase the dissipation factor. The increase in the dissipation factor during the "tip-up test" reflects the condition of the insulation.

With our systems, you can measure both the capacitance and the dissipation factor. Based on the results, you can then initiate any appropriate measures such as repairs or replacing a generator/motor bar.

Recommended solutions for dissipation factor/power factor measurements on generators and motors



CPC 100 + CP TD1 + CP CR500

Dissipation factor/power factor measurement including source, capacitor and compensation reactor

G158(15)

The software supports you in reactor configurations for an optimal installation of the high-voltage source.

CPC 100

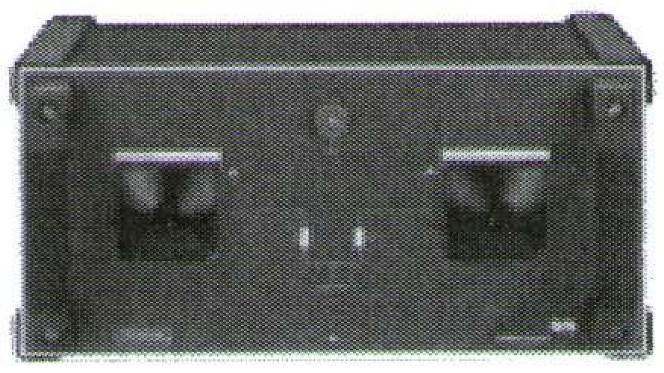
Multi-functional test system for high-voltage assets

View Product

CP TD1

Accessory for power/dissipation factor and capacitance testing

View Product



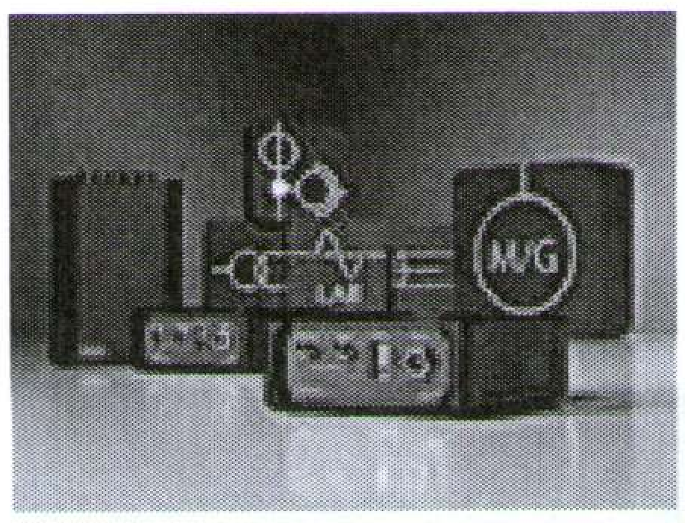
CP CR500

Compensating reactor for the CP TD1

View Product

Dissipation/Power Factor Measurement (Tan Delta)

G158(16)



TANDO 700

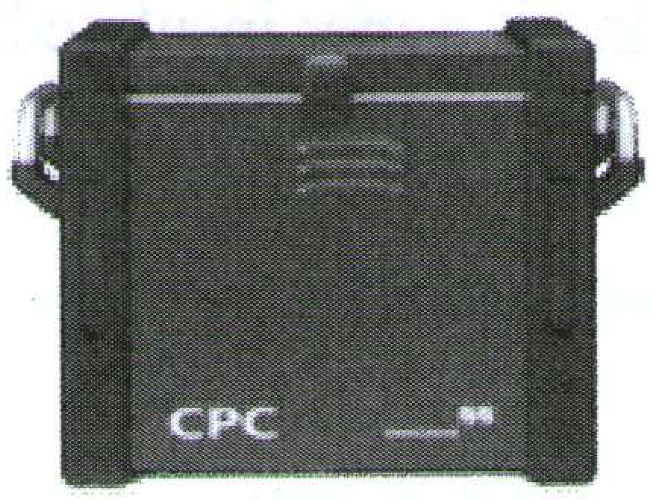
Precise measurement of dissipation factor, power factor and capacitance

Dissipation factor/power factor measurement including source, capacitor and compensation reactor

The CPC 100, the CP TD1 and the CP CR500 compensating reactor, allows you to test insulation's quality of generators and motors. The system is ideal for use in the field thanks to its modular design, easily transportable reactors and integrated high-voltage source. The flexible connection of several reactors ensures that an optimum compensation at nominal frequency will be reached.

By measuring the power / dissipation factor (Tan Delta) and using the tip up test, you can draw important conclusions about partial discharge activity in high-voltage stator windings. Thanks to the measurement method used and the freely selectable bandwidths, it is even possible to perform exact measurements in areas with high levels of interference.

Testing templates guide you through the test process, and a comprehensive test report can be generated automatically.



CPC 100

Multi-functional test system for high-voltage assets

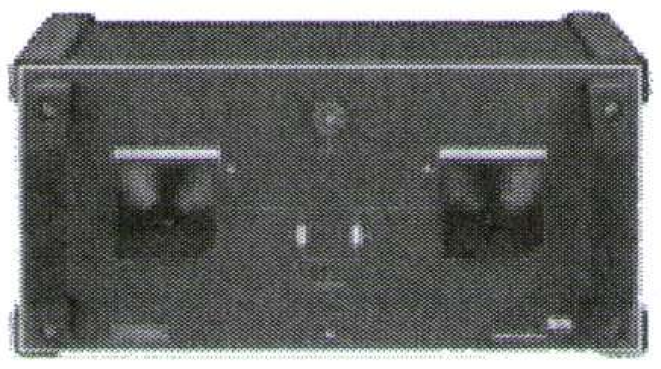
View Product

G158(17)

CP TD1

Accessory for power/dissipation factor and capacitance testing

View Product



CP CR500

Compensating reactor for the CP TD1

View Product

Related Products

- DIRANA

The DIRANA offers a fast, two-channel measurement of insulation systems like in power transformers, high voltage transformer bushings, cables and generators. In oil-paper insulated dielectrics the moisture content can be determined.

Precise measurement of dissipation factor, power factor and capacitance

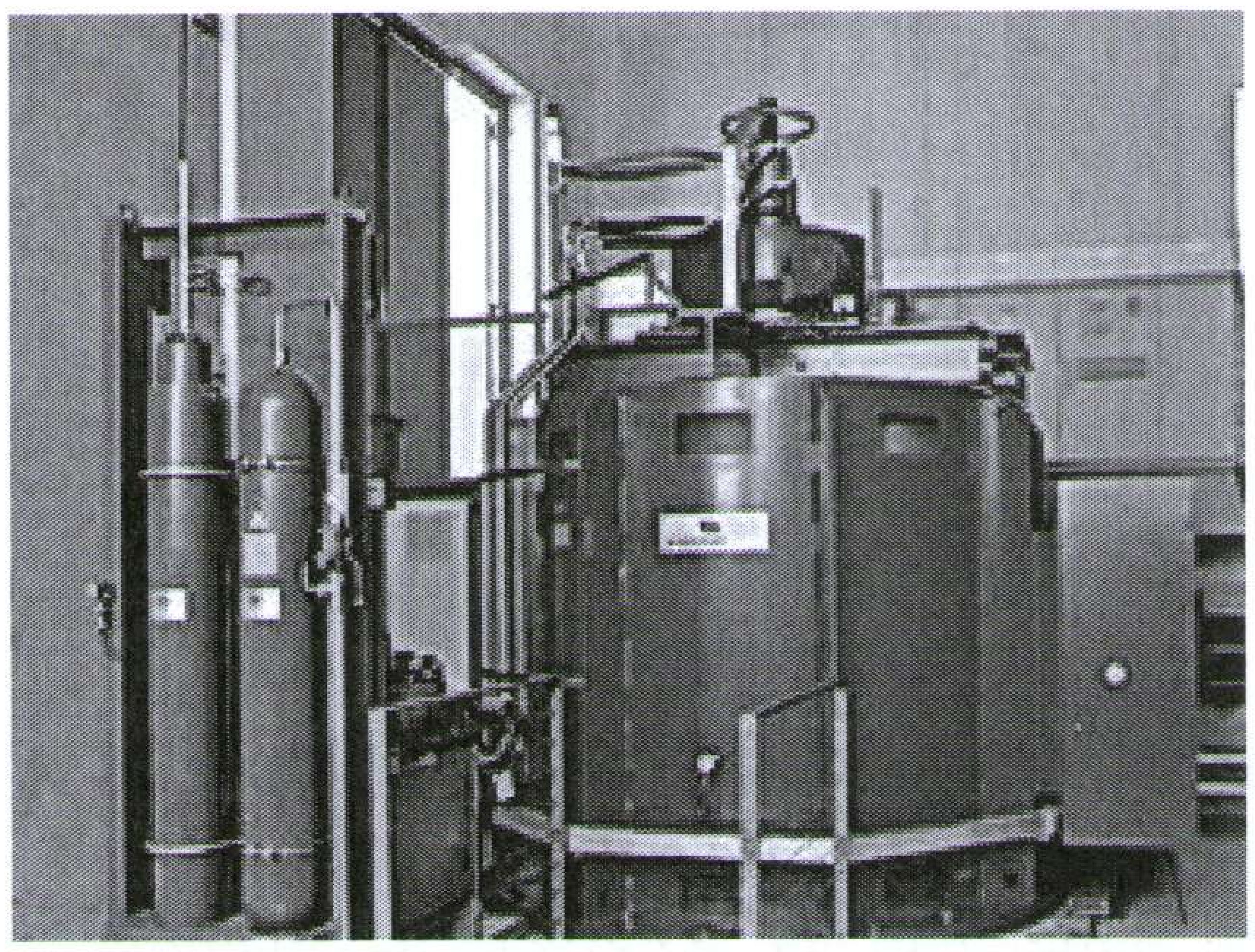
Our TANDO 700 supports you in the measurement and analysis of grounded and non-grounded generators and motors or single coils, since it is able to test at high voltage potential. You can use the TANDO 700 to measure dissipation/power factor (Tan Delta) and capacitance, both in test fields and on-site. In addition, it also measures parameters such as power, current, voltage, impedance and frequency.

The lightweight, modular system can be used both in test fields and on-site with an accuracy of IE-4 for achieving excellent results. Thanks to galvanic isolation between the test object and the measuring device, you can conduct your tests with a high level of safety.

The measurement range from 5 µA to 1 A can be extended with an external shunt of up to 28 A, allowing you to test even large generators. TANDO 700 shows you measurement data in real-time and displays related trends.

G152(18)

Dielectric Response Analysis

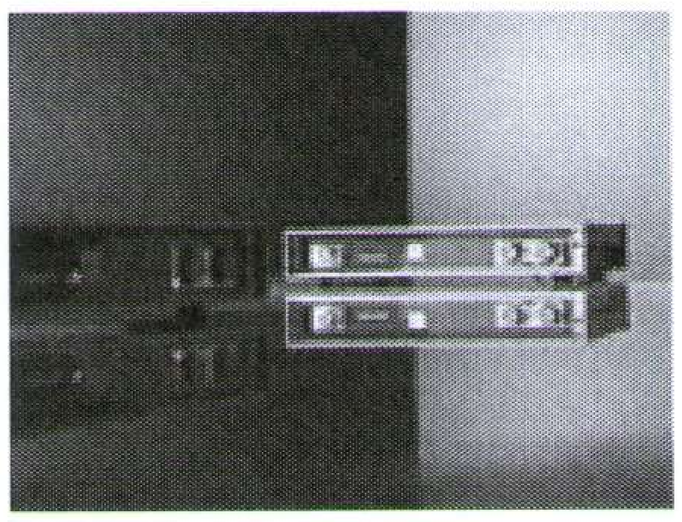


The condition of the insulation in rotating machines can be determined by measuring the dielectric characteristics of stator windings. Compared with classic measurements at just one frequency, measurements over a broad frequency range offer significant advantages. With these measurements, deteriorated or insufficient hardened parts of the insulation, moisture and other types of soiling can be identified more effectively.

Deviating or changing values, for example due to a comparison of various phases or with prior measurements, can indicate potential changes within the insulation. Aging processes, partial discharges in the insulation, or moisture ingress increase the dissipation factor, particularly in the low frequency range.

This diagnosis allows an early detection of impending failures. This enables timely corrective action to be initiated before the machine suffers major damage.

Recommended solutions for dielectric response analysis on generators and motors



DIRANA

Condition assessment of the insulation

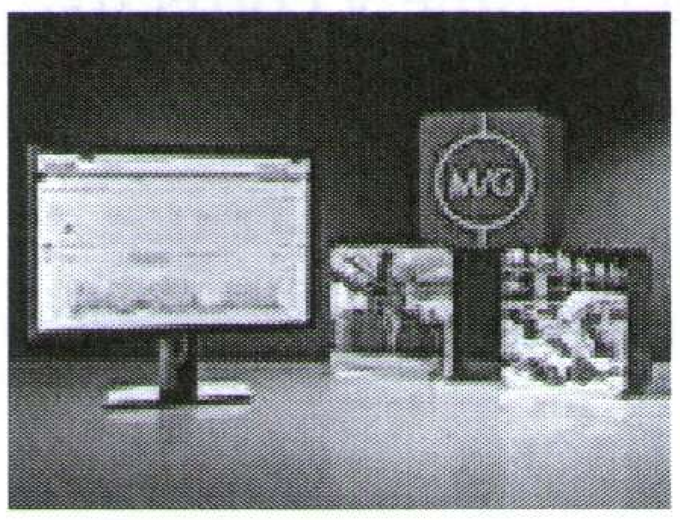
Partial Discharge Monitoring

According to failure statistics, the second most common cause of outage in motors and generators is related to stator insulation faults. During their service life a variety of stress and ageing factors result in partial discharge (PD) activity, which can cause defects and eventual dielectric failure in the insulation of stator windings.

A specific level of PD is allowed to occur in stator insulation of large rotating machines. Sensitive partial discharge measurements localize potential defects before failure occurs. Noise suppression and PD source separation algorithms are used to reliably identify and localize harmful PD activity.

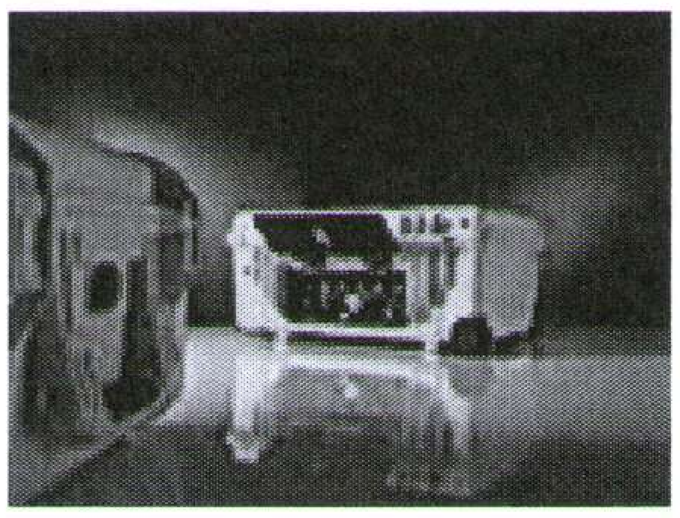
Continuous or temporary PD monitoring provides up-to-date information about the condition of stator insulation in rotating machines during normal operation.

Recommended solutions for partial discharge analysis on generators and motors



MONGEMO

Fixed-installed, continuous partial discharge monitoring



OMS 605 System

Portable, temporary partial discharge monitoring

G158(20)

What is HV Machine Testing & Plan layouts for electrical switchboards and control panels for marine electrical works

UENEEG158A-High voltage machines testing & measurement involve the following

- Partial discharge analysis in which testing how insulation layers deteoriate
- Dielectric response analysis in which how non sinusoidal components such as harmonic high frequencies downgrade the insulation in which checking dielectric tangent
- Gas analysis in which how gas compose the gas created by arc.
- Non destructive testing in which taking X Rays on machine components
- HV machine testing also consists monitoring the symptoms.

I got sufficient collections on it

UEENEEG128A - Plan layouts for electrical switchboards and control panels

It is marine engine room control switch gears customisation. Resources are ready

Switch layout

Hello Sirs,

What is HV Machine Testing & Plan layouts for electrical switchboards and control panels for marine electrical works
UENEEG158A-High voltage machines testing & measurement involve the following

- Partial discharge analysis in which testing how insulation layers downgrade (Harmonics are the main causes for partial discharge if the AC wave forms are non sinusoidal especially ac current formed by inverters can cause harmonics this is why sine wave inverters with PWM technology is required to reduce the partial discharge.
- Dielectric response analysis in which how non sinusoidal components such as harmonic high frequencies downgrade the insulation in which checking dielectric tangent
- Gas analysis in which how gas compose the gas created by arc.
- Non destructive testing in which taking X Rays on machine components
- HV machine testing also consists monitoring the symptoms.

I got sufficient collections on it

UEENEEG128A - Plan layouts for electrical switchboards and control panels
It is marine engine room control switch gears customisation. Resources are ready.

4 HIGH VOLTAGE TESTING AND MEASUREMENT

Benjamin Franklin: The man who dared to fly his kite in a thunder storm ...

In the previous chapters the insulation characteristics of materials under high voltage stresses were discussed. It was seen that overstressing leads to failure of the equipment. In this section laboratory tests and test equipment needed to assess the performance of materials and equipment relative to the specifications are discussed. The different methods to accurately measure high voltages are also discussed. The actual stresses that may occur on the power system will be dealt with in Chapter 5.

4.1 Generation of High Voltages

Laboratory testing attempts to simulate the voltage conditions that the apparatus may experience on the power system. These voltages include the normal AC or DC system voltages and switching and lightning impulse voltages. Tests can be performed to obtain the failure or flashover voltage or otherwise to obtain the withstand voltage of an apparatus.

4.1.1 Power frequency voltage and current (AC)

In an AC network the equipment is continuously subjected to full power frequency voltage. The equipment should therefore be able to withstand power normal frequency voltage, allowing for some overvoltage.

In a high voltage laboratory the test transformers steps up the voltage from a lower voltage (220 V or 11 kV) to the desired voltage level. All laboratory tests are single phase and the low voltage side of the transformer is supplied via a regulating transformer to be able to adjust the magnitude of the output high voltage. A typical AC high voltage set-up is shown in Fig. 4.1.

The following features should be noted:

- *Ground plane*: The high voltage is generated with respect to the laboratory ground, a low impedance sheet, connected to an earth electrode.
- *Voltage divider*: The voltage is measured with a resistive or capacitive voltage divider as is described in section 4.2.1.

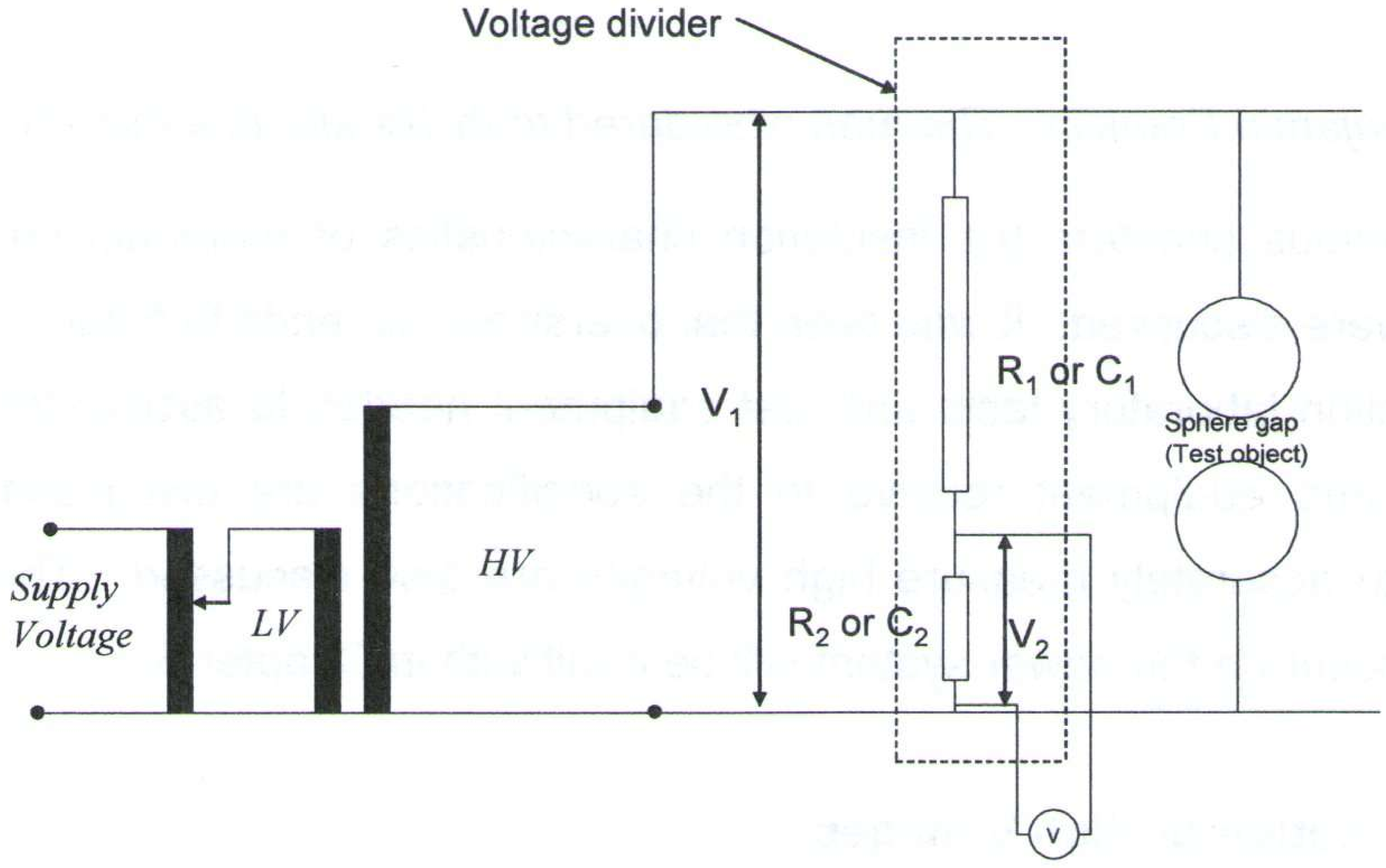


Fig. 4.1: Schematic diagram of a typical AC test transformer and its connections.

Typical designs of high voltage test transformers are shown in Fig. 4.2(a). In the design on the right an insulated tank (a resin impregnated paper cylinder) is used and a bushing is not required, as is shown in Fig. 4.2(b).

Test transformers can be used in cascade connections as is shown in Fig. 4.3. Each unit has 3 windings: a primary (low voltage), a secondary (high voltage) and a tertiary (low voltage) winding. The tertiary has the same rating as the primary winding; however, it is insulated for high voltage. The tertiary winding is used to supply the primary of the next unit. The tanks of the second and third units are insulated for high voltage and are mounted on insulators.

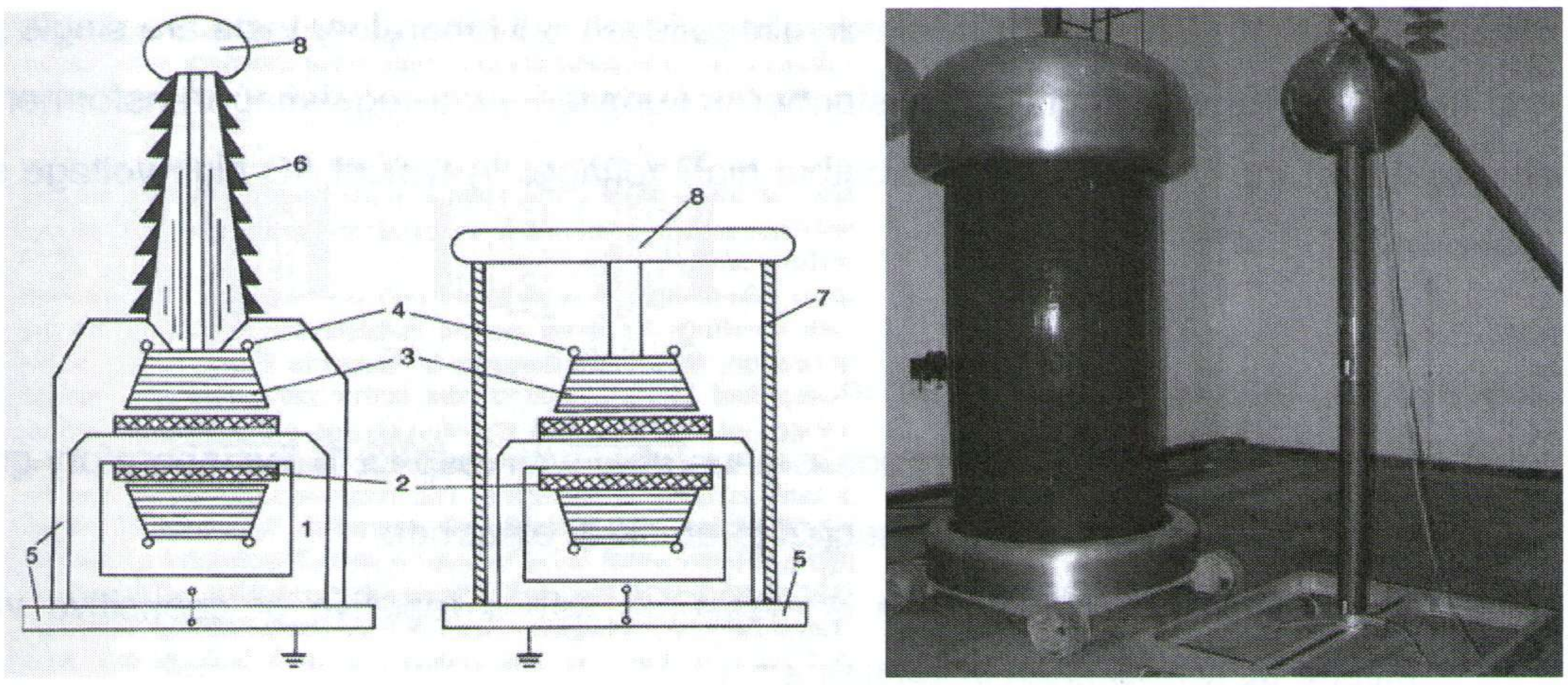


Fig. 4.2: Typical designs of AC test transformers

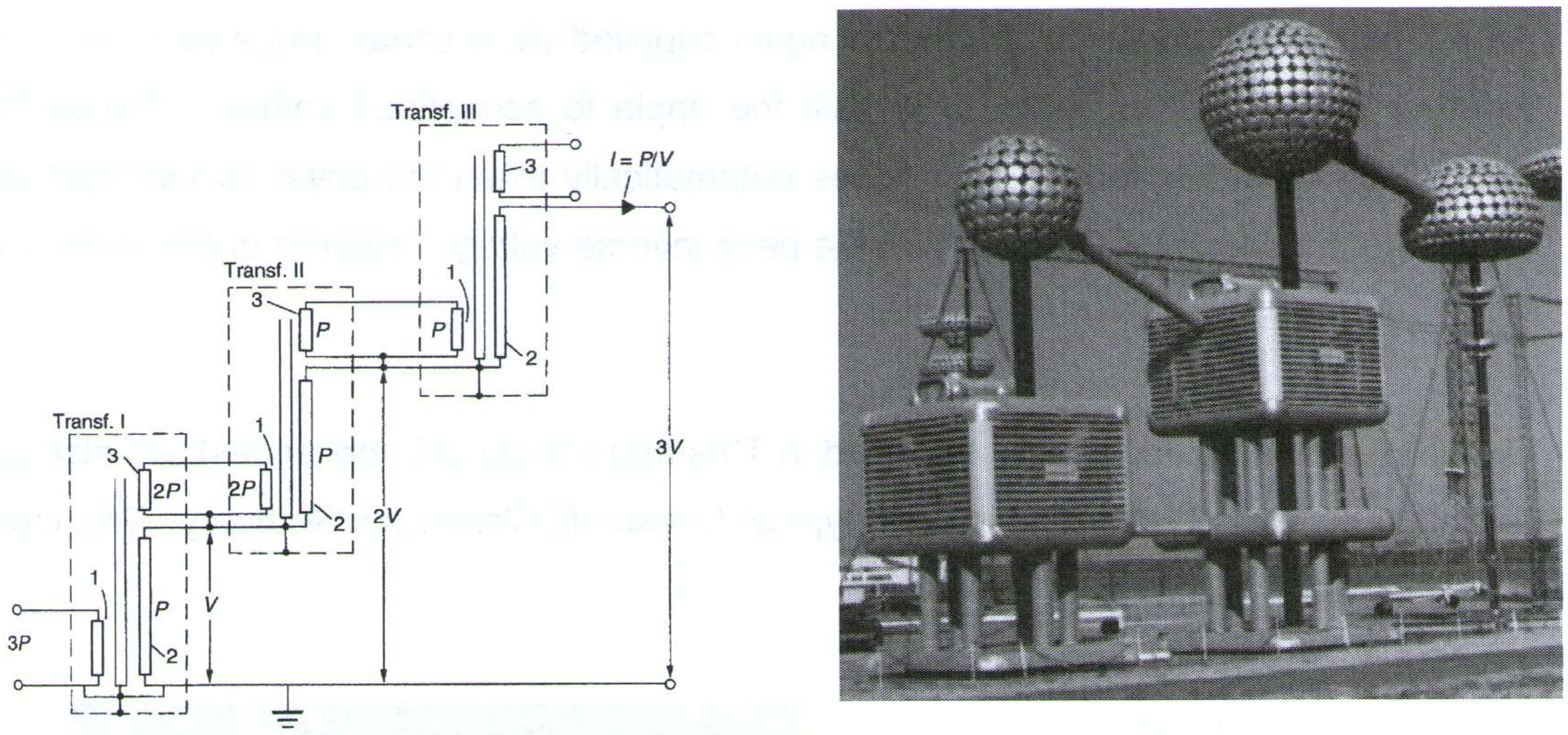


Fig. 4.3: Cascade connected test transformers

The method when performing AC tests is to increase the voltage gradually until flashover occurs. The voltage just before flashover is the flashover voltage.

4.1.2 Direct current (DC)

DC tests are used mainly to do "pressure tests" on high voltage cables. Although the cables operate with AC, AC testing is not practical. The high capacitance of the cables necessitates AC test sets with a high kVA rating to be able to supply the capacitive current. In the case of DC, once the cable is charged, only the losses have to be supplied.

DC test sets usually consist of half wave rectification, using HV selenium rectifiers. A typical DC test set-up is shown in Fig. 4.4.

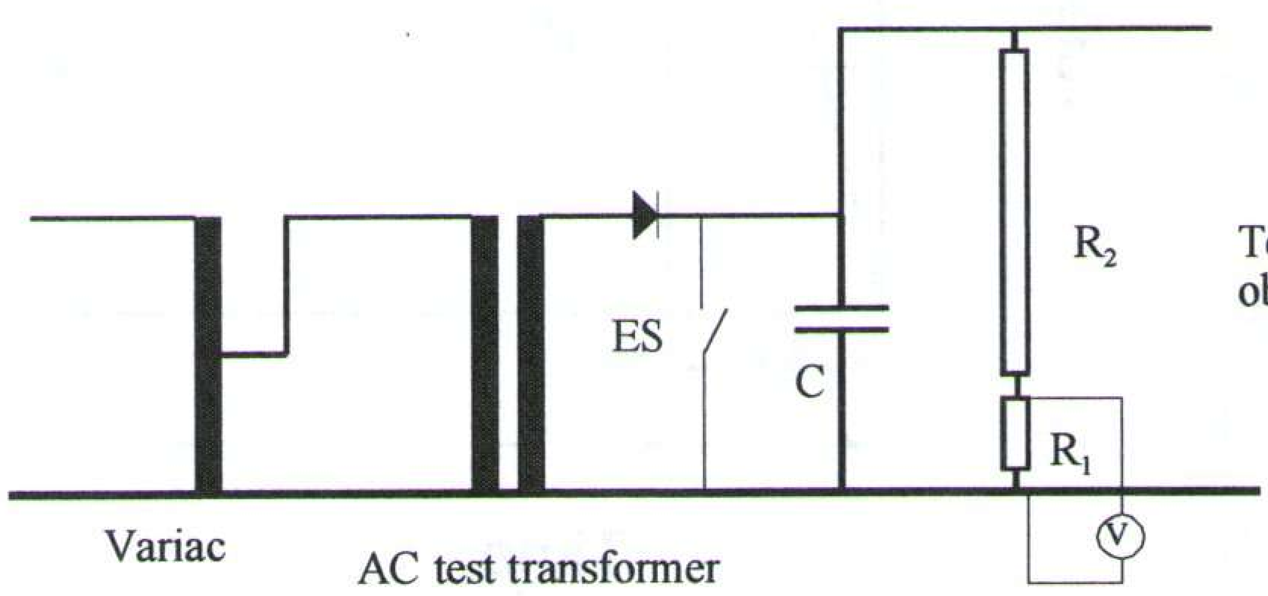


Fig. 4.4: Typical circuit for DC tests

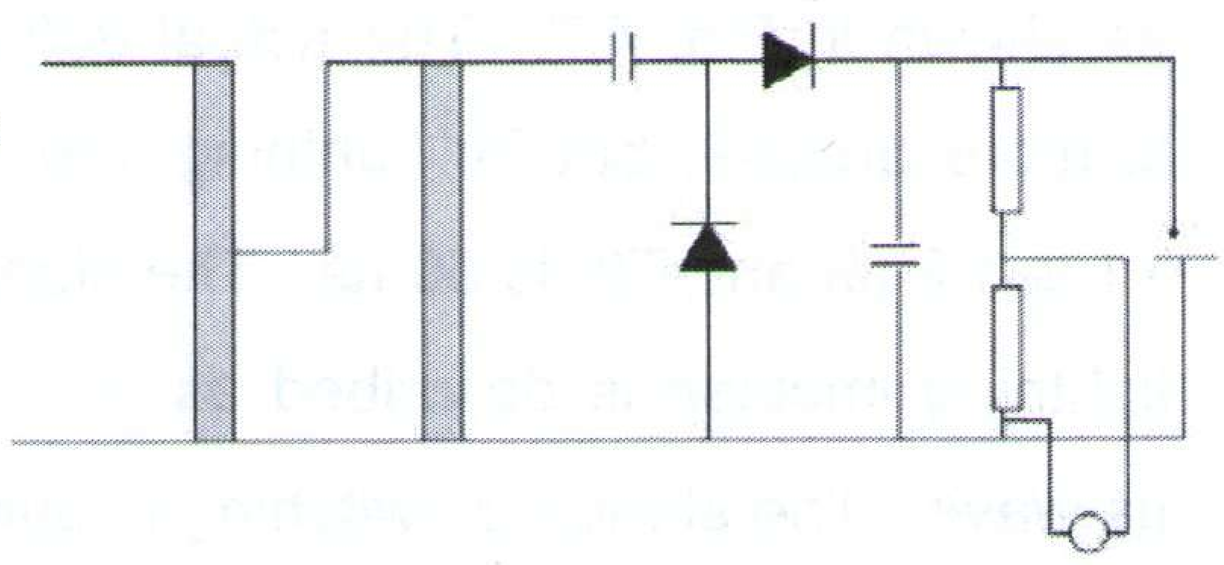


Fig. 4.5: Typical doubling circuit for DC tests

An AC high voltage test transformer is again supplied via a variac and a rectifier is used together with a filter capacitor C to limit the ripple to acceptable values. The earthing switch ES is a safety feature and closes automatically when the power is switched off to discharge the capacitor C. Note that the peak inverse voltage required of the rectifier is 2 V_m.

Doubling and multiplier circuits (as used in TV's and household appliances) are also used to obtain an even higher voltage. A typical Cockcroft-Walton (in Germany: Greinacher) doubling circuit is shown in Fig. 4.5.

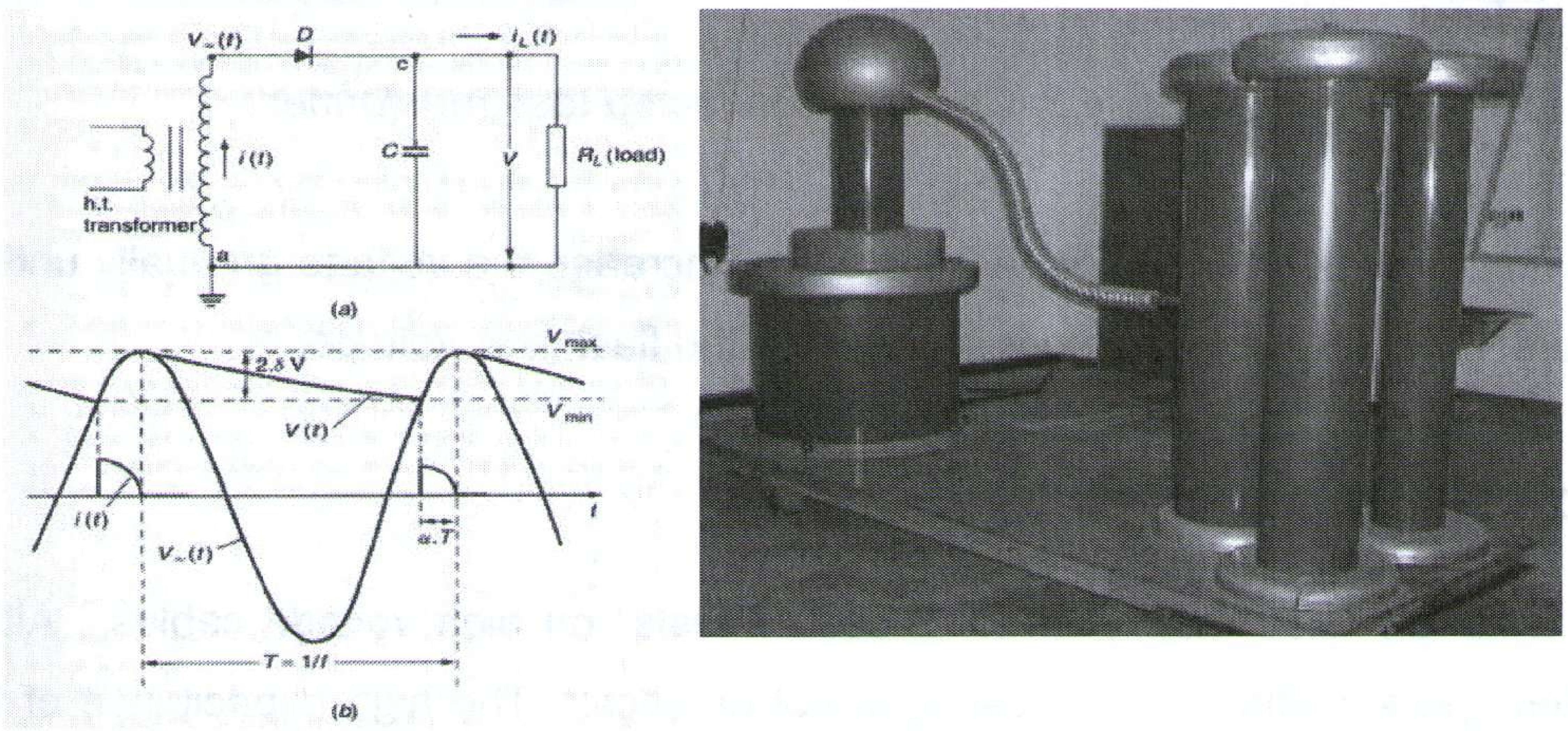


Fig. 4.6: Typical waveforms and a typical doubling circuit DC test source

4.1.3 Lightning and switching impulses

In chapter 5 it will be shown that the power system is also subjected to single overvoltage pulses, due to lightning and switching. In the field these transients can take on many different wave shapes. Standard impulse wave has been defined as shown in Fig. 4.7. The actual definition is more precise, but for lightning impulses, T1 is 1.2 µs and T2 is 50 µs. The standard lightning impulse is described as a 1.2/ 50 µs wave. The standard switching impulse is a 250/ 2500 µs wave.

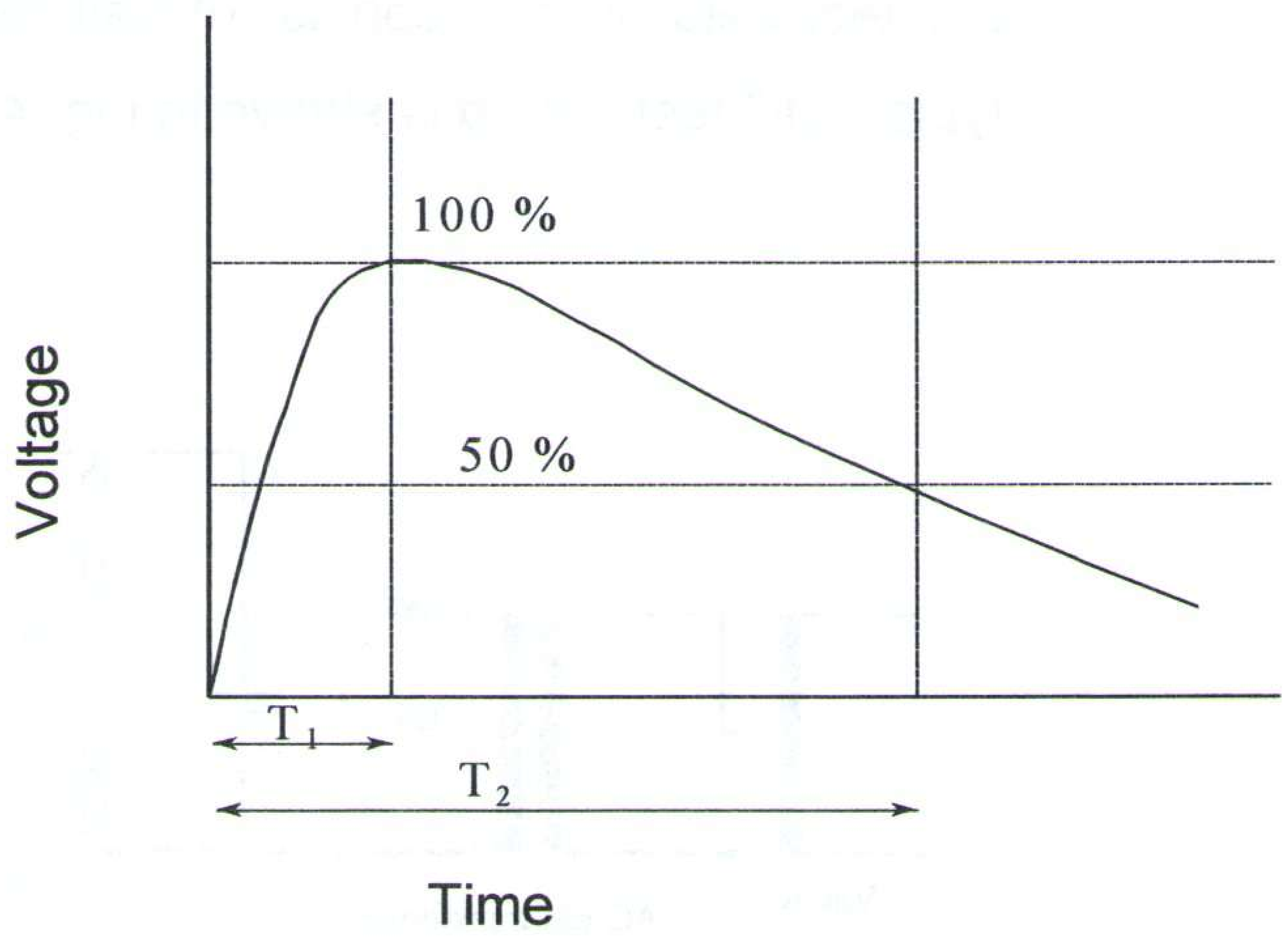


Fig. 4.7: Standard impulse wave

During transformer tests it is sometimes required to chop the impulse to obtain a high *dv/dt*, in order to test the inter-turn insulation.

The Impulse generator

In order to generate a wave with the required shape, circuits similar to that shown in Fig. 4.8 are used. A capacitor C_1 is charged via a current limiting resistor, R_s, from a HV dc source similar to those shown in Figs. 4.4 and 4.5.

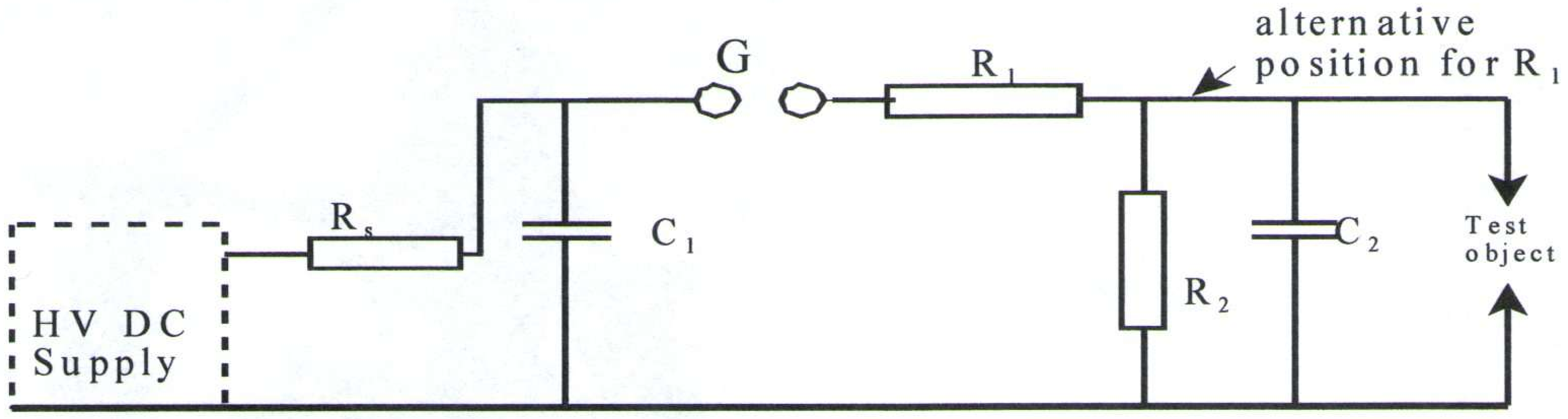


Fig. 4.8: Single stage impulse generator

As the DC voltage is raised slowly the stress across the spark gap G increases until the air in the gap breaks down. Capacitor C_1 now discharges into the circuit consisting of C_2, R_1 and R_2. The voltage appearing across the test object has the desired shape. The components C_1, C_2, R_1 and R_2 are chosen to give the required front and tail times. It turns out that $C_1 >> C_2$ and $R_2 >> R_1$. Capacitor C_1 will recharge via R_s and repetitive pulses will be generated.

There are two possible positions for R_1 as is shown in Fig.4.8.

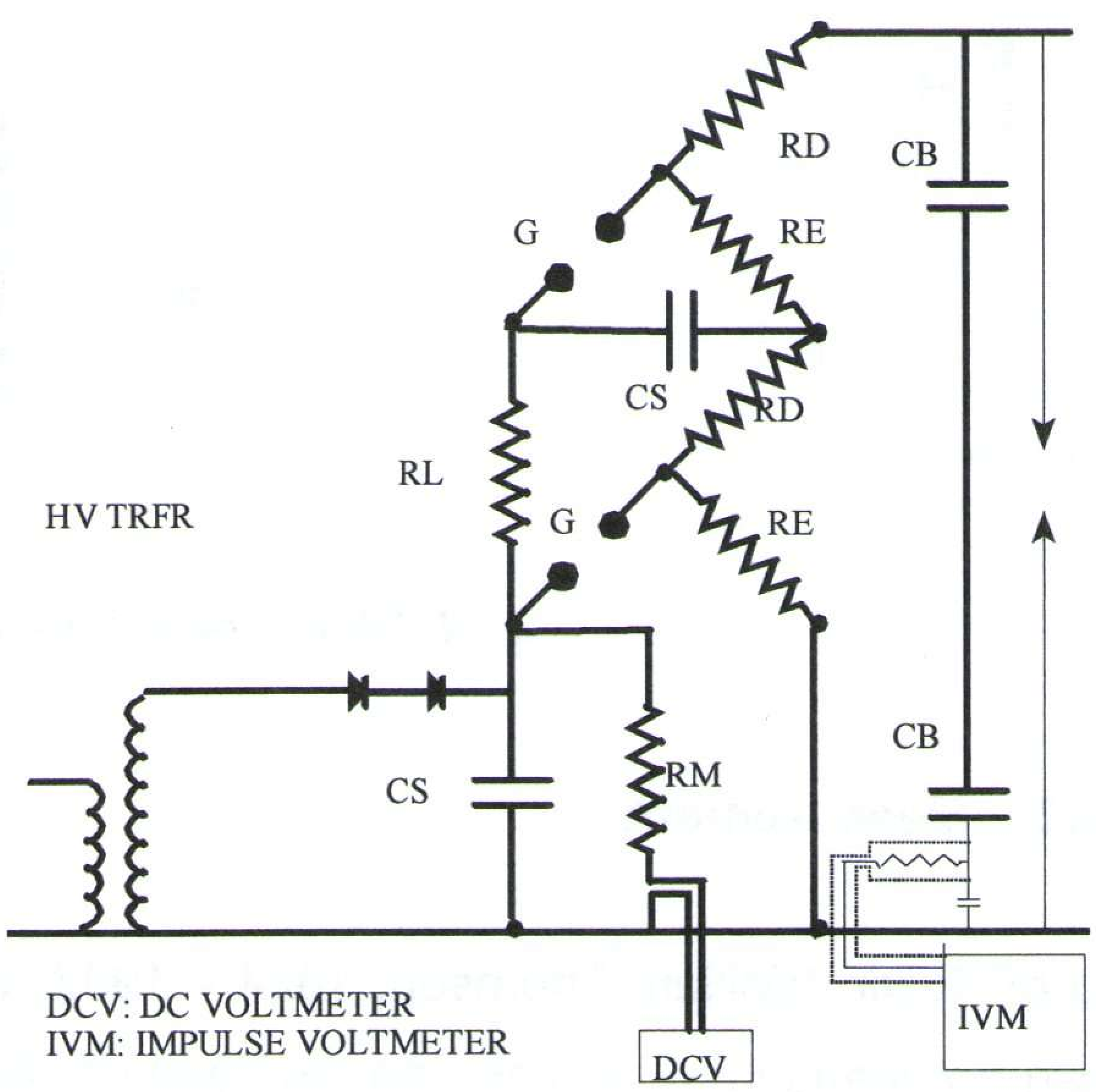


Fig. 4.9: Two-stage impulse generator

It is possible to design a multi stage impulse generator by charging the various stages in parallel and by discharging in series. This principle was invented by Marx in 1923. A typical circuit is shown in Fig. 4.9. Note that it is possible to trigger the lowest gap of the generator artificially. The resulting transient causes the other gaps to flash over simultaneously.

Impulse generators are specified in terms of the peak voltage and the stored energy. The generator shown in Fig. 4.10 is a 1.4 MV, 16 kJ generator.

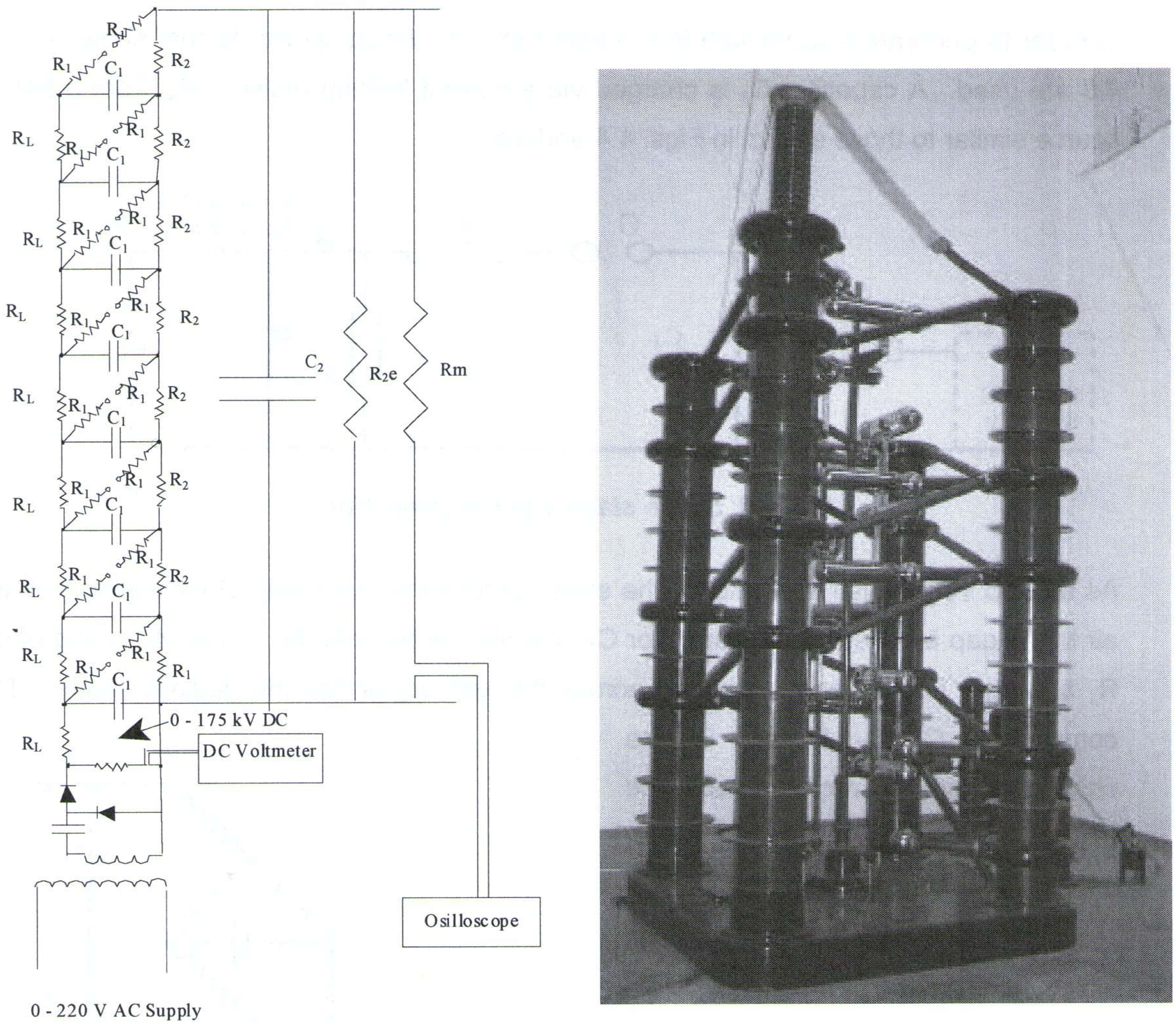


Fig. 4.10: 8- stage impulse generator

4.2 Measurement

Lord Kelvin (William Thomson, 1824 – 1907) wrote, "To measure is to know" and, "If you can not measure it, you can not improve it." Accurate measurements are likewise the key to successful testing and research. The problem with high voltage is, however, that, due to safety reasons, the meters can not be connected directly to the high voltage conductors. It is therefore necessary to use equipment to scale down the voltage signal to a safe value that can be displayed on instruments. On the power system, voltage and capacitive voltage transformers are used (section 1.3.5), while voltage dividers are used in the laboratory. Obviously, accuracy of the whole system is of the utmost importance.

4.2.1 Voltage dividers

The operation of voltage dividers depend on the division of voltage across two series impedances, Z_1 and Z_2, as shown in Fig. 4.11. In this figure:

$$V_2 = \frac{Z_2}{Z_1 + Z_2} V_1 \qquad (4.1)$$

In this equation $Z_2 \ll Z_1$, resulting in V_2 being a scaled version of V_1. The nature of Z_1 and Z_2 depends on the type of voltage to be measured, as is shown in Table 4.1.

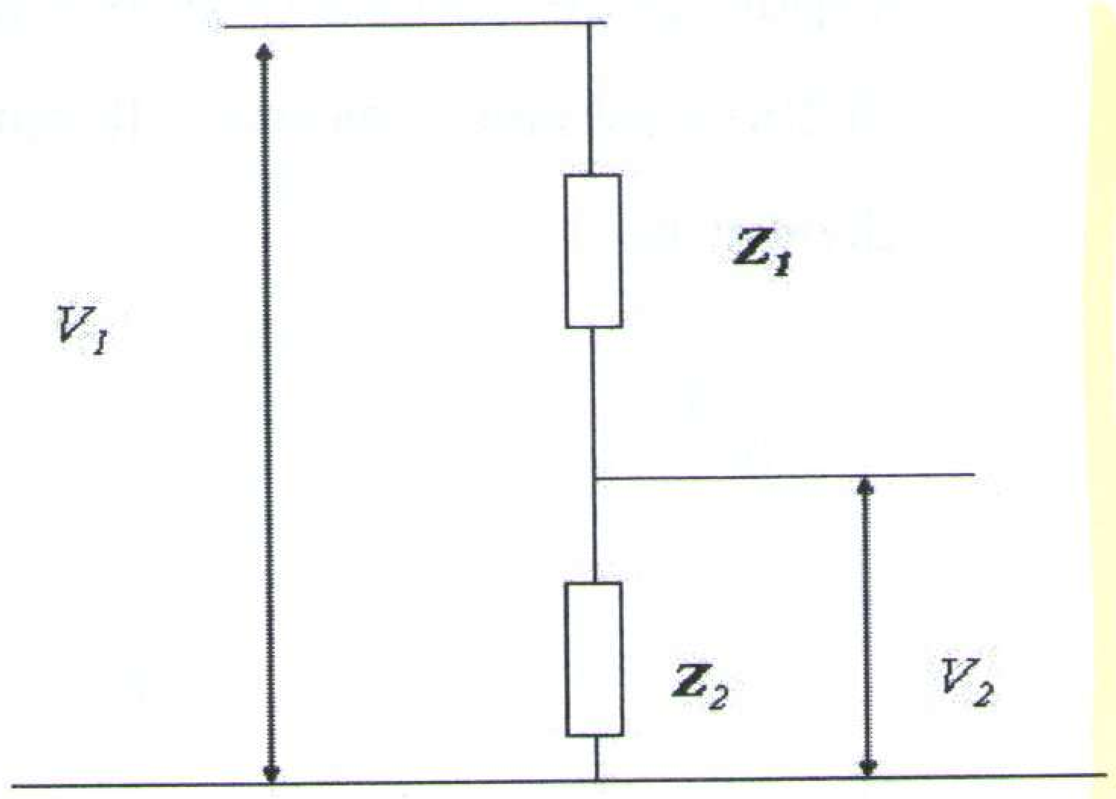


Fig. 4.11: General voltage divider

Table 4.1: Voltage dividers for different types of voltages

Type of voltage	**Nature of the impedances**
DC	Resistors
AC	Resistors or Capacitors
Impulse	Resistors or Capacitors

AC and DC measurements

For a resistive divider:

$$V_2 = \frac{R_2}{R_1 + R_2} V_1 \qquad (4.2)$$

For a capacitive divider:

$$V_2 = \frac{C_1}{C_1 + C_2} V_1 \qquad (4.3)$$

The voltmeter is directly calibrated in terms of the high voltage. *The sphere gap* is used to calibrate the voltage measurement.

Impulse measurement

Impulse waves can be measured and displayed on an oscilloscope, using resistive or capacitive dividers.

Resistive impulse dividers

A resistive divider has distributed stray capacitance to ground that may affect the accuracy of high frequency measurements. As is shown in Fig. 4.12, this stray capacitance can be approximated by an equivalent capacitor, C_e, connected to the centre of the resistive column. It can be shown that $C_e=\frac{2}{3}C$ and that the time constant of the divider is:

$$\tau = \frac{1}{6} R_1 C_e \qquad (4.4)$$

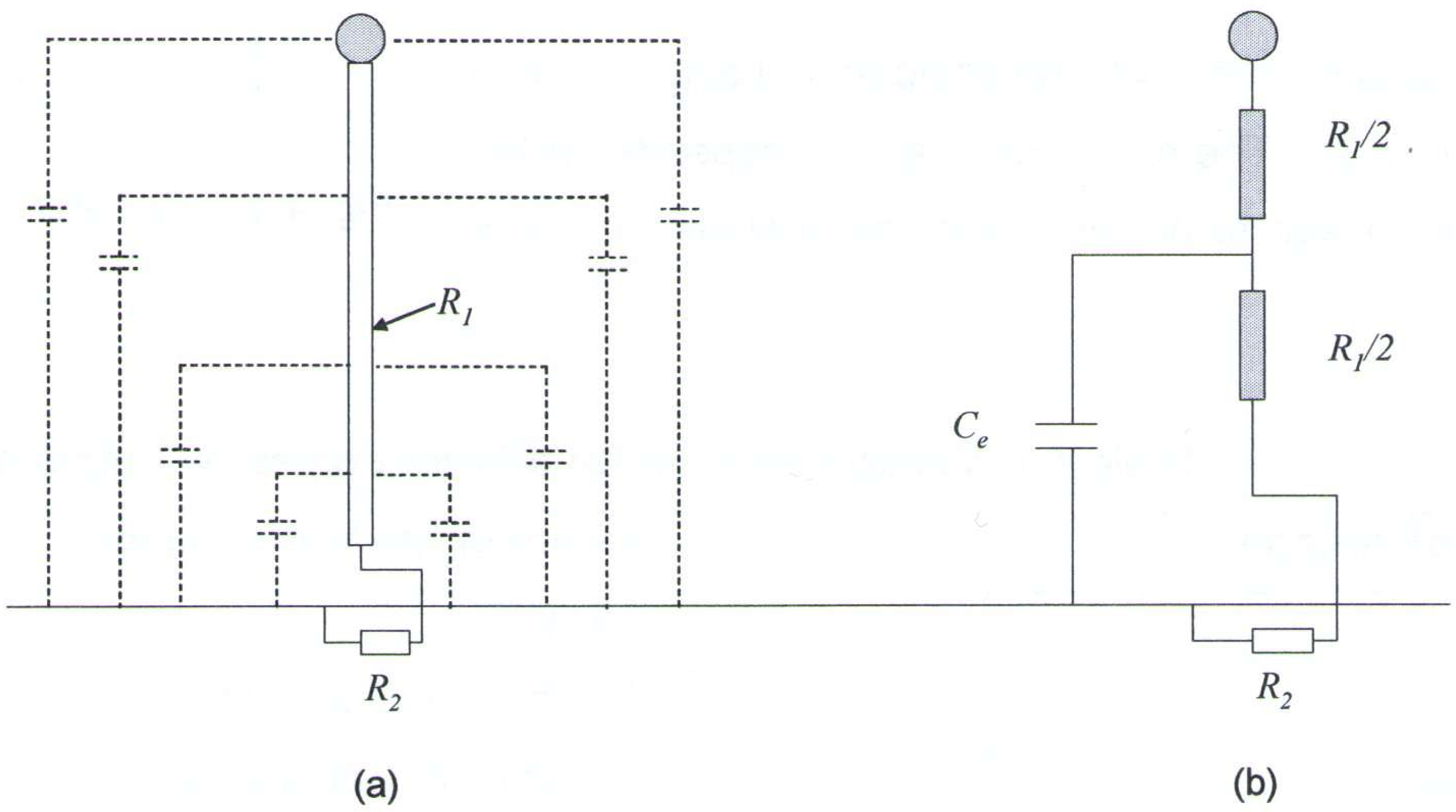


Fig. 4.12: (a) Stray capacitance of a resistive divider and (b) the equivalent circuit

The total capacitance-to-ground of vertical structures, such as dividers, are estimated at 15 to 20 pF/m height. Thus, a 1 MV divider, having a height of 3 m and a resistance of 20 kΩ would have a time constant of approximately 200 ns, only just adequate for a 1.2/50 μs wave.

Note that the coaxial cable must be terminated in its characteristic impedance at both ends, as is the case in the circuit in Fig. 4.13.

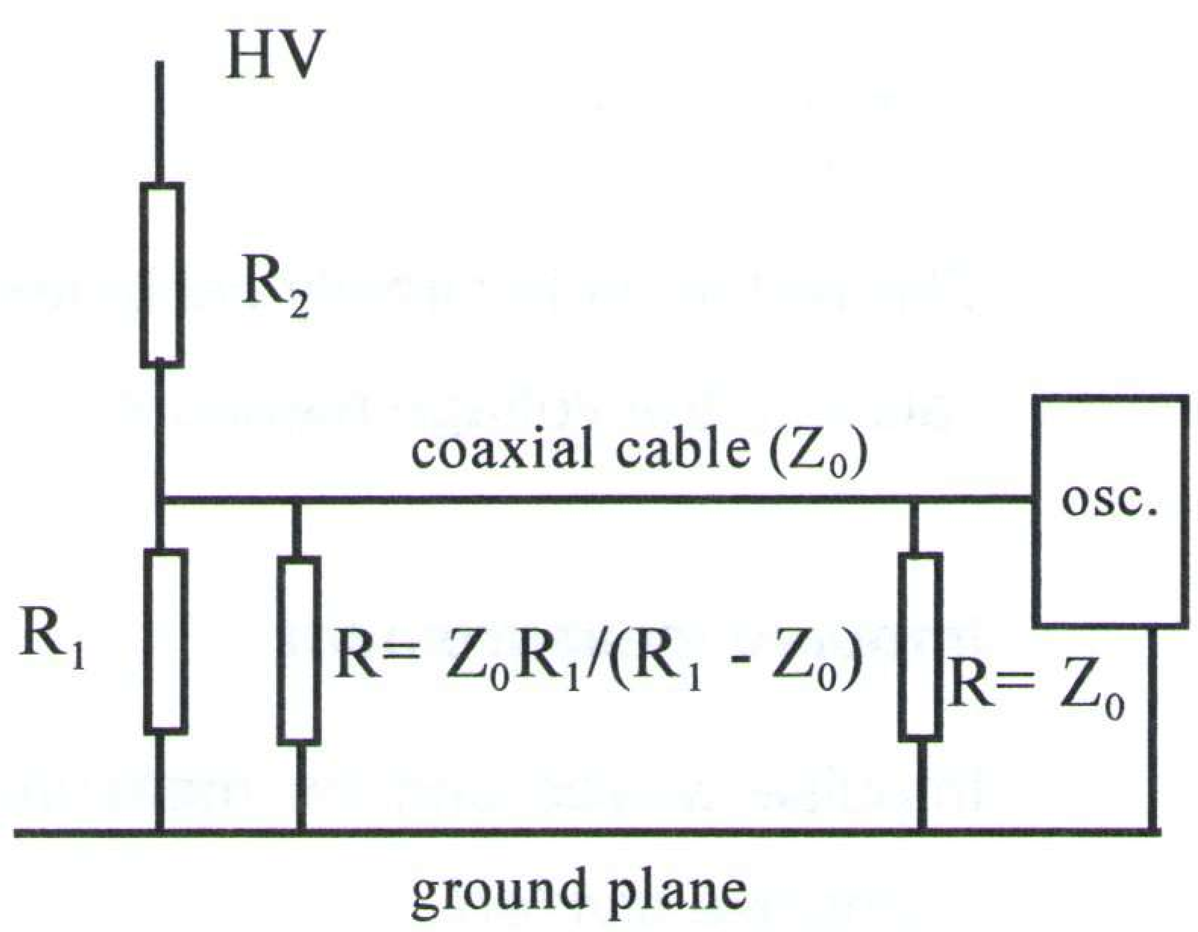


Fig. 4.13: Resistive impulse divider

Capacitive impulse dividers

In the case of a capacitive divider the stray capacitances are usually negligible, compared to the capacitance values of the divider.

9158(35)

Typical values for a 100 kV capacitive divider are C_1= 100 pF and C_2= 100 nF.

For the capacitive divider, shown in Fig. 4.14, the shunt resistor would allow the charge on C_1 to leak away and series matching must be used. The resistor R= Z_0 and the characteristic impedance of the cable forms a divider to halve the impulse when it travels along the line. At the oscilloscope, having a high input impedance, voltage doubling takes place and the original wave appears at the oscilloscope.

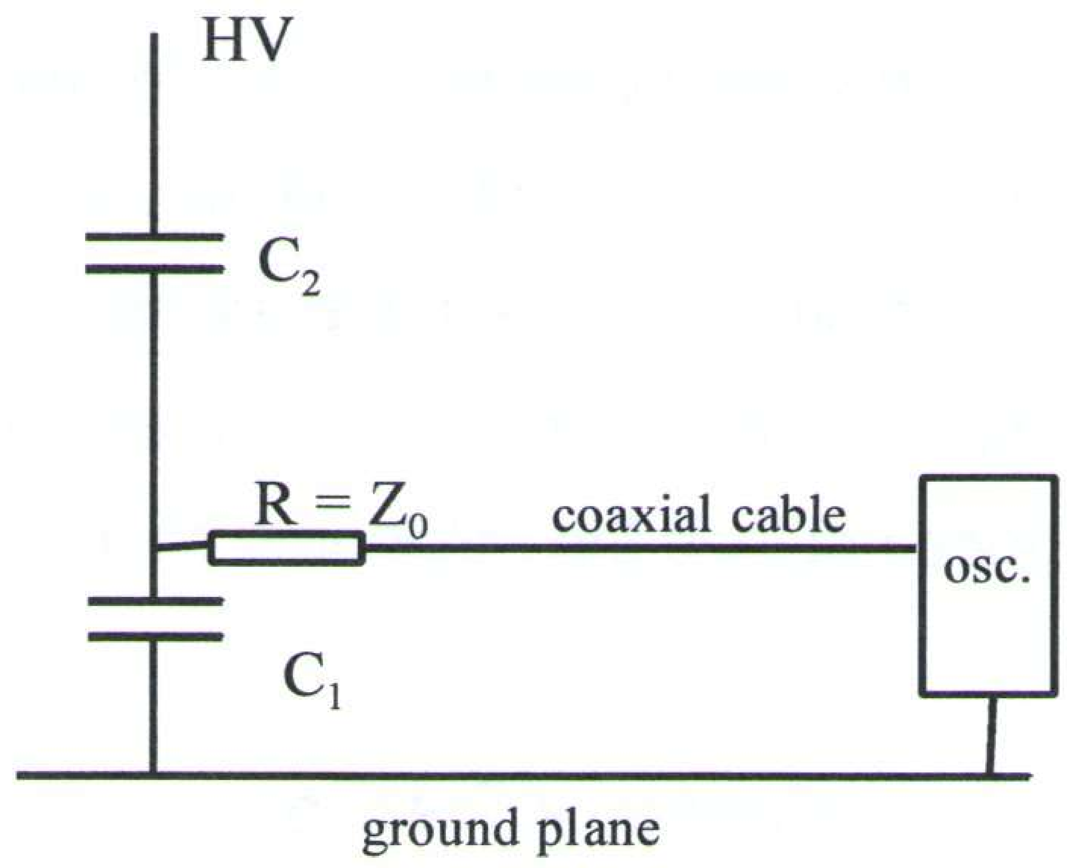


Fig. 4.14: Capacitive impulse divider

4.2.2 Peak and RMS voltmeters

Since flashover usually takes place at the peak of the AC wave, it is necessary to measure the peak and not the rms voltage (the voltage may deviate from a pure sinusoid). A typical circuit is given in Fig. 4.15, using a peak -hold circuit. Despite the fact that the metre measures peak, it is calibrated (scaled) in terms of $V_{peak}/\sqrt{2}$. The time constant RC should be low enough to allow the meter to follow variation in the supply voltage. The resistance R (includes the resistance of the voltmeter V) must be much larger than $1/(2\pi fC)$.

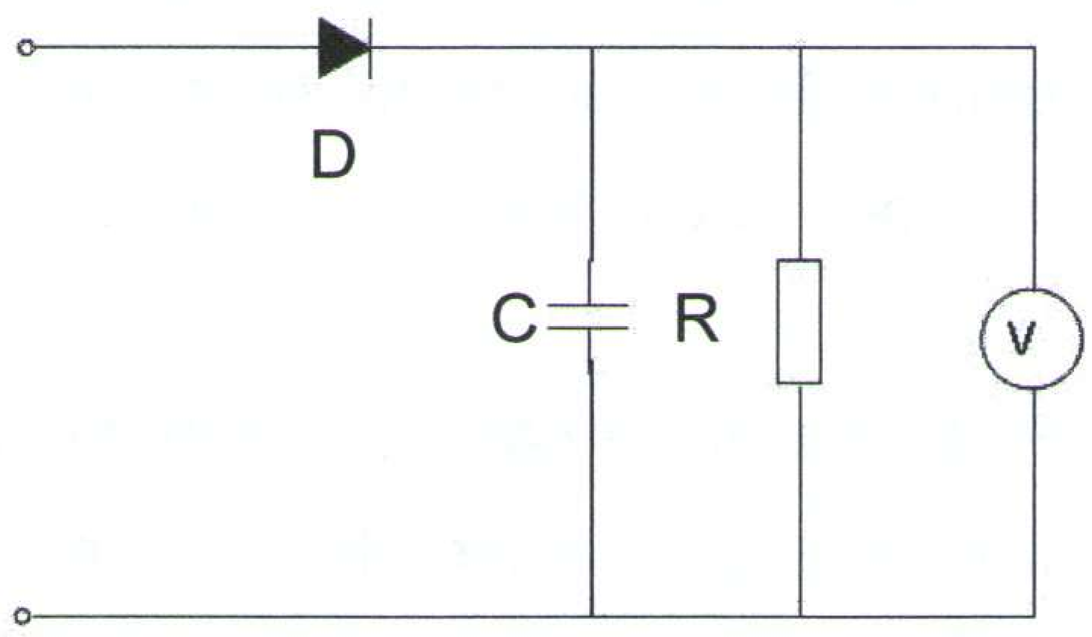


Fig. 4.15: Typical AC peak voltmeter circuit

4.2.3 Sphere gaps for voltage measurement

Paschen's Law indicates that there exists a relationship between the flashover voltage, the gap length and the gas density (section 3.1.5). International standards have therefore been drawn up to relate the gap length with flashover voltage. Provision has been made to correct for air pressure and temperature. Usually an accuracy of about 3 % can be obtained. Specifications such as IEC 52-1960 contains tables for various sphere diameters and gap sizes.

4.2.4 Electrostatic voltmeters

Electrostatic voltmeters rely on the Coulomb force of attraction between two electrodes that have a potential difference between them. Such a measuring system has the advantage that the measurement relies on the laws of physics. In addition, the input impedance of the meter is capacitive. Especially in the case of DC, the meter therefore does not load the measured circuit.

4.3 Laboratory Testing

4.3.1 Interpretation of AC, DC and Impulse test results

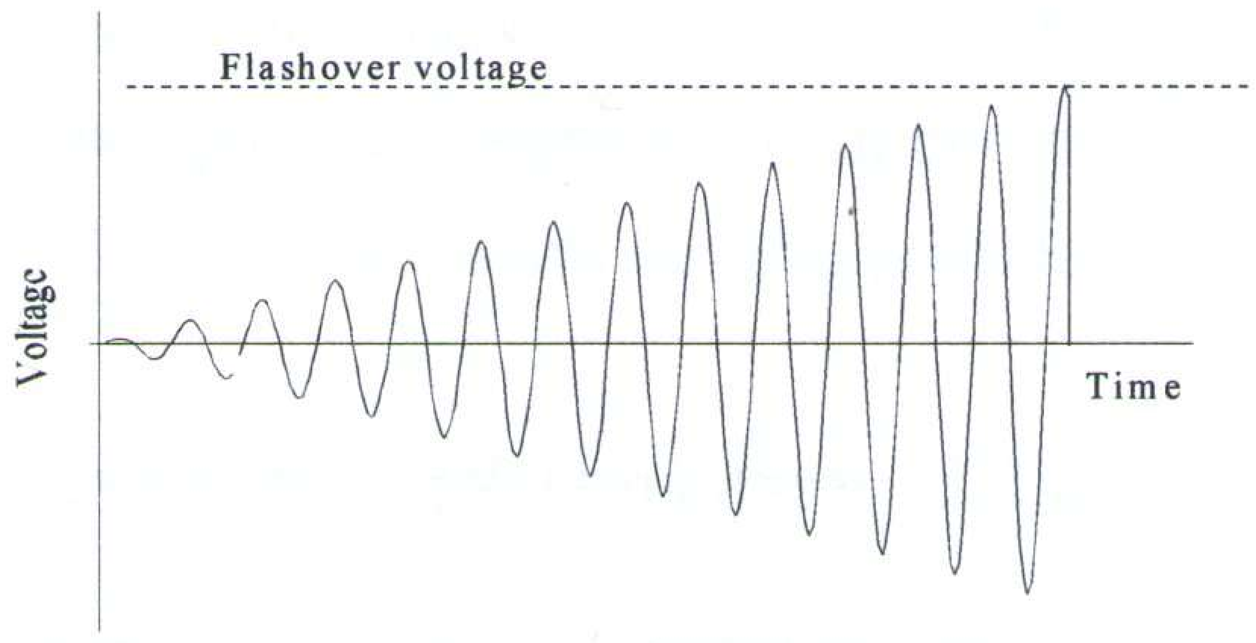


Fig. 4.16: AC flashover with increasing voltage.

With DC and AC tests the voltage across the test object is gradually increased until flashover. This is schematically portrayed in Fig. 4.16 for the AC case. The voltage, just before flashover, is taken as the flashover voltage. These tests are also performed on oil samples, using a 2.5 mm gap.

Flashover tests can be performed on air insulation, such as the flashover tests on power line insulators. More often, however, "non-destructive" withstand tests are performed, i.e. equipment must be able to withstand a specified withstand level for 60 seconds. The voltage is then increased up to the required voltage and kept at that value for 60 s.

Impulse tests are however more difficult to interpret. As shown in Fig. 4.17, the result of a test is either a flashover or a withstand (no flashover). A large impulse will cause a flashover on the front of the impulse. Flashovers are also possible on the tail of the impulse, although not shown.

It is also important to note that flashover is a statistical phenomenon as it depends on the availability of initialising electrons and other environmental influences. Even with AC and DC tests, a certain statistical variation is to be expected. With impulse testing, the critical flashover value as shown in Fig. 4.17 is not well-defined. In consecutive tests near this value on the same gap, some tests will result in flashover and others in withstand. The critical flashover voltage (CFO) is therefore defined as the 50 % flashover voltage. Out of 10 tests, an impulse with a peak value equal to the CFO will result in 5 flashovers and 5 withstands. This can also be seen from Fig. 4.18 where the flashover probability is shown as a function of impulse voltage.

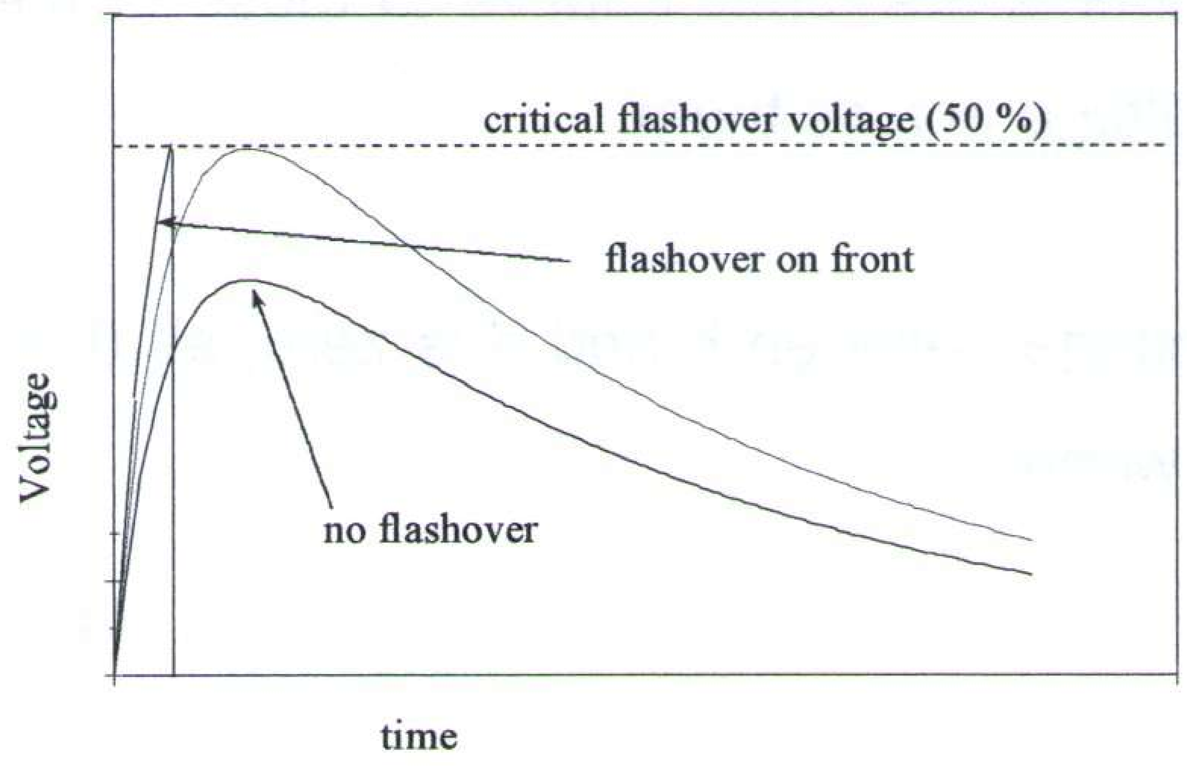


Fig. 4.17: Impulse flashover – time to flashover

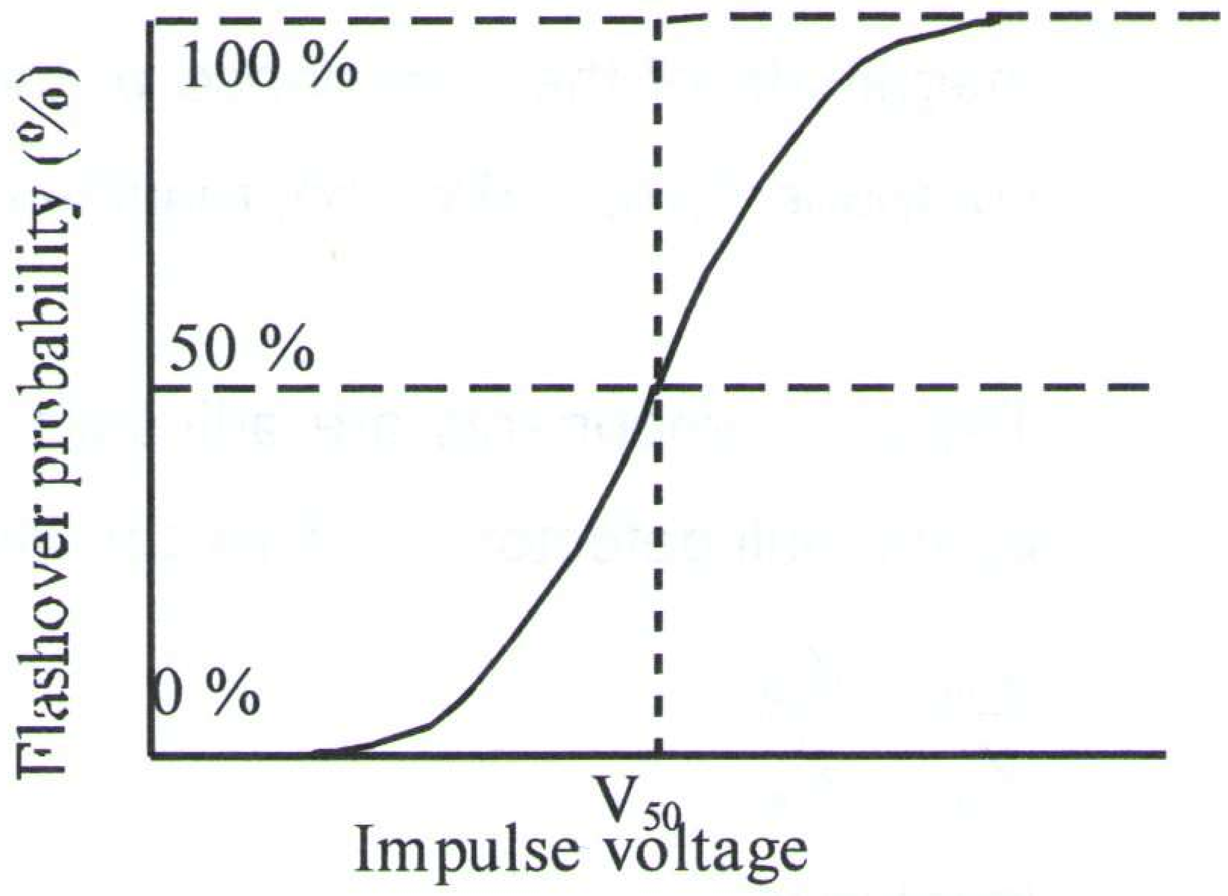


Fig. 4.18: Impulse flashover probability.

4.3.2 Non-destructive tests

Measurement of tan δ and capacitance with the Schering bridge

It was shown in section 4.2 that the loss factor, tan δ, is an indication of the quality of solid or liquid dielectrics. Measurement of tan δ of apparatus, such as high voltage current transformers provides a non-destructive indication of the quality of the insulation.

The capacitance and tan δ of high voltage equipment is measured, by applying the test voltage to the specimen in a way that corresponds to the way the apparatus is normally energised. In the case of a current transformer the secondary winding and core, connected together, would form the lower terminal of Rx/Cx in Fig. 4.19 while the primary winding would be connected to the high voltage.

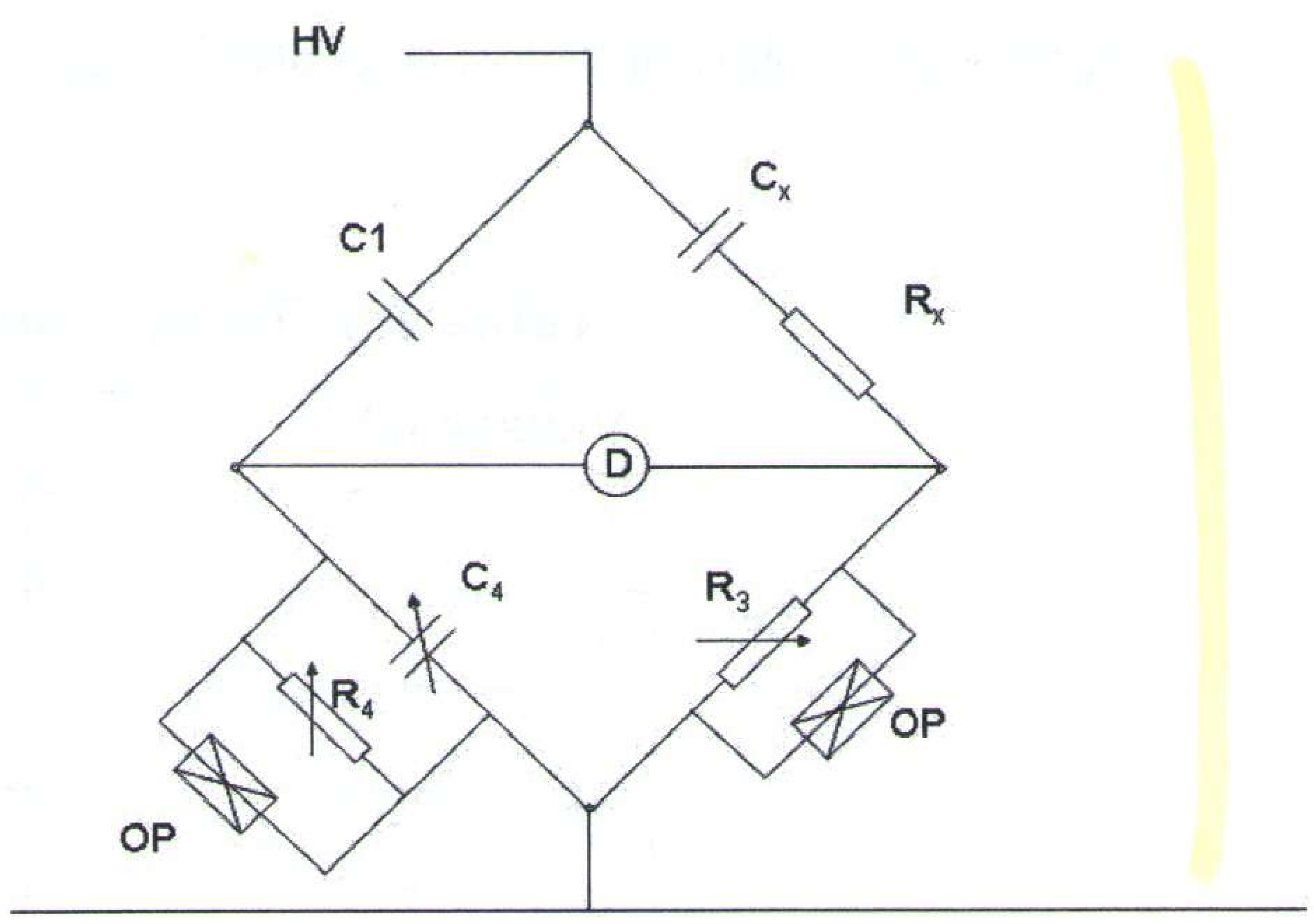


Fig. 4.19: Basic Schering bridge circuit

Although the usual model for an insulating material (dielectric) is a parallel RC circuit, as in Fig 3.18, it is possible to derive an equivalent series RC circuit (R_x and C_x in Fig. 4.19).

Capacitor C1 is a standard lossless capacitor, usually gas-filled with an accurately known capacitance (typically 92.926 pF). The "earth" sides of both C1 and Cx are connected to the low voltage arms of the bridge, housed in the resistor/capacitor box of the bridge. The magnitude of the impedance of these components are small relative to those of the HV components (C1, Rx, Cx), resulting in a low voltage across them.

The LV components are adjusted until the voltage between b and d is zero, as detected by the null detector, D. This condition occurs when:

$$\frac{Z_{ab}}{Z_{bc}} = \frac{Z_{ad}}{Z_{dc}} \tag{4.5}$$

leading to:

$$C_x = C_1 \frac{R_4}{R_3} \quad \text{and} \quad R_x = \frac{C_4 R_3}{C_1} \tag{4.6}$$

Hence:

$$\tan\delta = \omega C_4 R_4 = \omega C_4 R_4 \tag{4.7}$$

The capacitance of the unknown sample, together with the loss factor is therefore known from these equations. Interpretation of measured tan δ values is assisted by experience. Typical values, pertaining to high voltage bushings are given in Table 4.1.

A typical implementation of a 60 kV Schering bridge is shown in Fig. 4.20.

Table 4.1: Typical permissible tan δ levels

Voltage (kV)	Tan delta (%)
11	7
22	5
66	2.5
88	2
132	1.5
275	1
400	0.5

Measurement of partial discharges

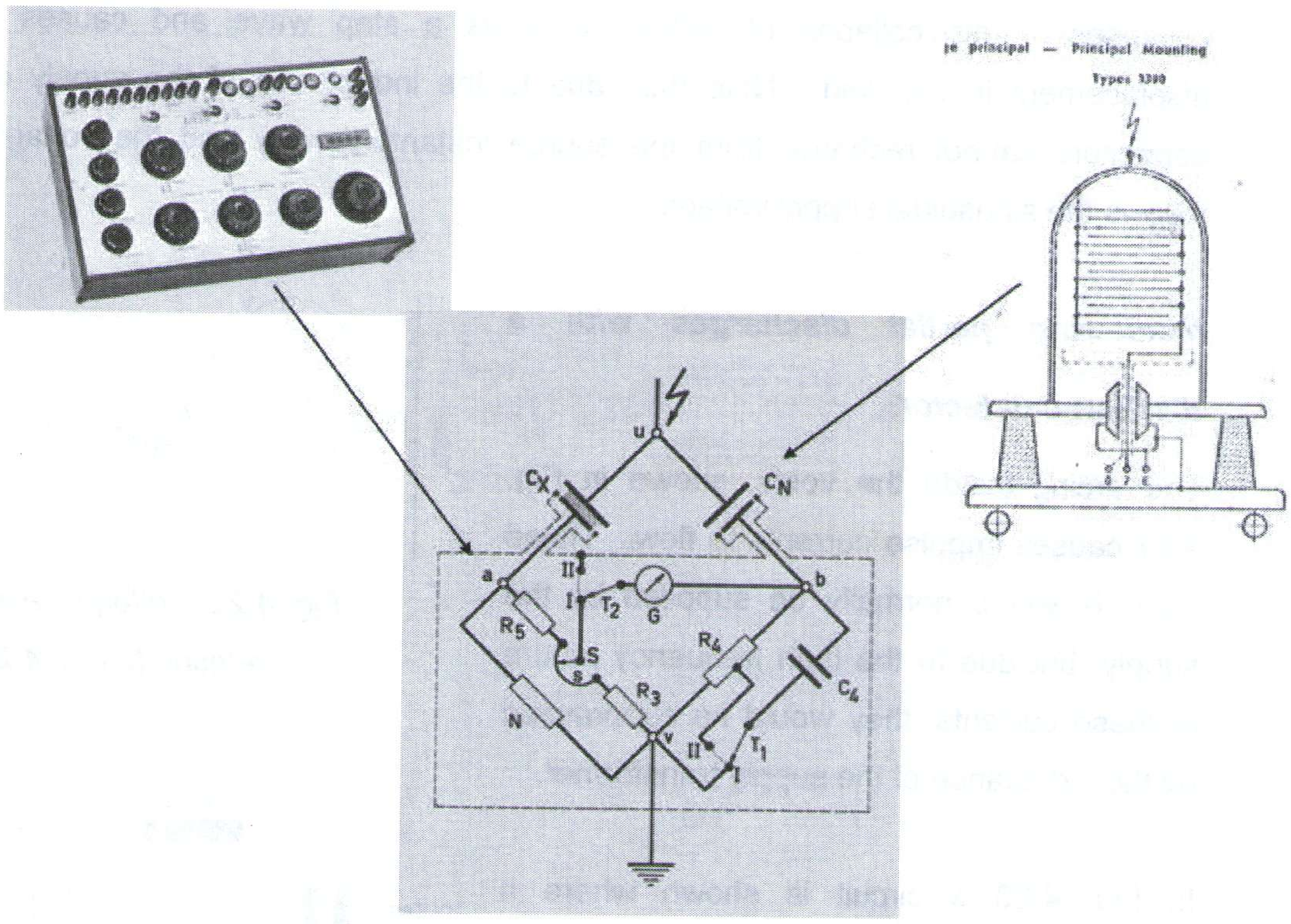


Fig. 4.20: Typical Schering Bridge set-up (Tettex)

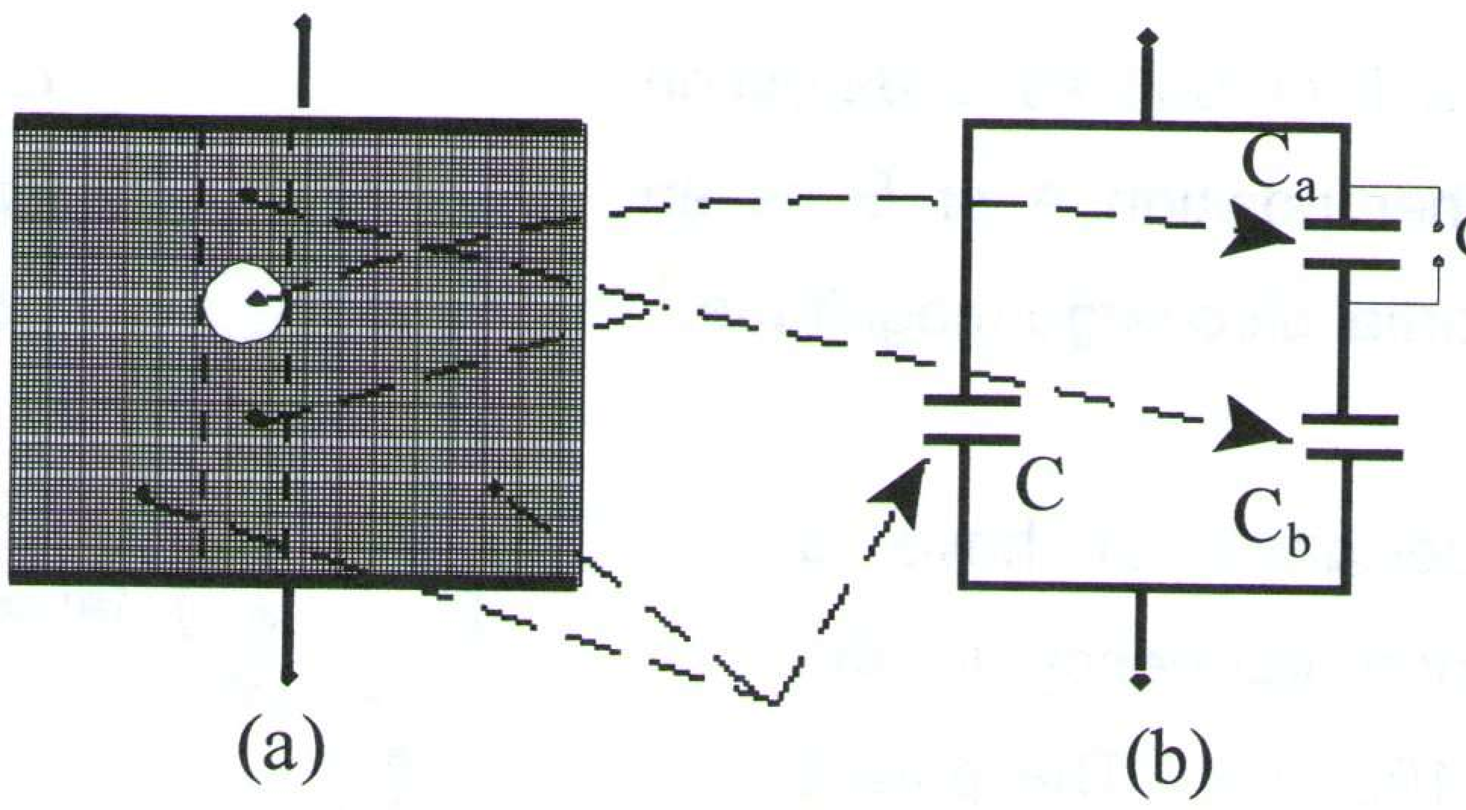


Fig. 4.21: Equivalent circuit for a void in a solid dielectric

As explained in section 3.3.2, discharges occur in voids in solid insulating materials. Consider a sample with a void as shown in Fig. 4.21. Note that the capacitance C represents the bulk of the sample, C_a that of the void and C_b the sections "in series" with the void.

The voltage waveforms, associated with Fig. 4.21 are shown in Fig. 4.22. Note that C_a and C_b form a capacitive voltage divider to give V_a the voltage of the air gap. When V_a reaches the breakdown value of the gas in the void, V_i, the voltage across the gap collapses. This collapse of voltage acts as a step wave and causes a charge displacement in the void. Note that, due to the inductance of the supply circuit, the capacitors cannot recharge from the source instantaneously and the voltage build-up follows the sinusoidal supply voltage.

Monitoring partial discharges with a discharge detector

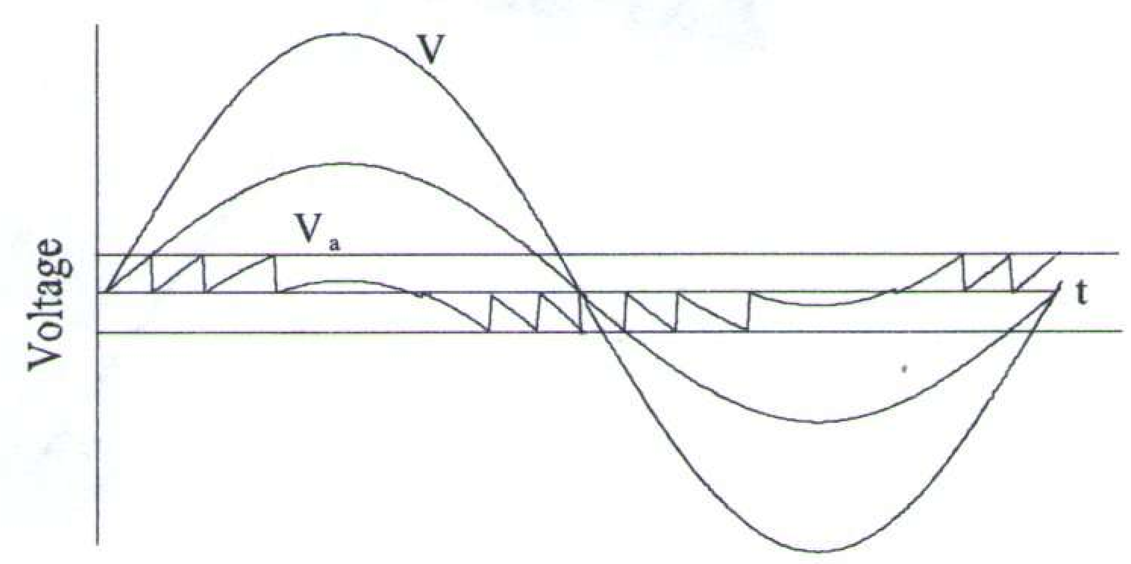
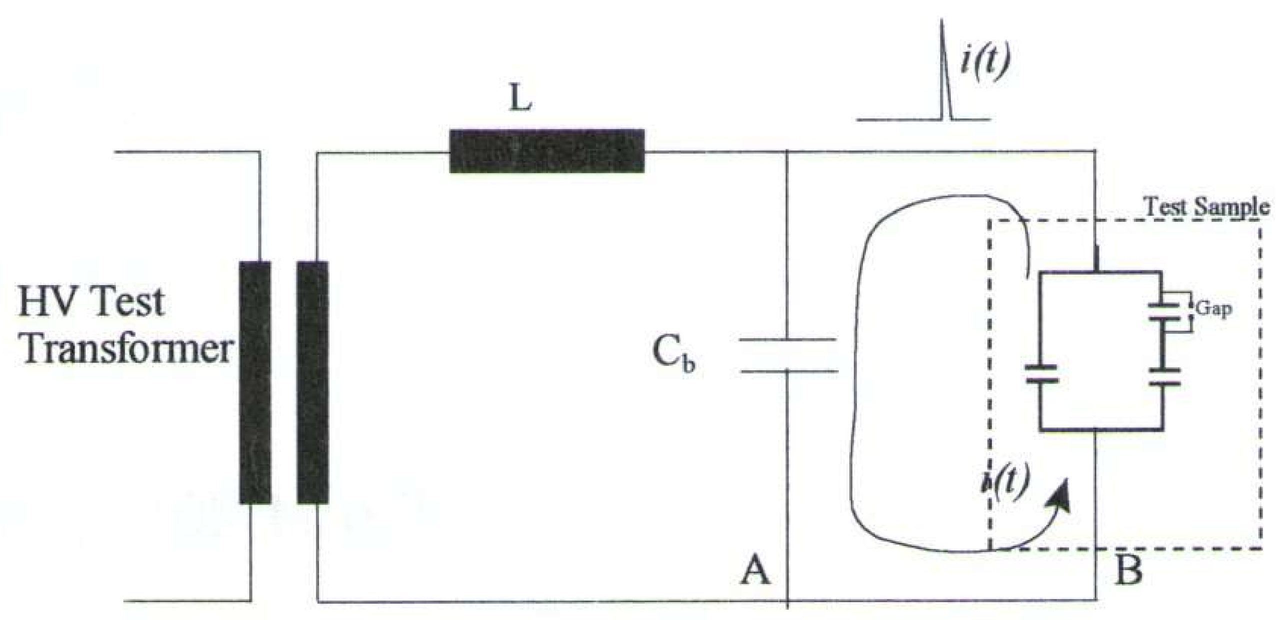


Fig. 4.22: Voltage waveforms relating to Fig. 4.21

The arcing inside the voids, shown in Fig. 4.22 causes impulse currents to flow. These currents would normally be supplied by the supply, but due to the high frequency nature of these currents, they would be suppressed by the inductance of the supply transformer.



C_b: Blocking capacitor

Fig. 4.23: Discharge detector circuit

In Fig. 4.23 a circuit is shown where a "blocking" capacitor is connected across the sample to permit the flow of the current impulses i(t). The impulse currents are then measured, using a filter unit as a detection impedance, in either position A or B as an indication of the partial discharge magnitude.

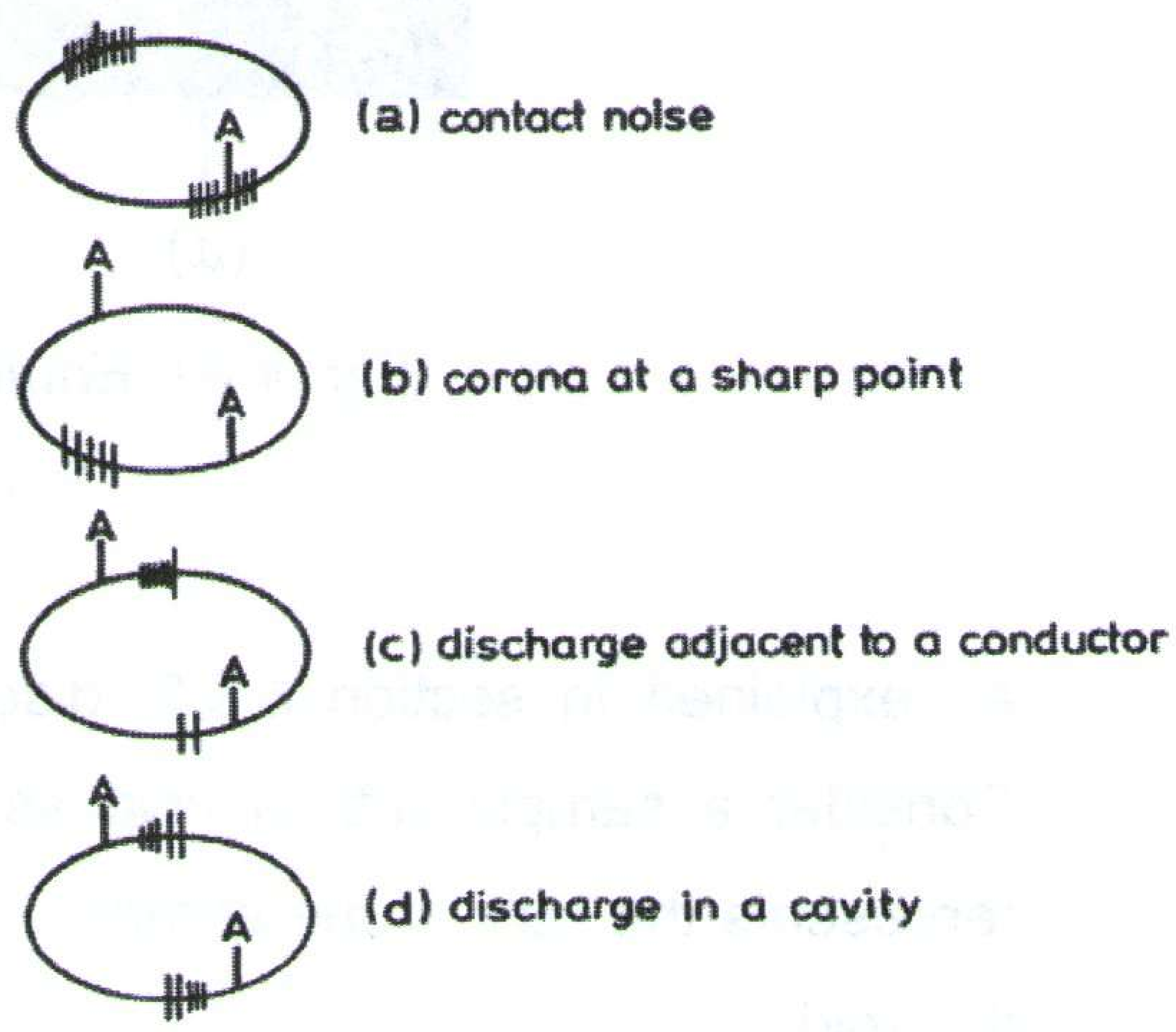
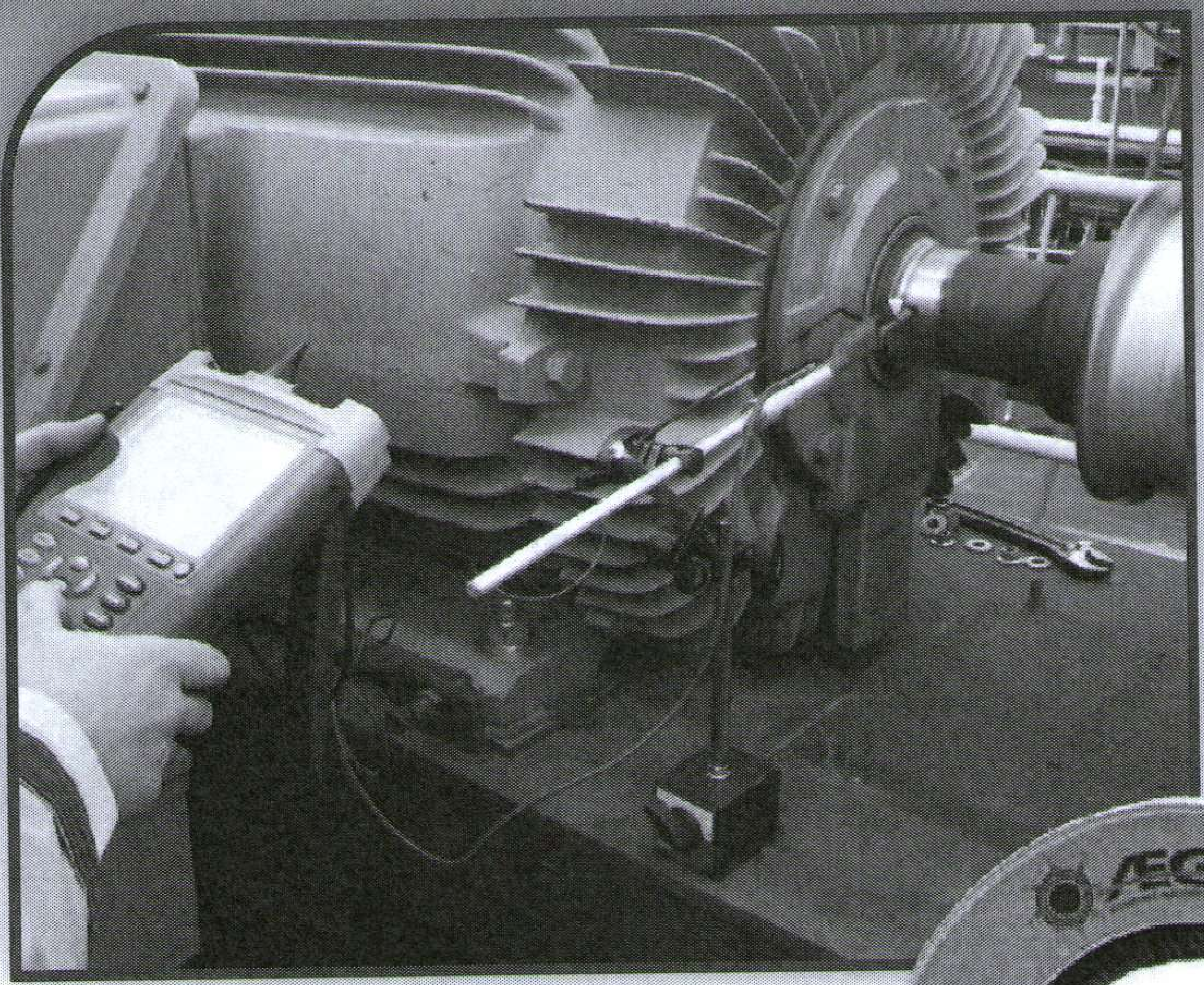


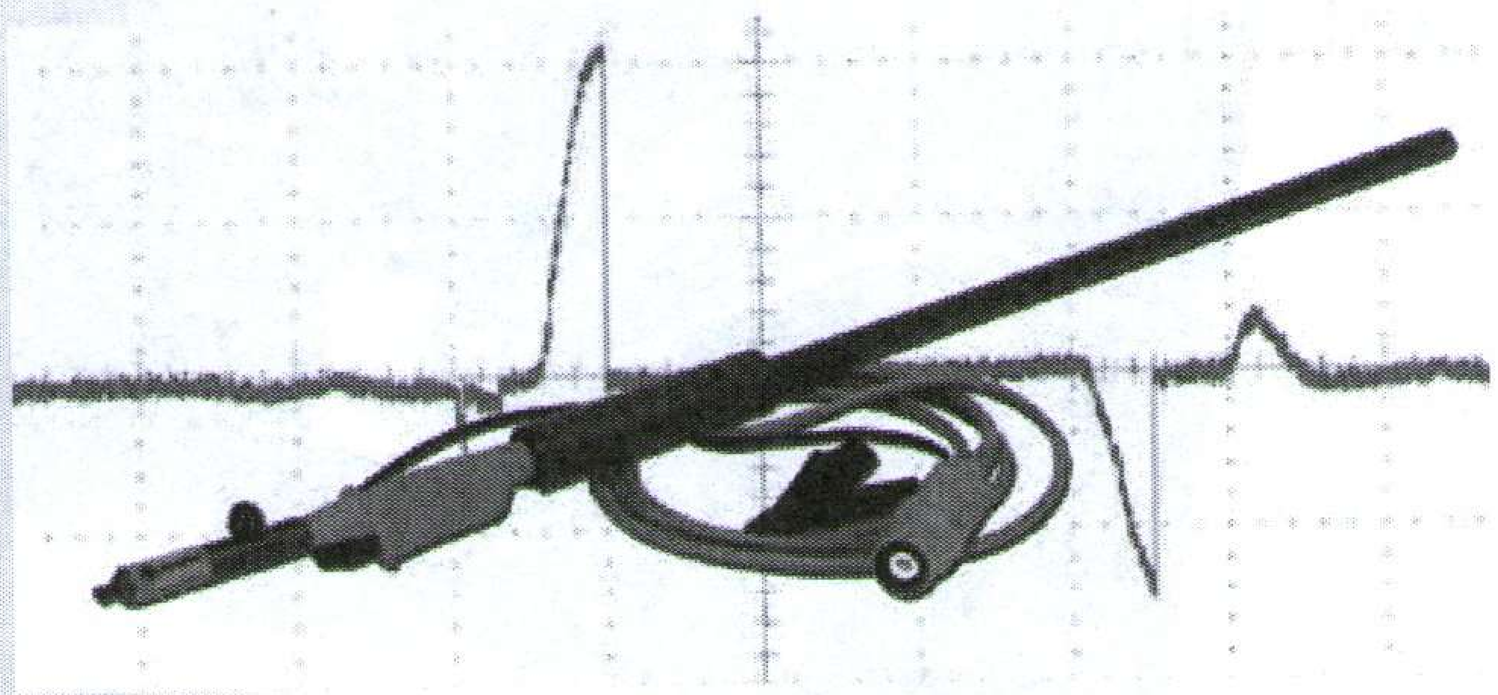
Fig. 4.24: Discharge detector display diagnostics

The circuit is designed to have a particular resonance frequency in the range 30 kHz to 100 kHz. The pulses are fed into a wide band amplifier and the output pulses are displayed on a CRT screen, superimposed on the supply sine wave to be able to detect the points on the wave where the discharges occur, relative to the zero crossings. The positive and negative half waves are often displayed as an

G158 (41)

Testing Procedure for Shaft Voltage and Discharges using a Fluke 190 Series II ScopeMeter®



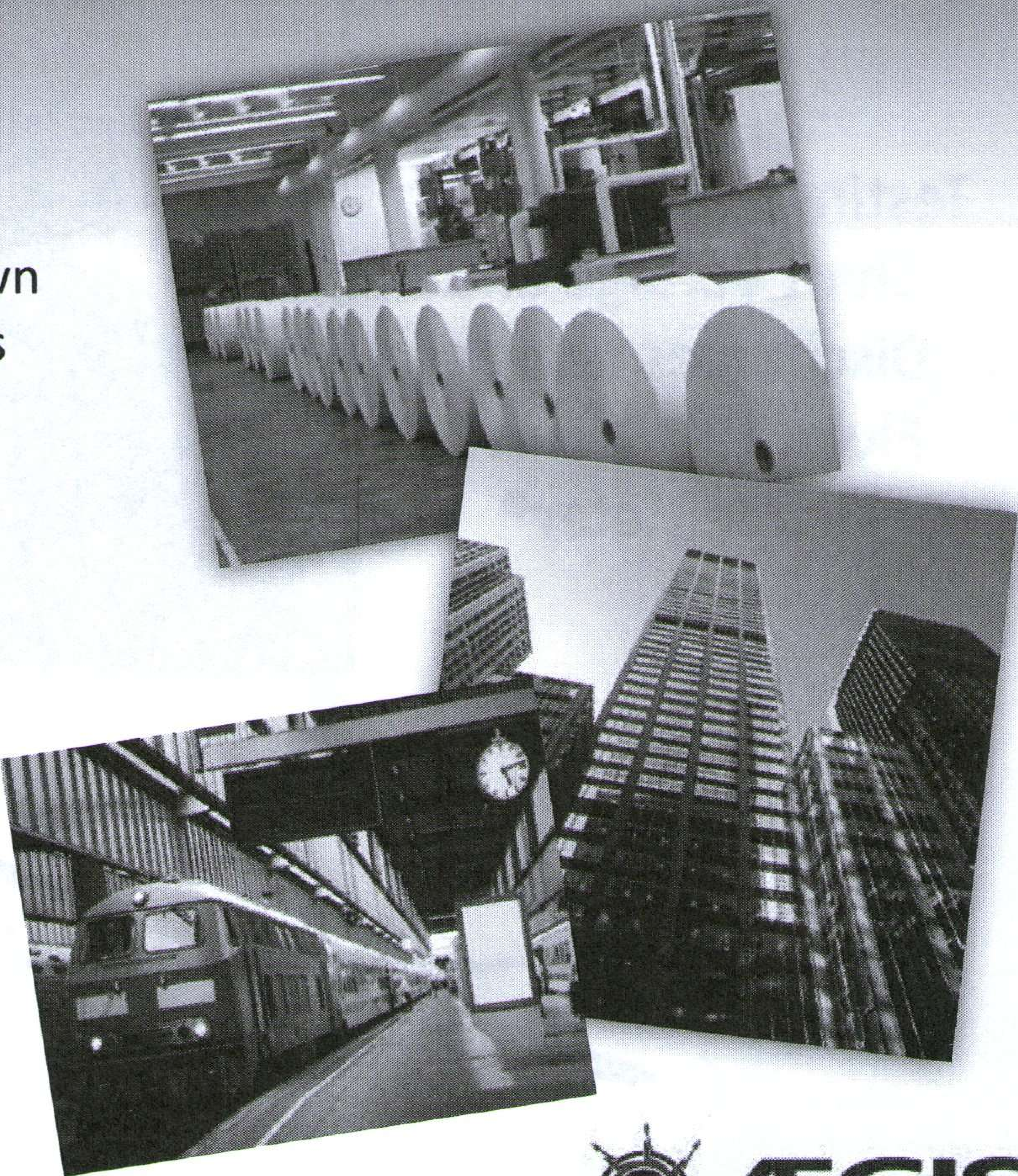


ÆGIS™ BEARING PROTECTION RING

G158(40)

Why Test for Shaft Voltages…

- Unexpected production down time due to a failed motor is costly.
- Air conditioning failure in a commercial building is unacceptable.
- A stopped train during rush hour is avoidable.

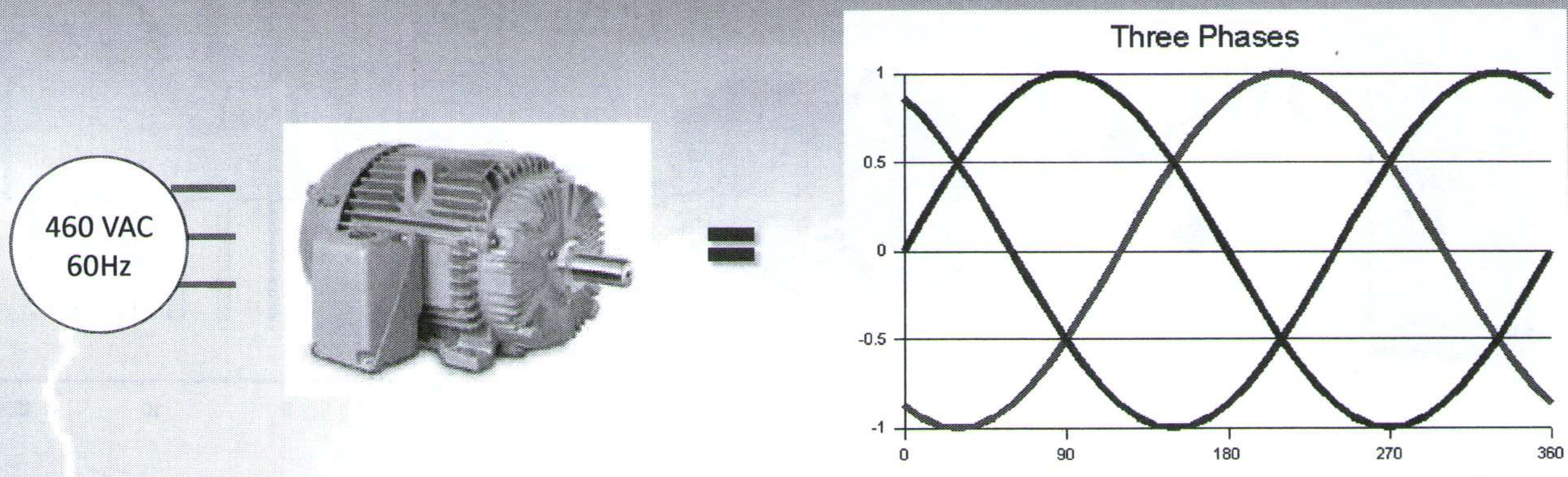


www.est-aegis.com

ÆGIS™ BEARING PROTECTION RING

a150(43)

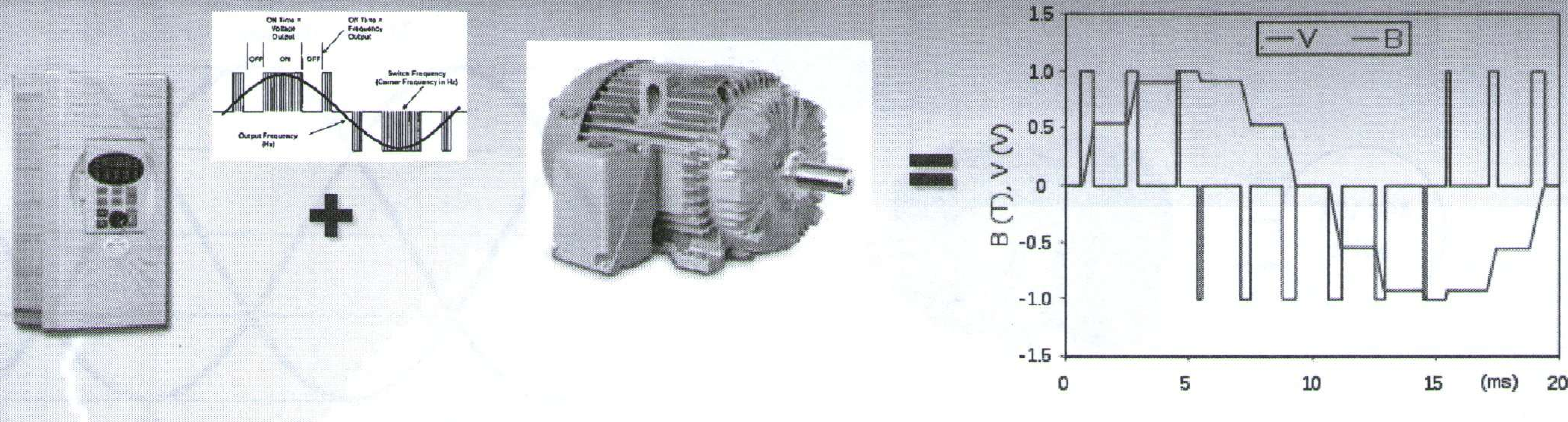
Electric Motor Design



- Most electric induction motors were designed for operation on 3 phase sign wave power – either 50 or 60 Hz.
- The input power was balanced in frequency, phase (120 degrees apart) and in amplitude.
- Common mode voltage – the sum of the 3 phases would always equal zero volts.

G153(44)

Electric Motor Operation by VFD



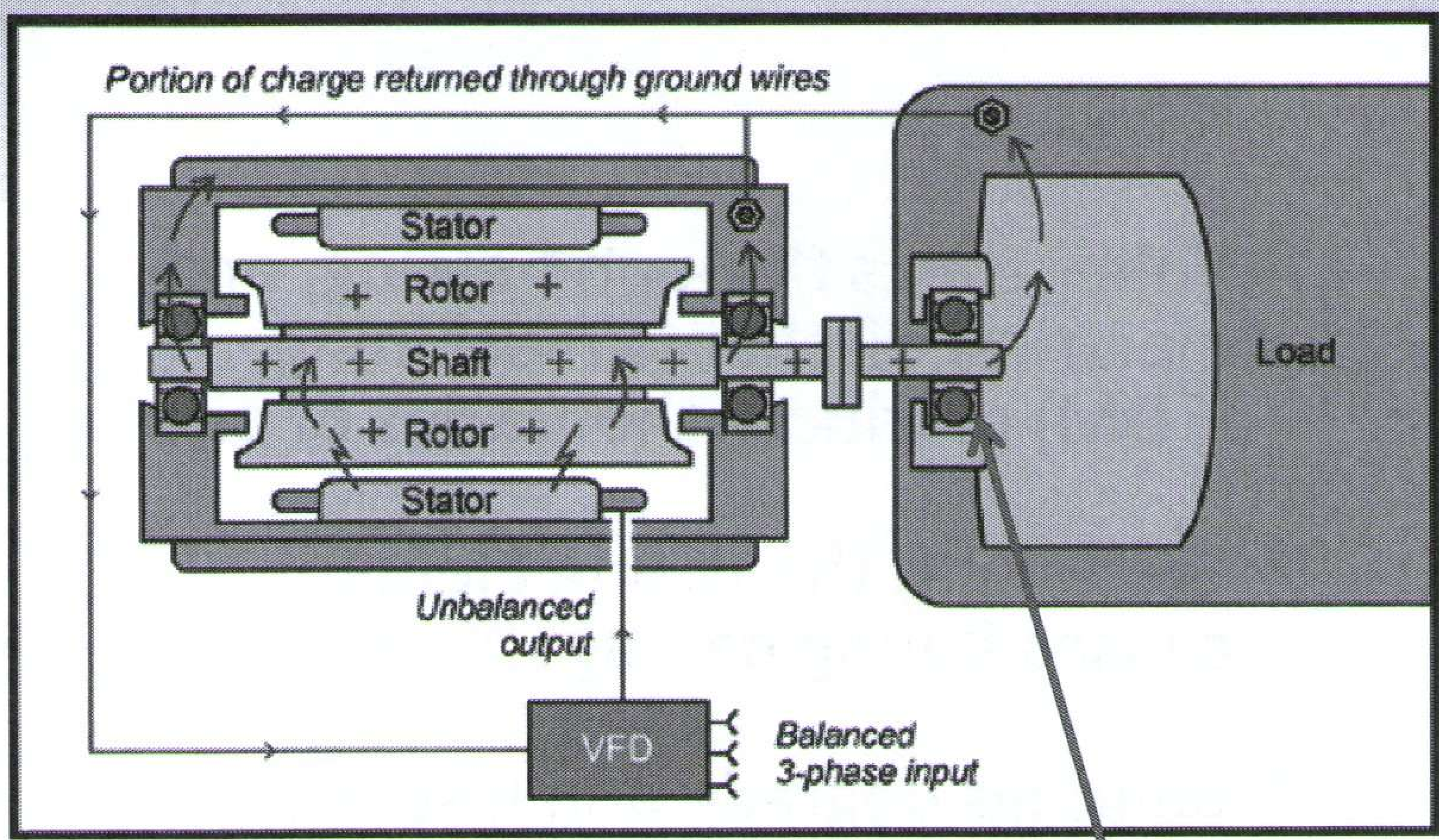
- When operated by VFD, the power to the motor is a series of pulses instead of a smooth sign wave.
- The input power is never balanced because the voltage is either 0 volts, positive, or negative with rapid switching between pulses.
- The Three phases of voltage pulses ensures that the common mode voltage is never equal to zero and instead is a “square wave” or “6 step” voltage.

VFD – variable frequence device

a158(45)

An Electric Motor acts like a Capacitor

- The pulses to the motor from the VFD create a capacitively coupled common mode voltage on the motor shaft.
- The voltage looks for a path to ground and breaks down the dielectric in the bearing.
- The resulting discharge creates a pit in the bearing race. This occurs multiple times a second and overtime the bearing may fail.



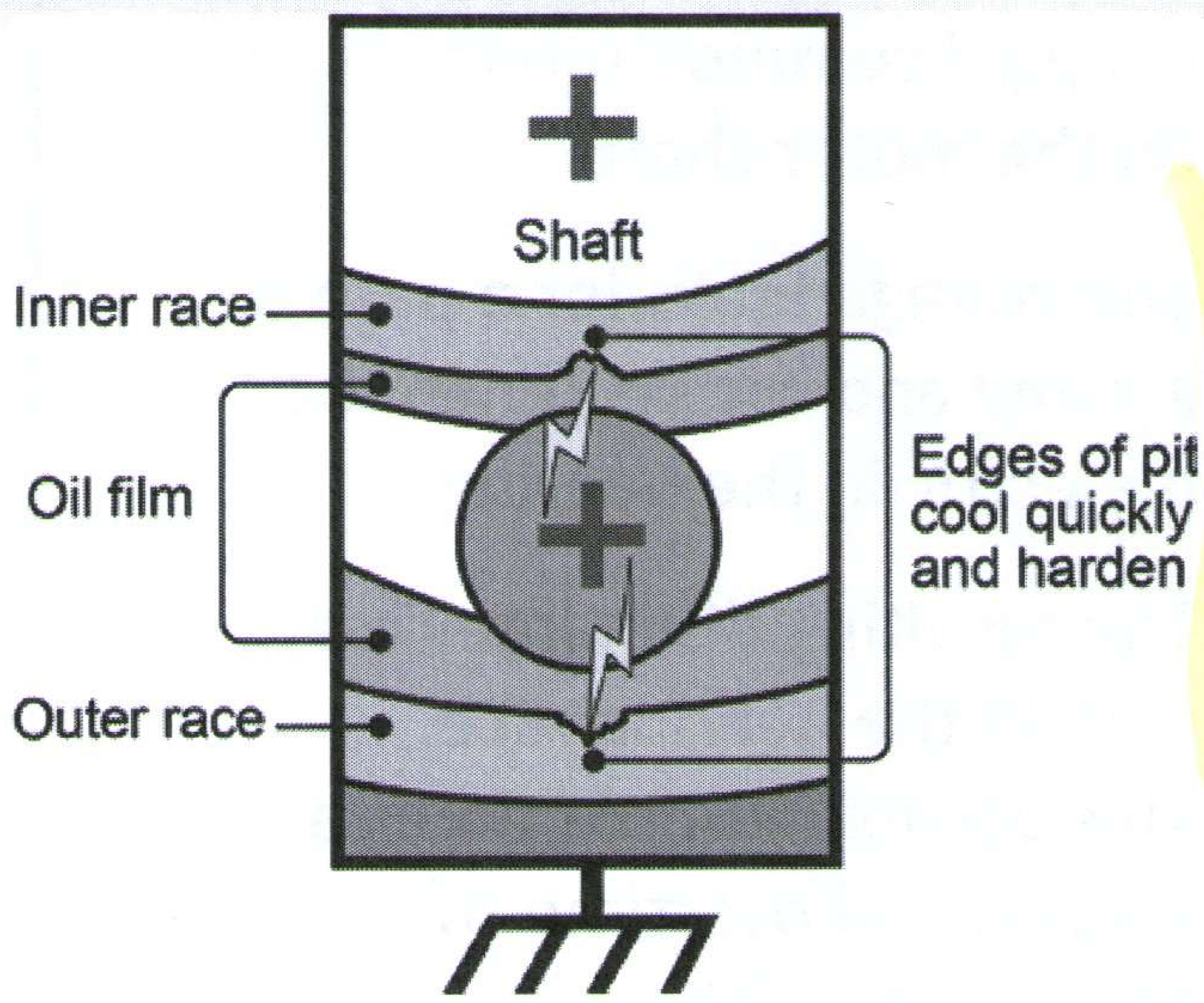
www.est-aegis.com

ÆGIS BEARING PROTECTION RING

G15B(46)

Voltage arcs through the bearing

- Voltage arcs through bearing, and electrical discharge machining (EDM) produces thousands of pits
- Eventually, the rolling element causes fluting damage to race
- Bearings degrade and lose their function resulting in bearing and motor failure



www.est-aegis.com

ÆGIS™ BEARING PROTECTION RING

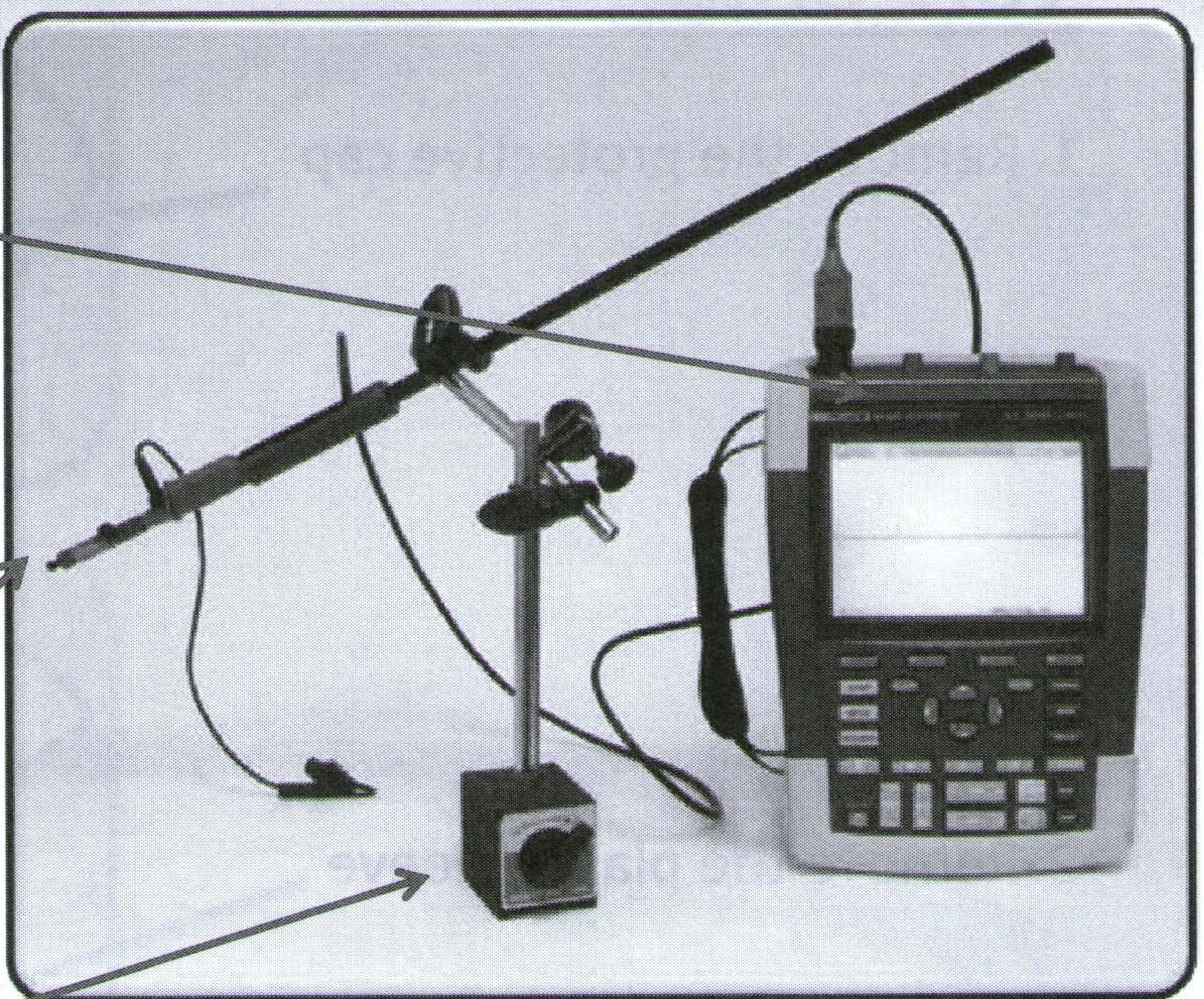
G158(47)

Recommended Testing Equipment

- Oscilloscope with a 10:1 probe. We recommend a minimum 100MHz bandwidth to accurately measure the waveform. The Fluke 190 Series II ScopeMeter® 2 channel also has an Ohm meter function which can be used to measure the resistivity of the shaft. (Fluke 190 Series II ScopeMeter® 4 Channel shown)

- AEGIS™ SVP KIT (**S**haft **V**oltage **P**robe)

- Magnetic base to fit the 3/8” (9.5mm) probe extension rod.

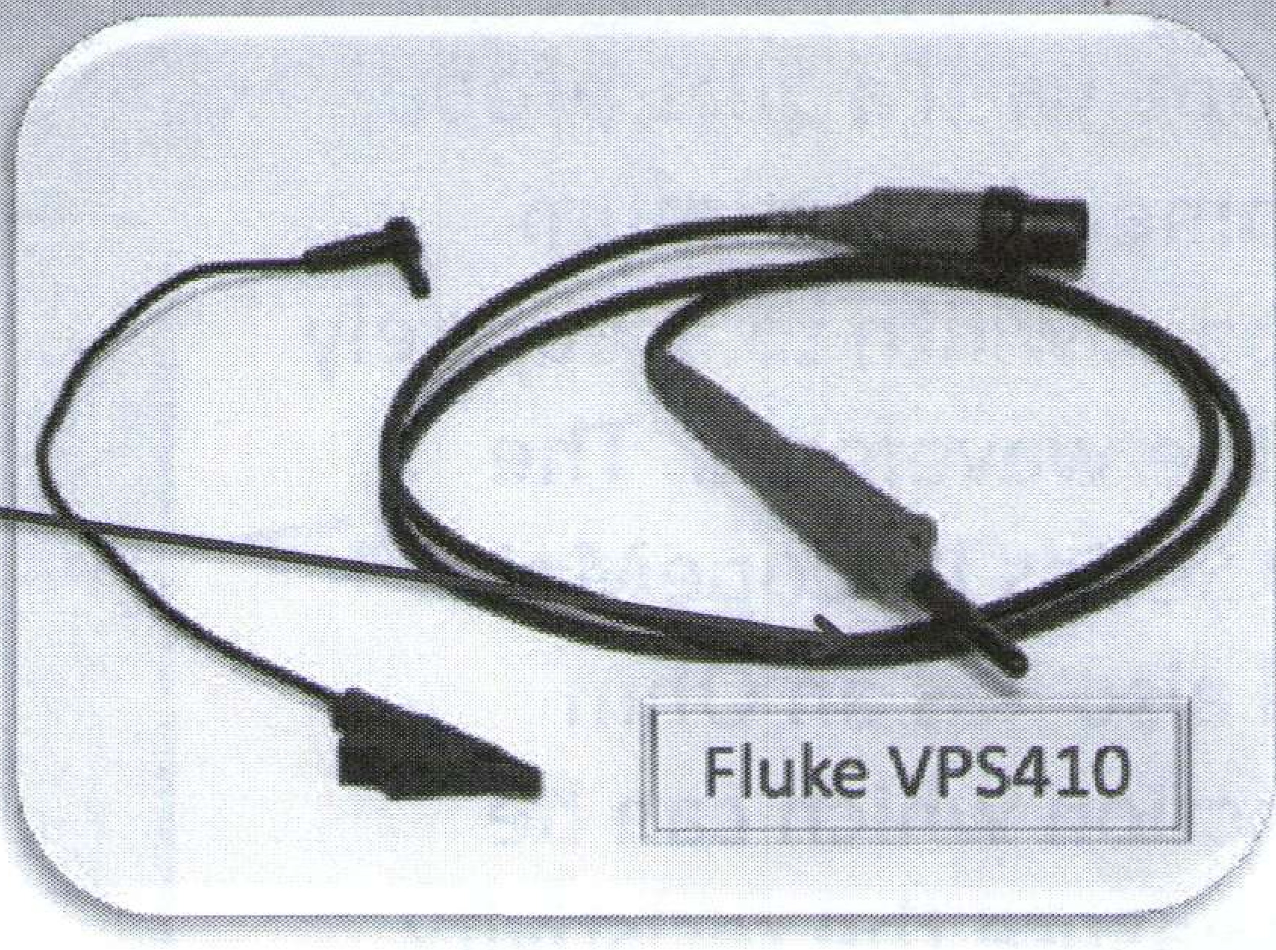


G153(48)

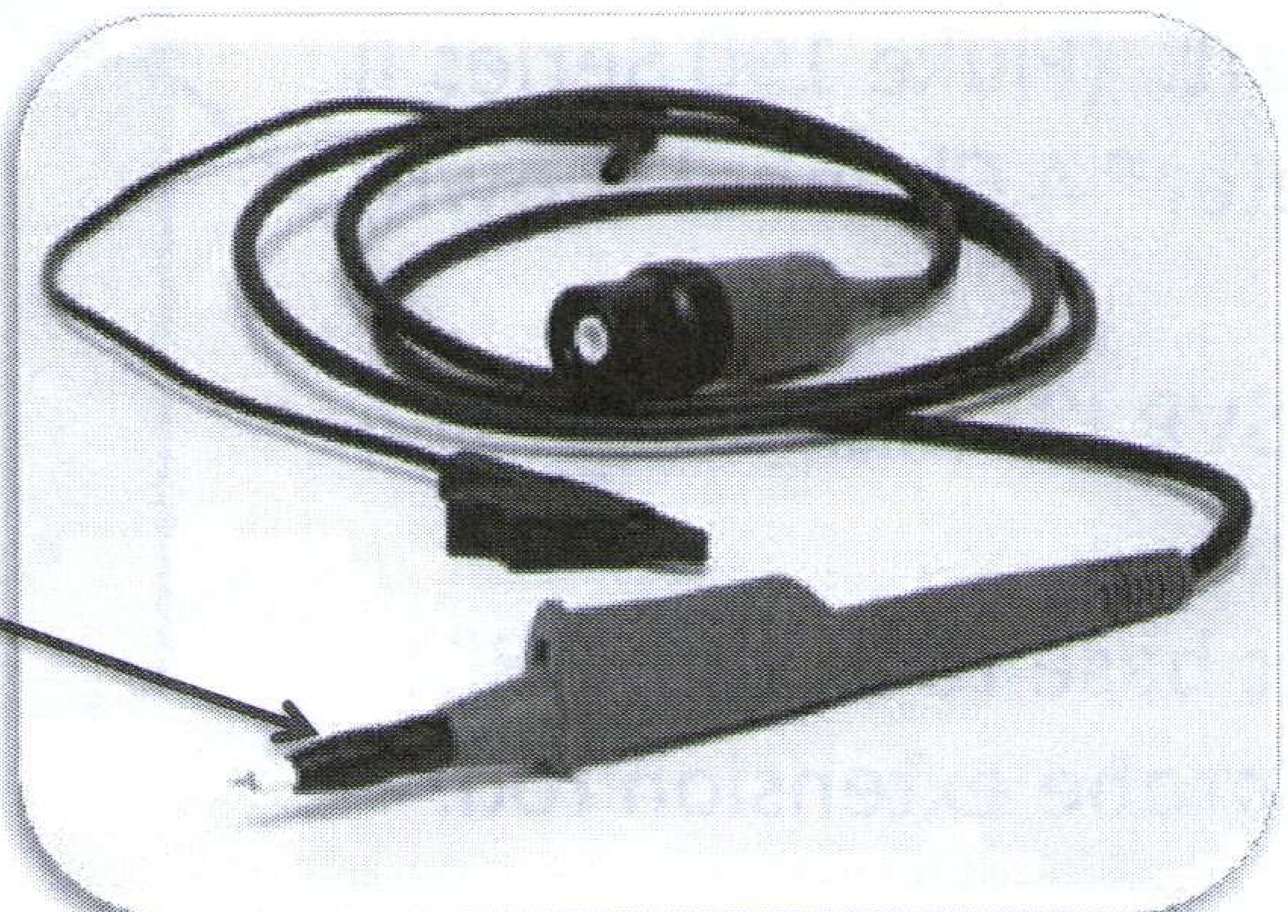
Installing the AEGIS™ SVP Tip

10:1 probe

1. Remove the protective cap



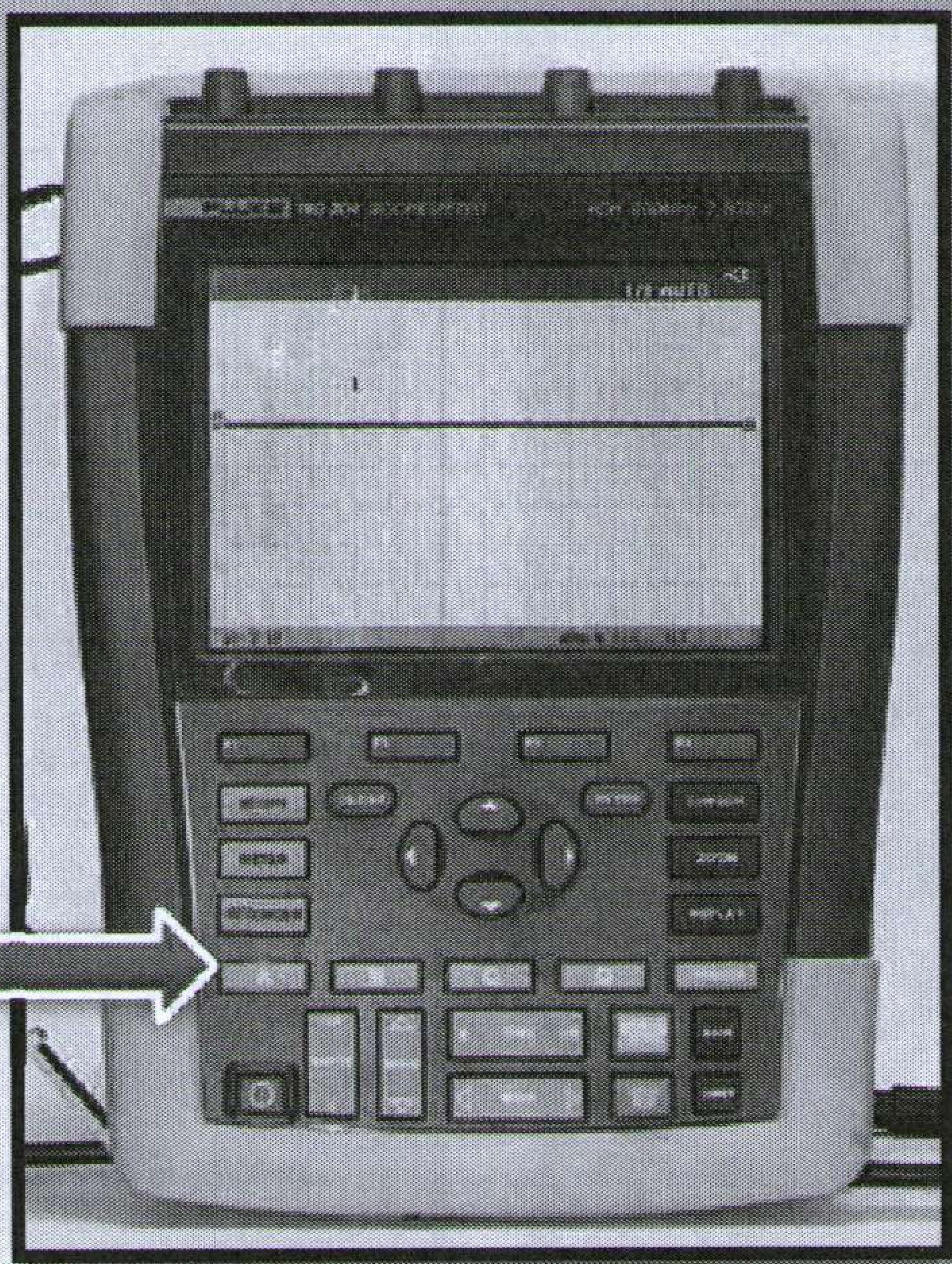
2. Remove the plastic sleeve



AEGIS™ BEARING PROTECTION RING

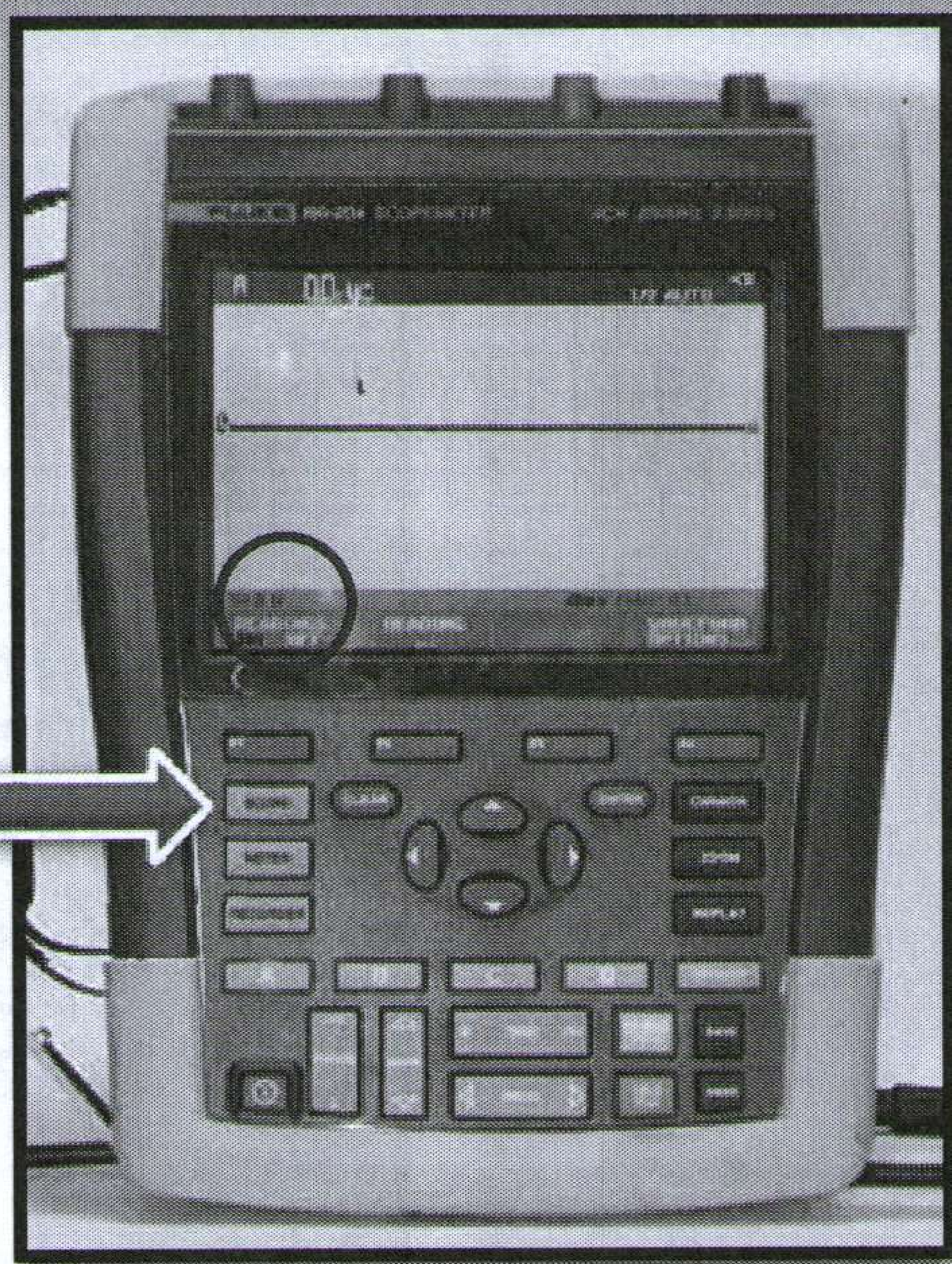
G153(49)

ScopeMeter Parameters *Set Readings "ON"*



Press the **A** button for channel A.

A menu will appear at the bottom.



Press **SCOPE**

Press **F1** to toggle **ON**

Press **CLEAR** to clear menu

Instructions are specific to the Fluke 190-204 ScopeMeter. Refer to your owner's manual for a different meter.

ÆGIS™ BEARING PROTECTION RING

G153(50)

ScopeMeter Parameters *DC Coupling*

Press the **A** button for channel A.

A menu will appear at the bottom.

Press **F2 COUPLING** to toggle between the DC and AC Coupling.

Choose **DC** and press **ENTER**.

Press **CLEAR** to clear menu.

DC Coupling will pick up DC and AC voltages.

AEGIS™ BEARING PROTECTION RING

G158(S1)

ScopeMeter Parameters **Set Voltage Peak-Peak**

Press the **SCOPE** button. A menu will appear at the bottom.

Press **F2 READING**. Move cursor to desired channel and press **ENTER**.

Note: VPS410 should be connected to the ScopeMeter; preferably Channel A.

Use up/down arrows to choose **Peak** and press **ENTER**.

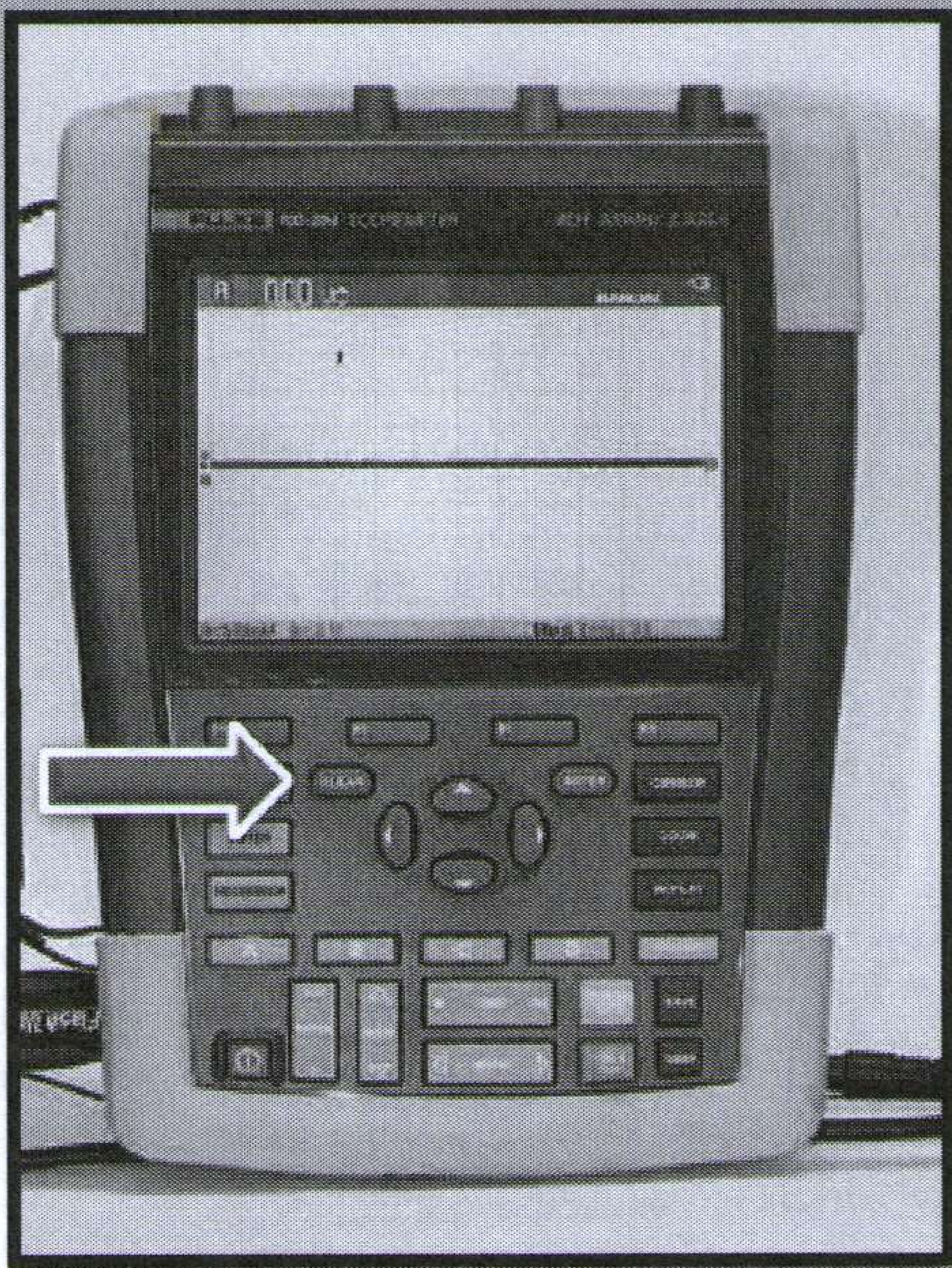
ÆGIS™ BEARING PROTECTION RING

www.est-aegis.com

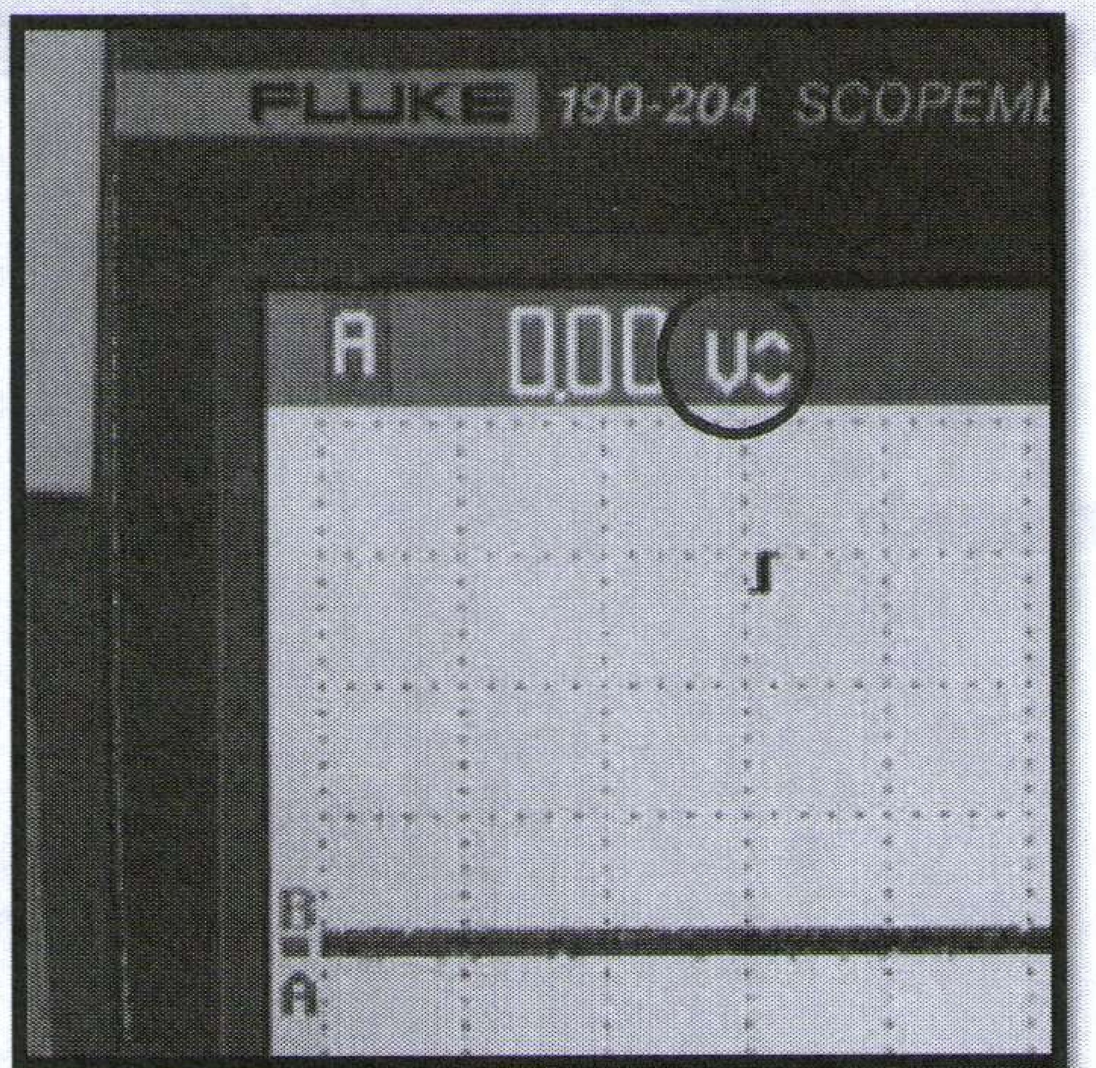
G1520(52)

ScopeMeter Parameters *Set Voltage peak-peak*

Choose **Peak to Peak** and press **ENTER**.



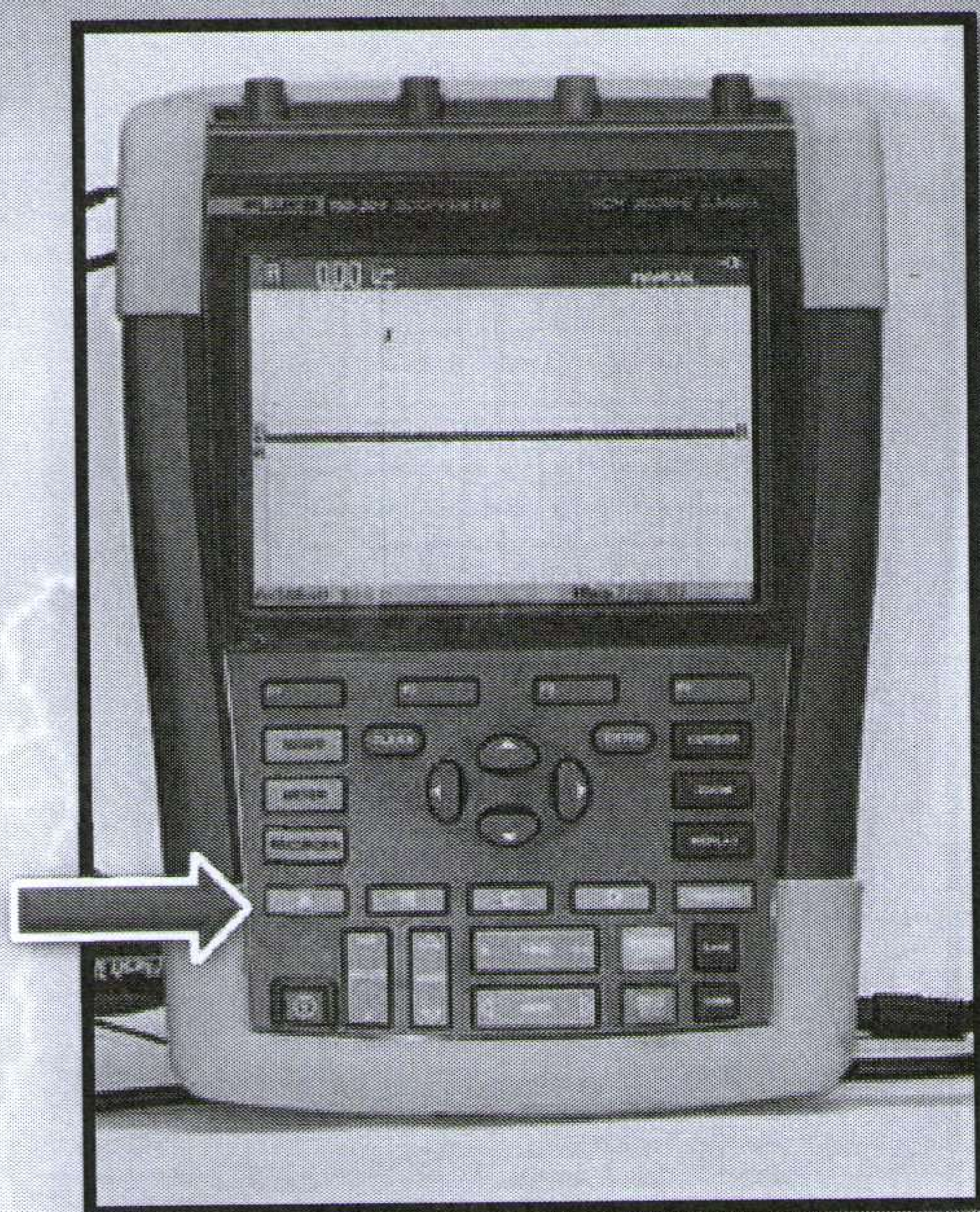
Press **CLEAR** to remove the menu bar.



Voltage **Peak to Peak** is now set.

a153(53)

ScopeMeter Parameters *Set Polarity and Bandwidth*



Press the **A** button. A menu will appear at the bottom.

Press **F4 INPUT A OPTIONS**.

Column 1 choose **Normal** and press **ENTER**

Column 2 choose **Full** and press **ENTER**

Press **CLEAR** to clear the menu

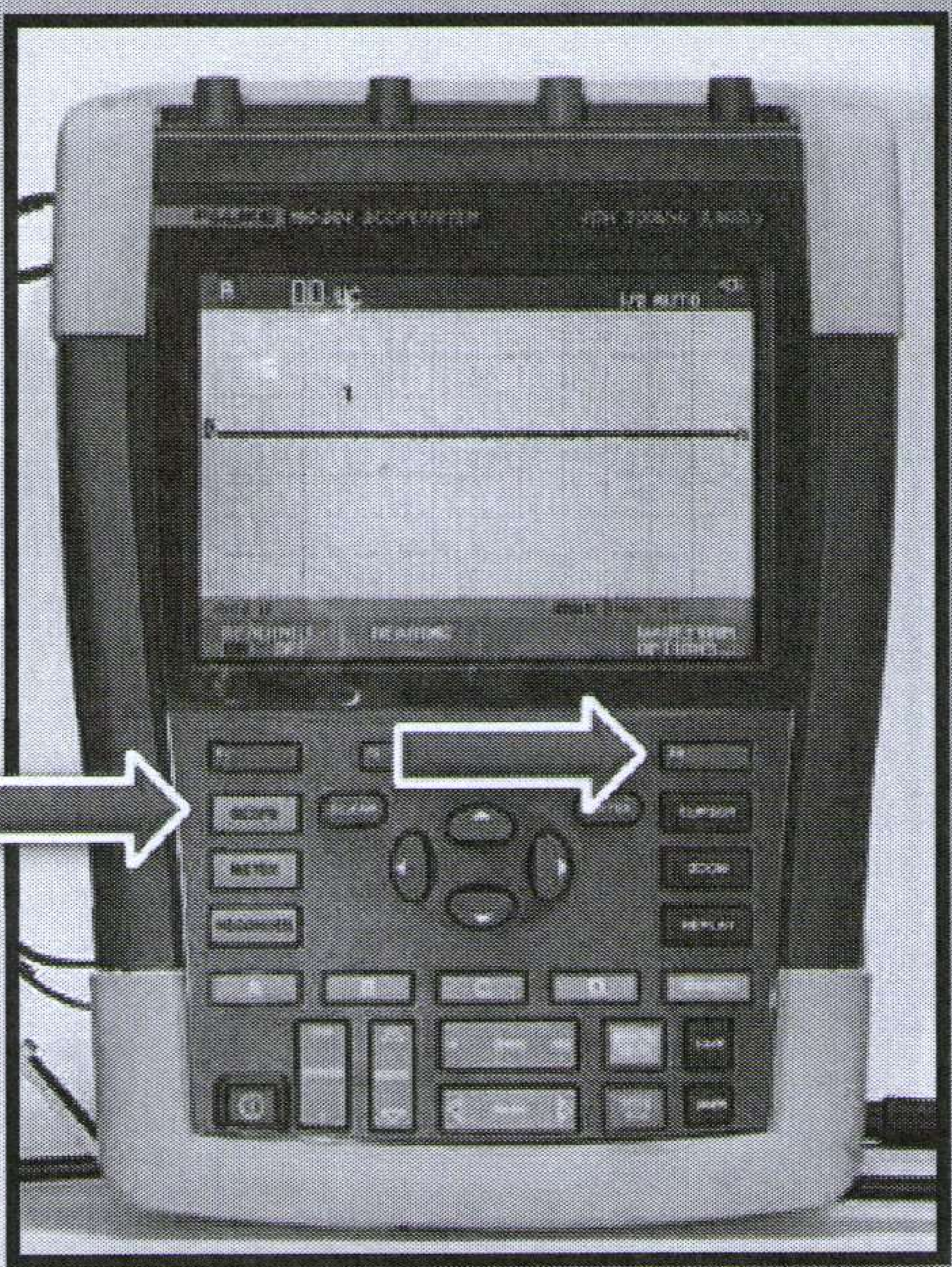
Instructions are specific to the Fluke 190-204 ScopeMeter. Refer to your owner's manual for a different meter.

ÆGIS™ BEARING PROTECTION RING

G15b(54)

ScopeMeter Parameters

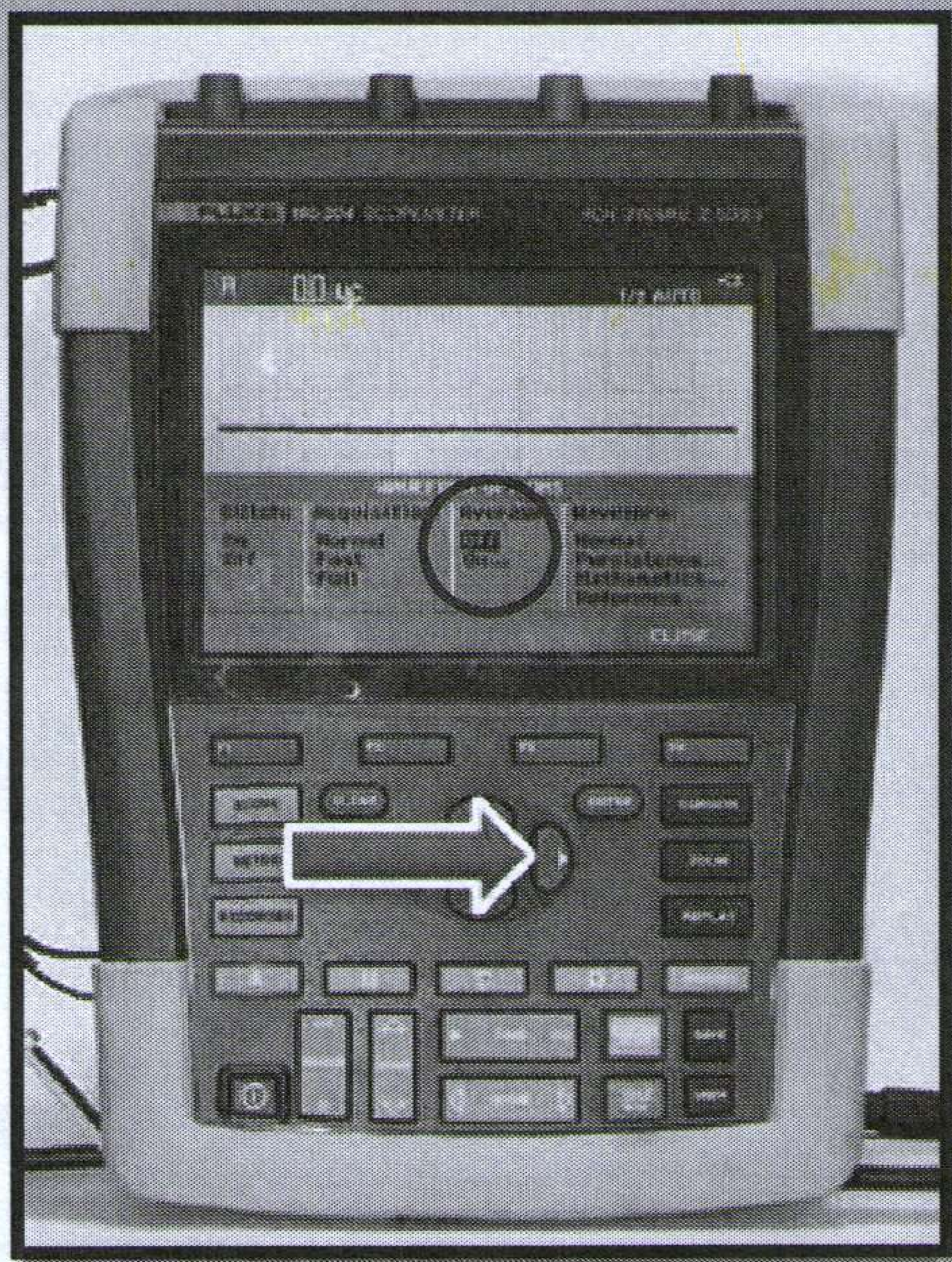
Set Waveform Averages "OFF" and Waveform "Normal"



To show specific voltage measurements instead of averages:

Press the **SCOPE** button.

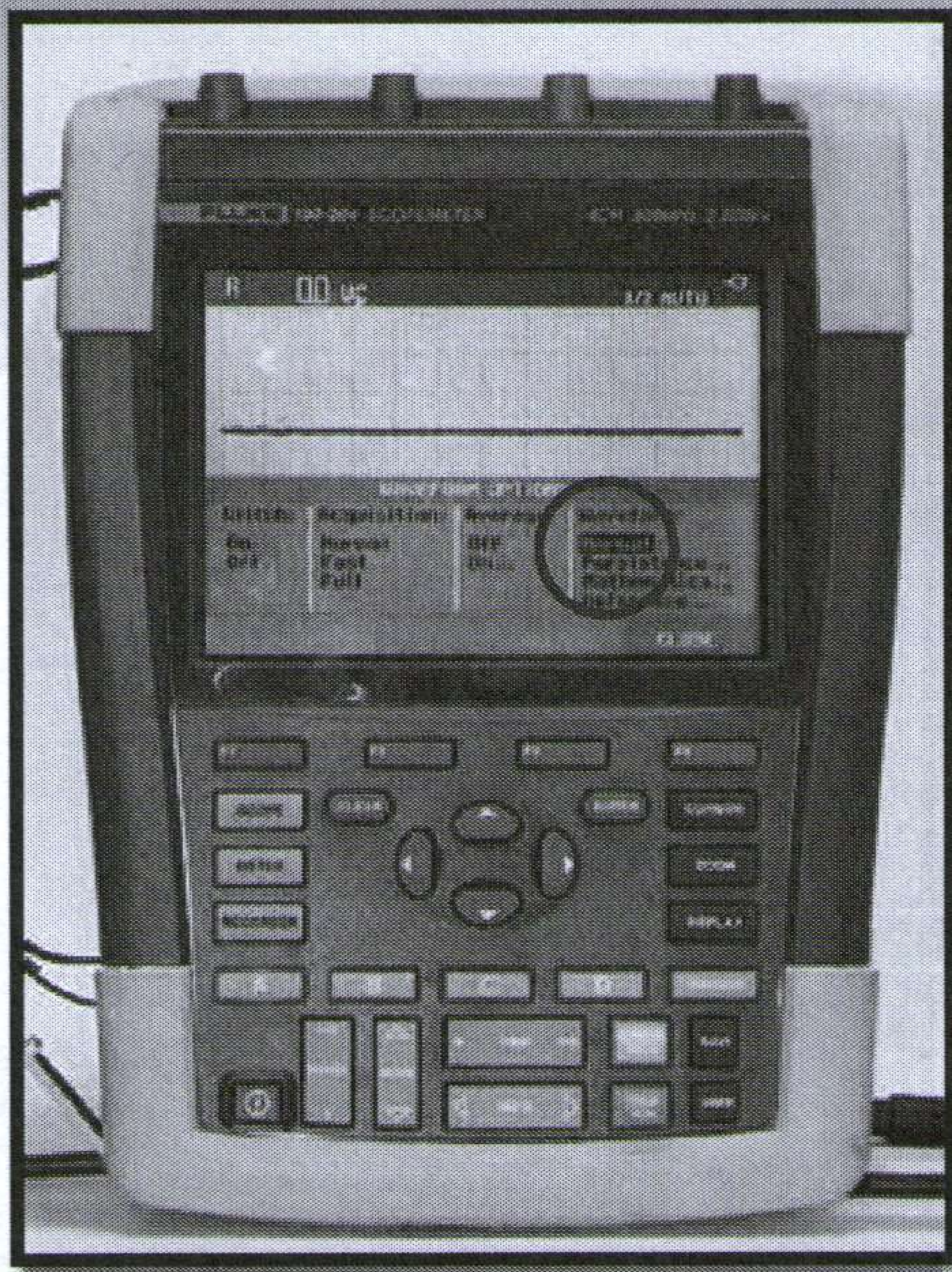
Press **F4 WAVEFORM OPTIONS**



Move cursor to 3rd column using arrow buttons.

Averages: **Off**

Press **ENTER**



In column 4

Waveform: **Normal**

Press **ENTER**

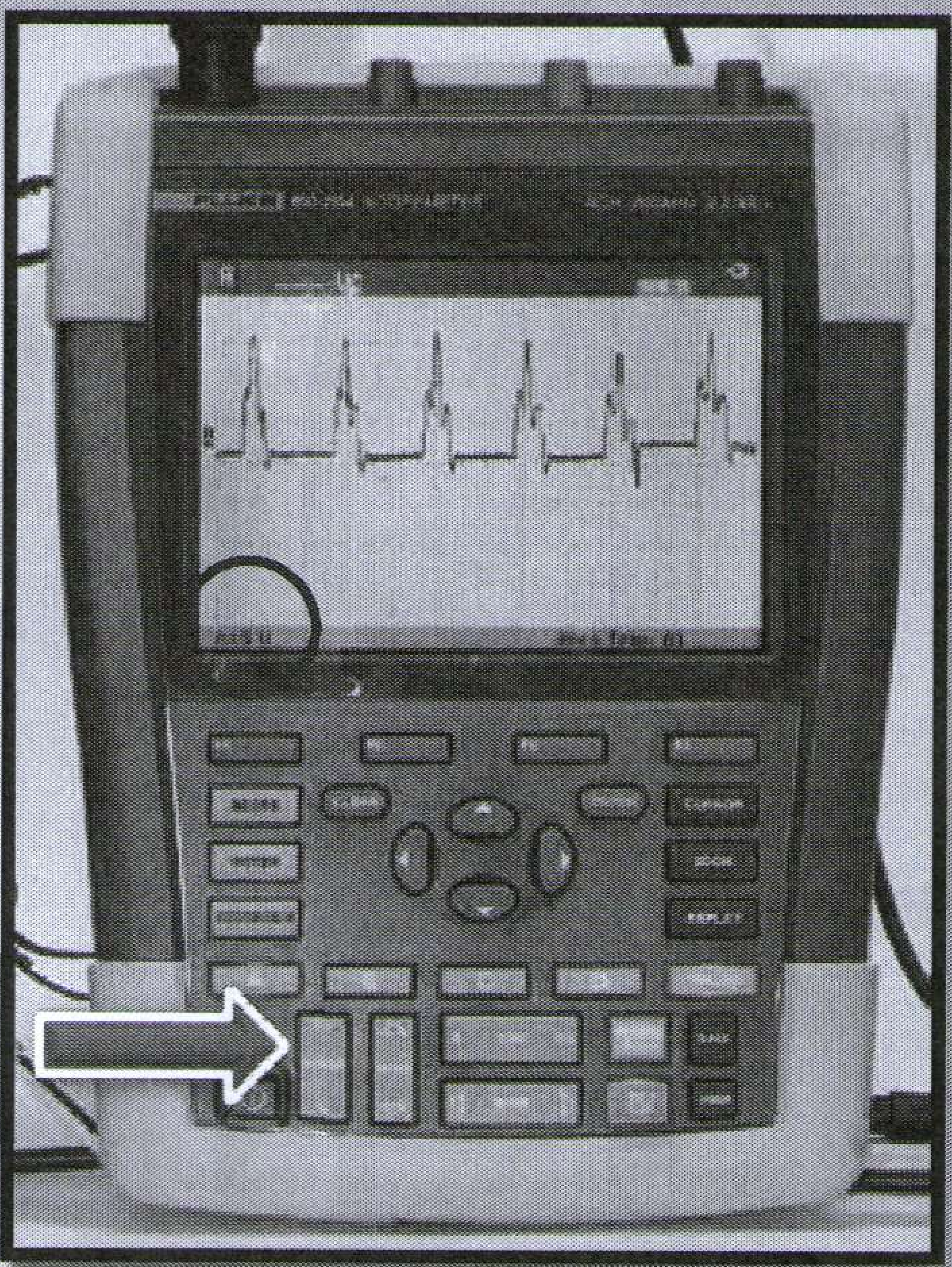
Press **CLEAR** to clear the menu

www.est-aegis.com

ÆGIS™ BEARING PROTECTION RING

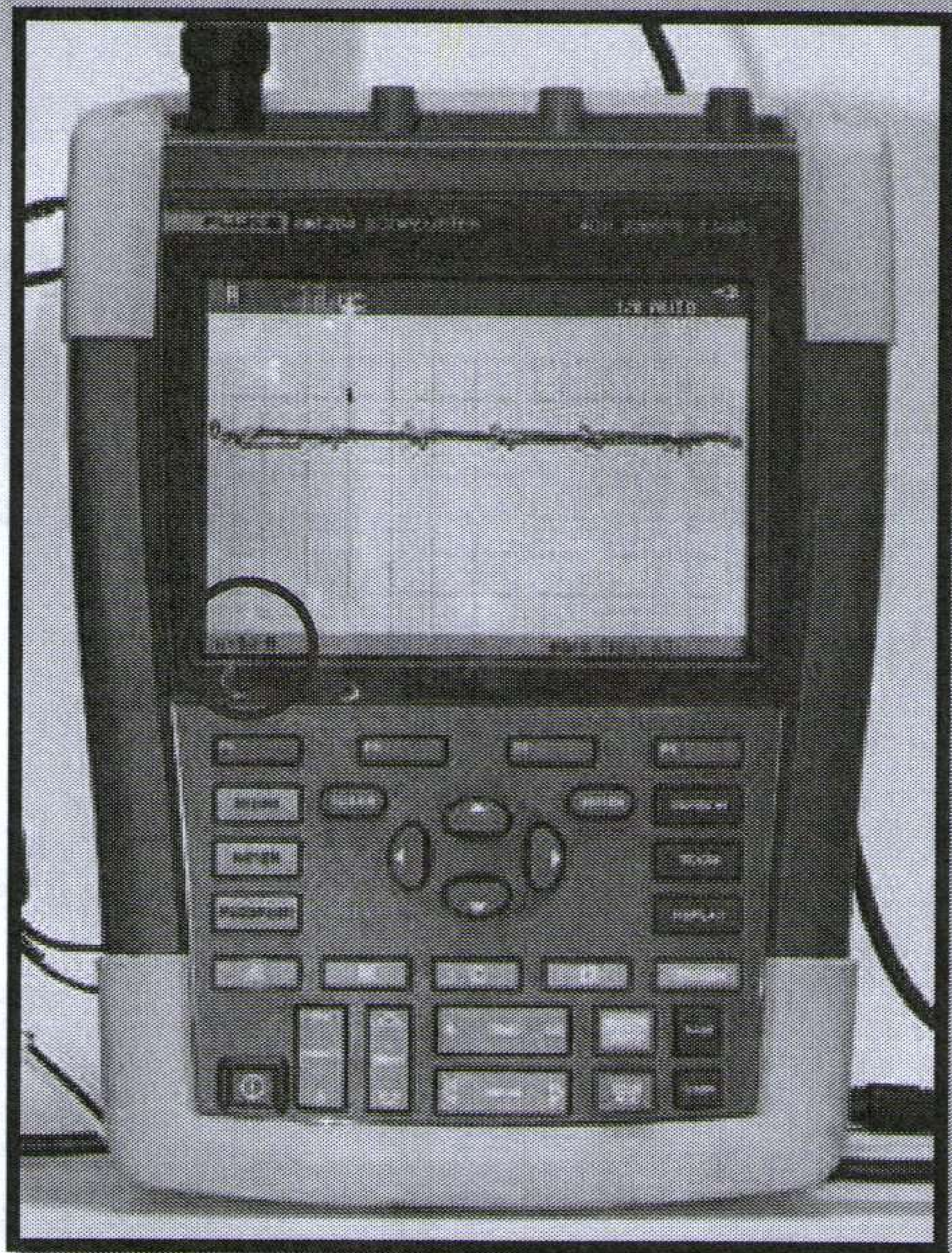
9152(55)

ScopeMeter Parameters ***Set Voltage Amplitude***

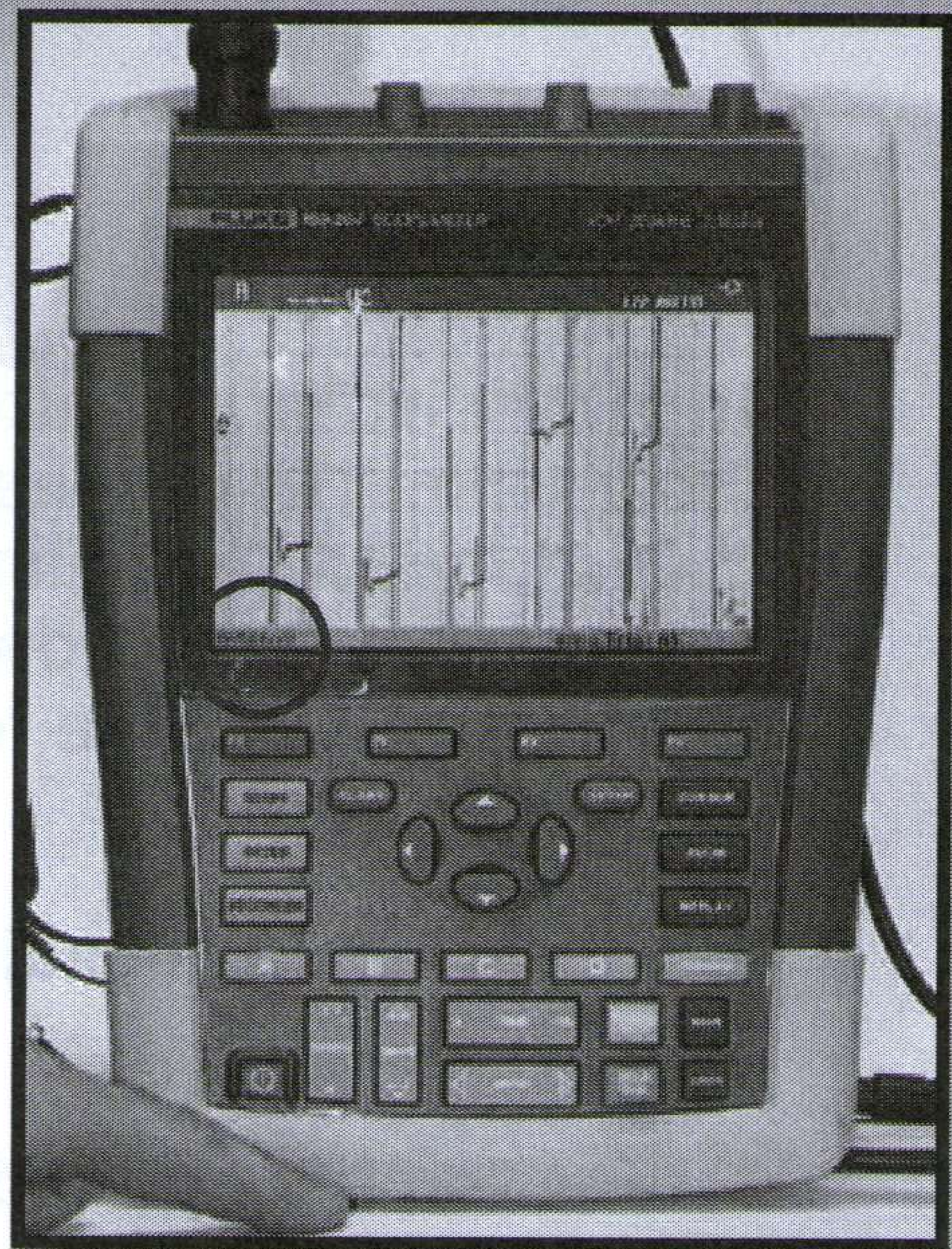


Amplitude will need to be adjusted according to the conditions.

Set to show complete sign wave from top peak to bottom peak using the **RANGE** button.



In this example the amplitude is <u>too small</u>. Increase **RANGE** to show more detail.



In this example the amplitude is <u>too large</u>. Decrease **RANGE** to show top and bottom peaks.

ÆGIS™ BEARING PROTECTION RING

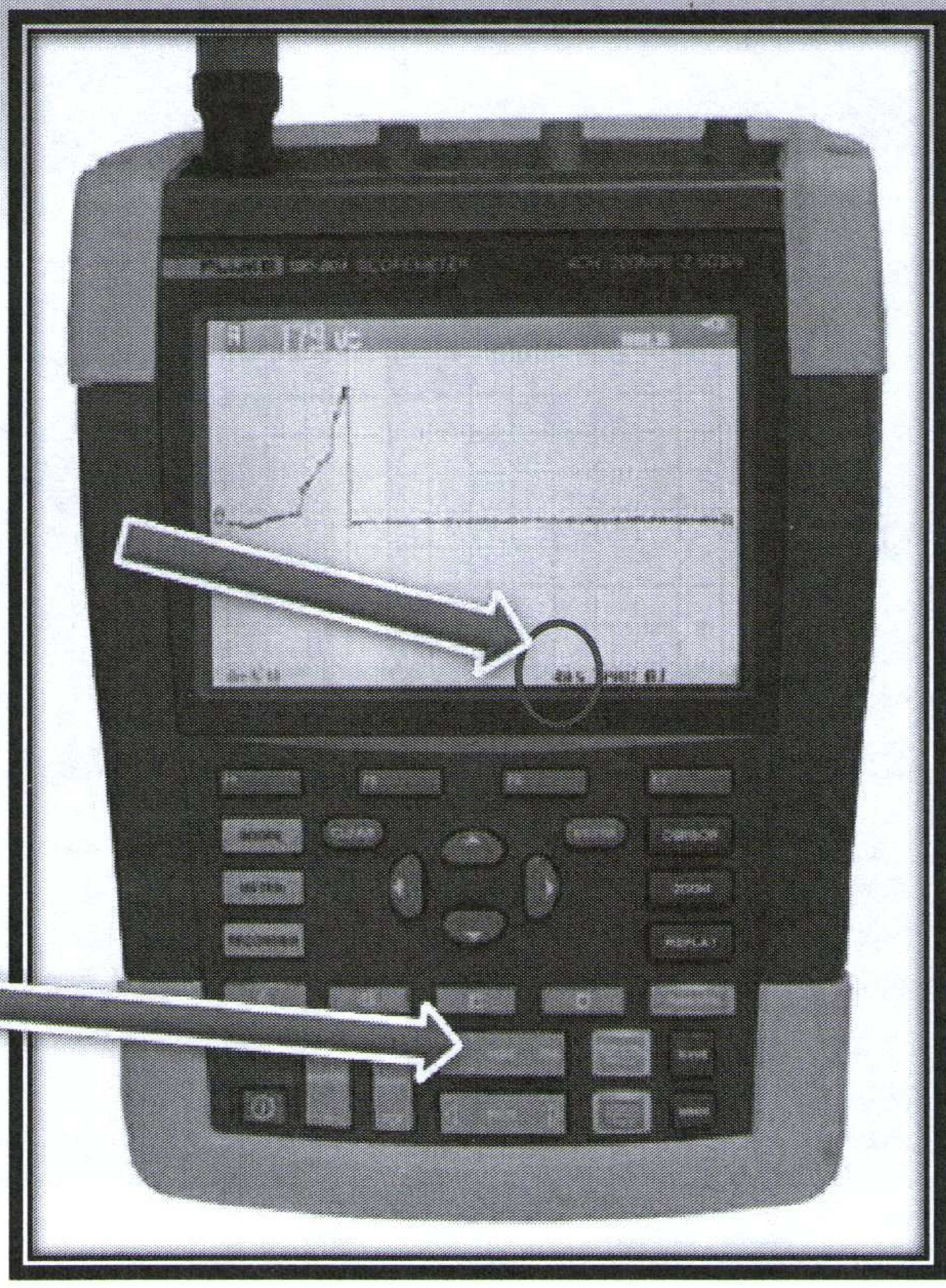
G158(56)

ScopeMeter Parameters *Set Time Period*

An EDM discharge pattern will show a climb in voltage and then a sharp vertical line. The sharp vertical line shows the moment of discharge to ground.

To show this detail, adjust the **TIME**.

Setting the time period to 10μs (microseconds) is a good place to start and then you can adjust the **TIME** based on the conditions of the reading.



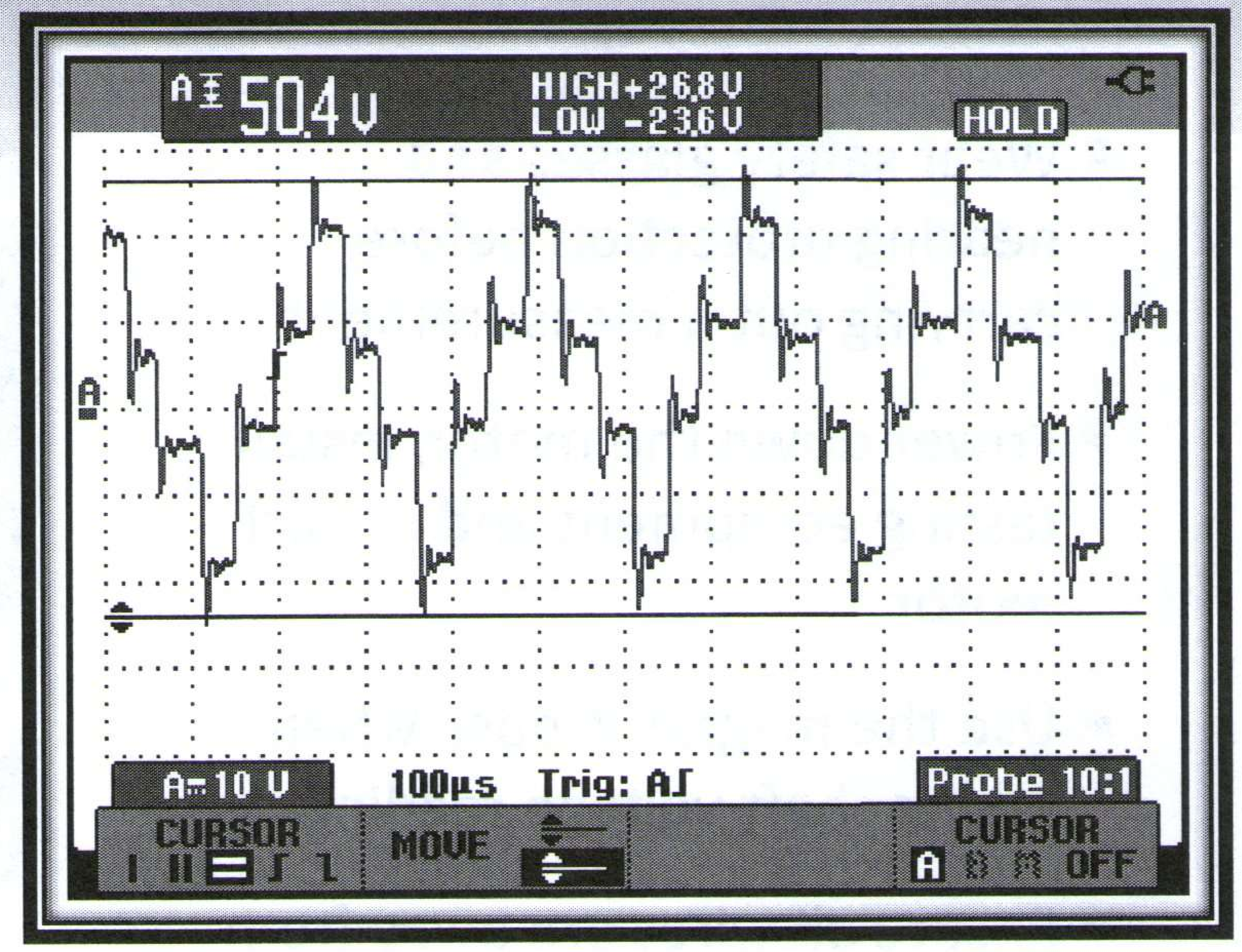
www.est-aegis.com

ÆGIS™ BEARING PROTECTION RING

G158(57)

ScopeMeter Parameters *Time Period*

This is an example of a Time period set to 100 microseconds. It is a 6 step pattern in the wave form. 4 full cycles of the pattern are shown.



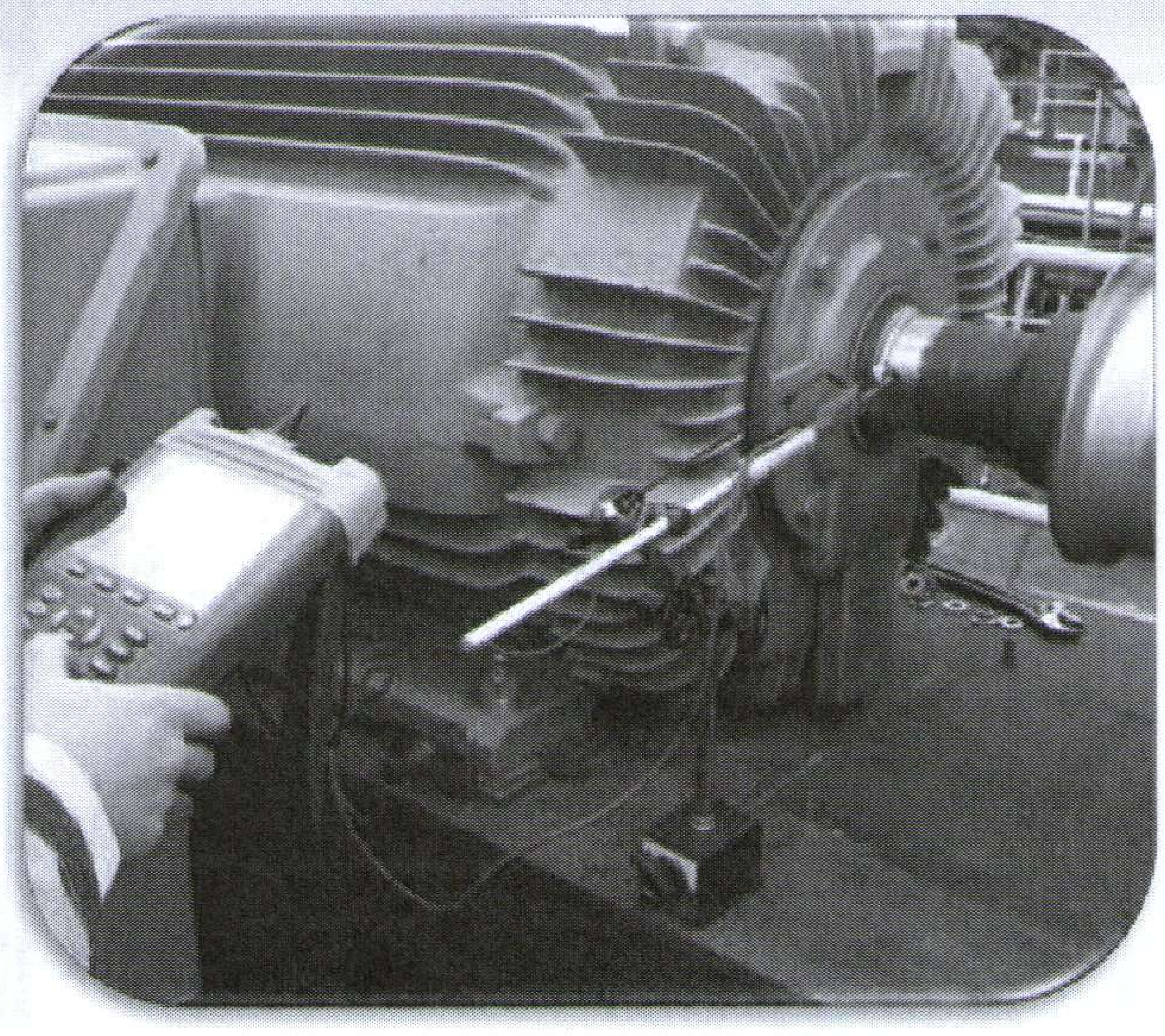
www.est-aegis.com

AEGIS BEARING PROTECTION RING

G15b (58)

Safety

- Wear safety glasses and hearing protection before carrying out a measurement
- Power down the motor, install testing equipment and restart motor
- Use the magnetic base when taking shaft voltage readings
- Ensure all wires are away from rotating equipment



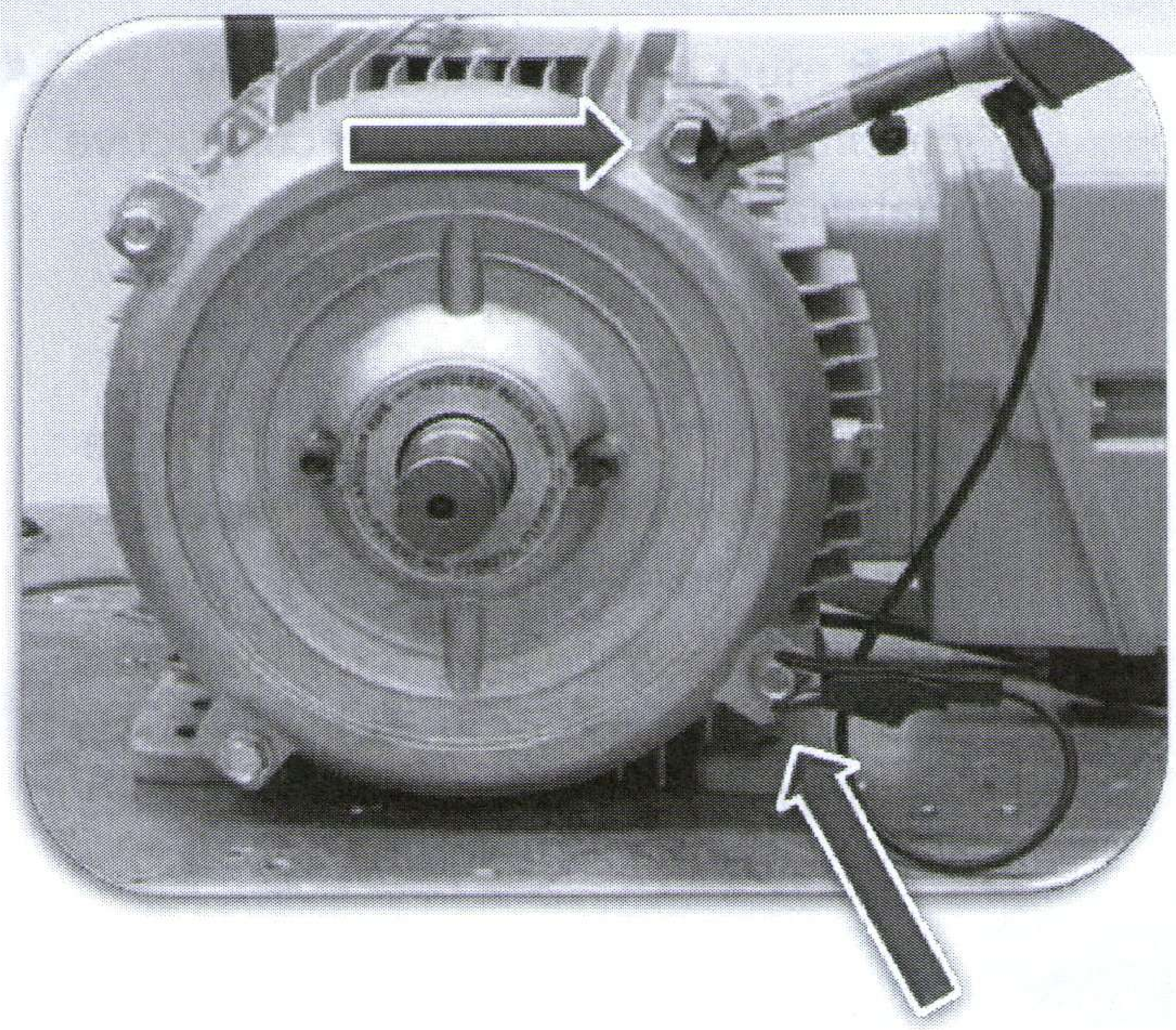
AEGIS™ BEARING PROTECTION RING

G152(59)

Taking the Measurements

Ground Reference Reading: EMI

1. The reading displays ground noise or EMI being produced by the motor system.
2. Find 2 ground points on the motor. Must be bare metal and conductive.
3. Place the SVP on one of the points and the probe grounding clip on the other point.
4. Measurements will vary depending on the motor size and conditions.



www.est-aegis.com

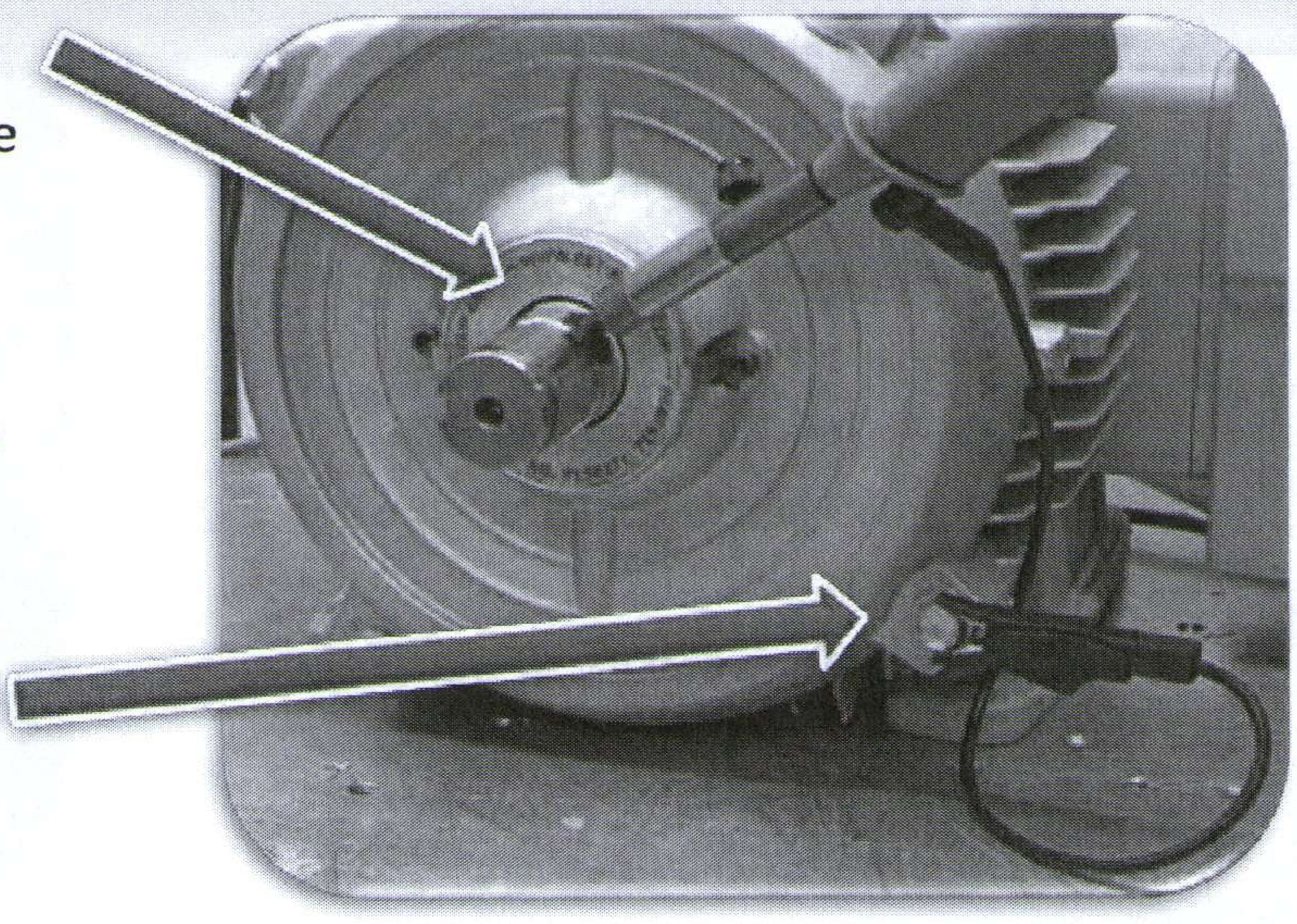
AEGIS™ BEARING PROTECTION RING

915b(60)

Taking the Measurements

Shaft Voltage Reading

1. Shaft must be clean & free of any coatings, paint or other nonconductive material.
2. Secure the probe in place with magnetic base.
3. Align AEGIS™ SVP on shaft end or side ensuring continuous contact. Avoid keyway if possible.
4. Place oscilloscope grounding lead on bare metal of motor ensuring conductive path to ground.



www.est-aegis.com

ÆGIS™ BEARING PROTECTION RING

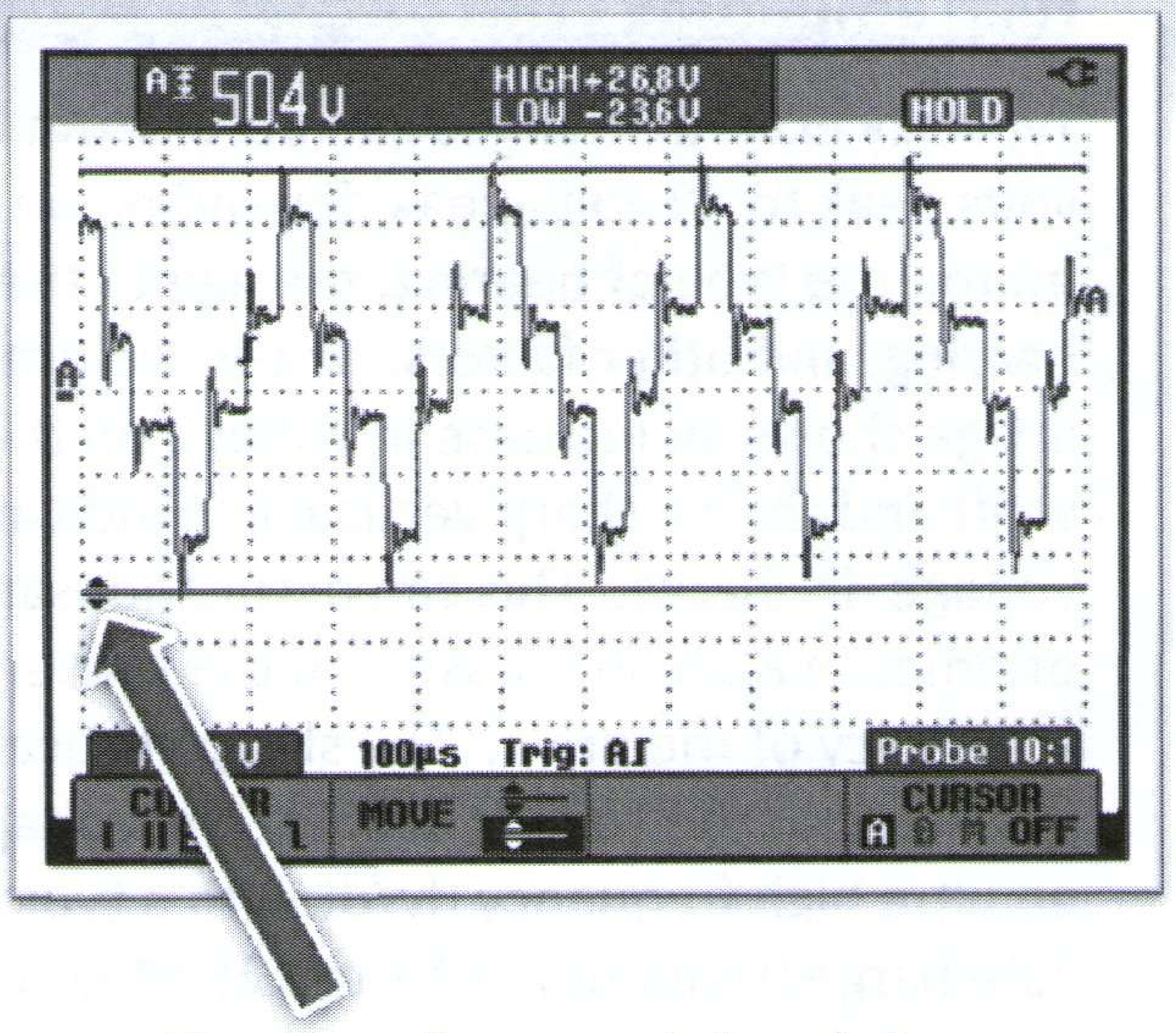
G153(61)

Examples of Shaft Voltage Readings

High Peak to Peak common mode voltage –

Typically 20 to 120 volts peak to peak. The waveform image shows the capacitive coupled common mode voltage on the shaft of the motor. The "six-step" wave form is the result of the 3 phases of pulses from the VFD. The timing of the pulse width modulation (PWM) pulses to the motor from the drive determines what the wave form looks like. Sometimes it will look like a square wave.

Important note: This six-step or square wave is what is seen when there is no bearing discharge and the peak to peak shaft voltage is at it's maximum level. The voltage may eventually overcome the dielectric in most bearings and begin discharging.



The use of cursors is handy to determine voltages at a specific spot in the reading.

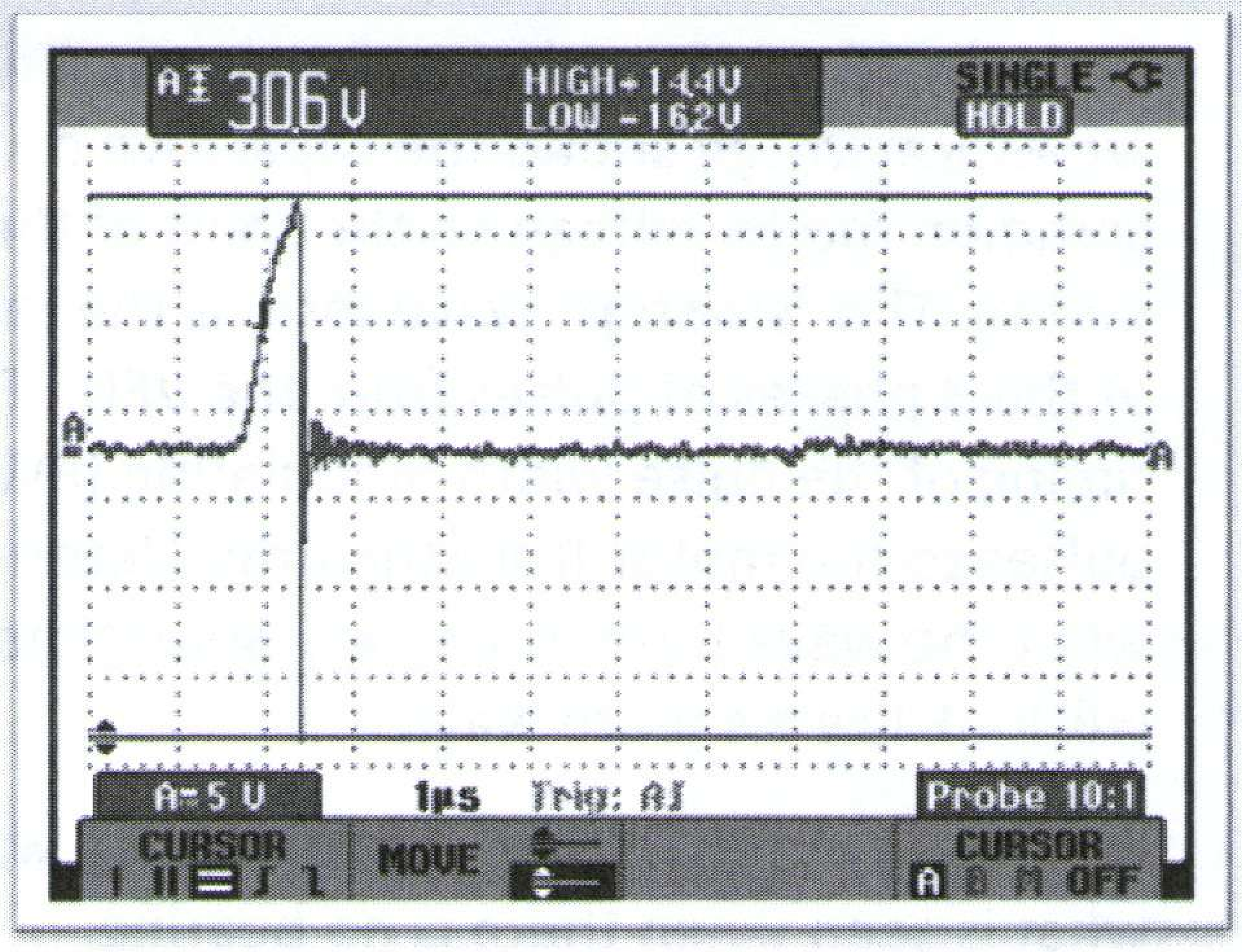
ÆGIS BEARING PROTECTION RING

G158(62)

Examples of Shaft Voltage Readings

High amplitude EDM discharge pattern –

Typically EDM discharges can occur from 6 volts peak to 80 volts peak depending on the motor, the type of bearing, the age of the bearing, and other factors. The waveform image shows an increase in voltage on the shaft and then a sharp vertical line indicating a voltage discharge. This can occur thousands of times in a second, based on the carrier frequency of the drive. The sharp vertical discharge at the trailing edge of the voltage is an ultra high frequency dv/dt with a typical "discharge frequency" of 1 to 125 MHz (based on testing results in many applications).



www.est-aegis.com

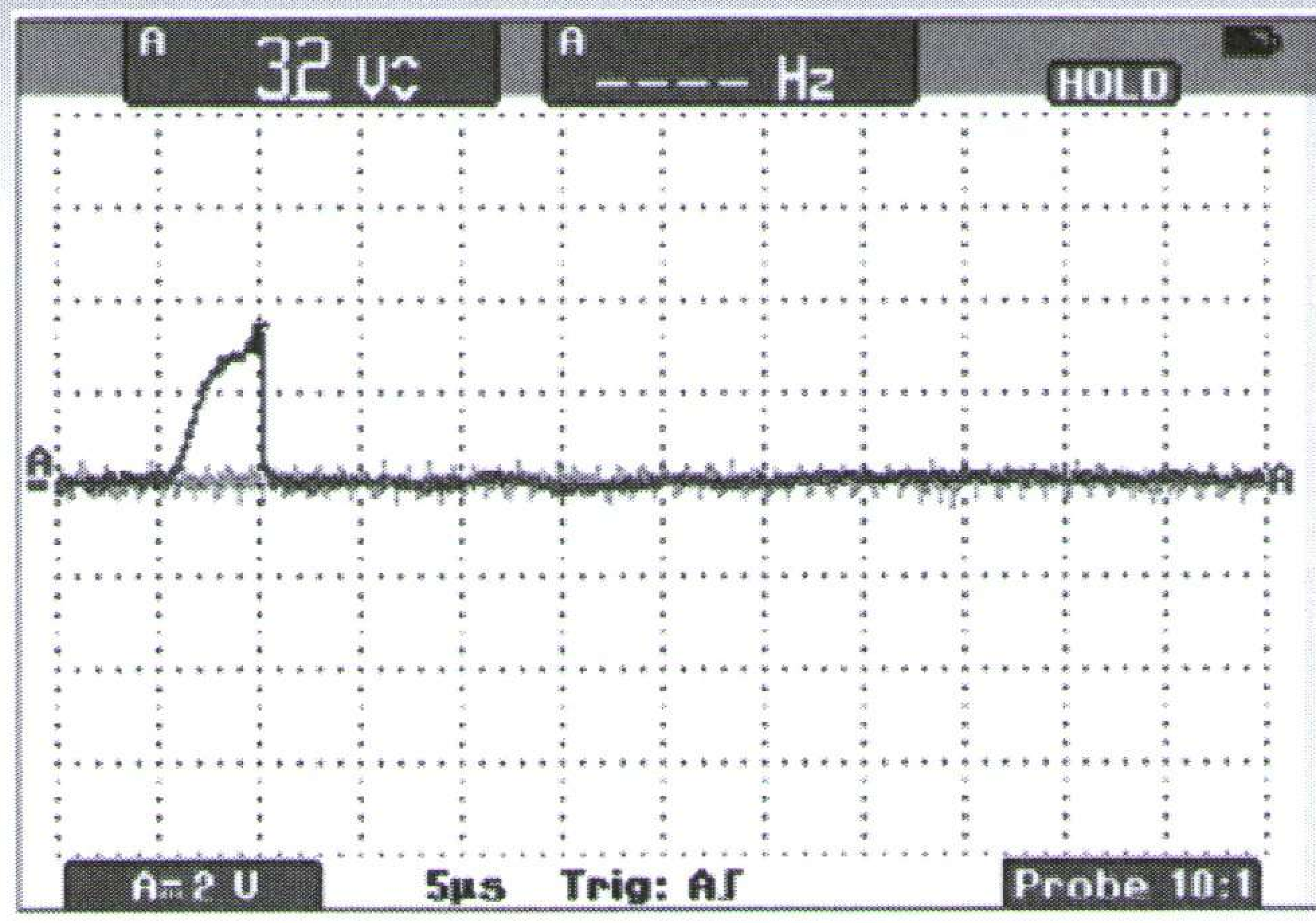
ÆGIS™ BEARING PROTECTION RING

GLS8(63)

Examples of Shaft Voltage Readings

Low amplitude EDM discharge pattern –

Even though the voltage peak to peak waveform shows a small change (3.2V pk-pk in this case) the bearing is still experiencing arcing thousands of times in a second.



www.est-aegis.com

ÆGIS™ BEARING PROTECTION RING

CHAPTER I

Split-phase Motors

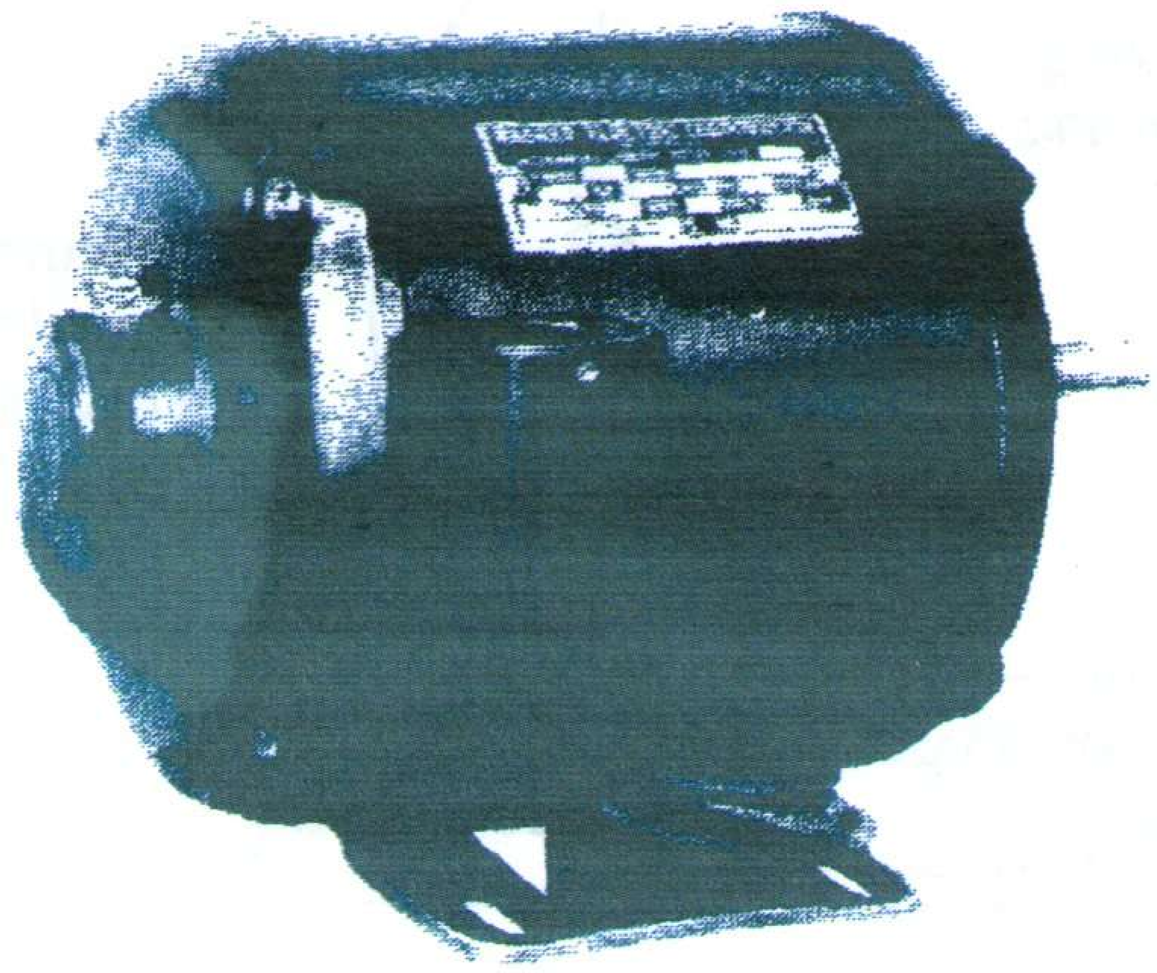


FIG. 1-1.—A split-phase motor. (*Wagner Electric Co.*)

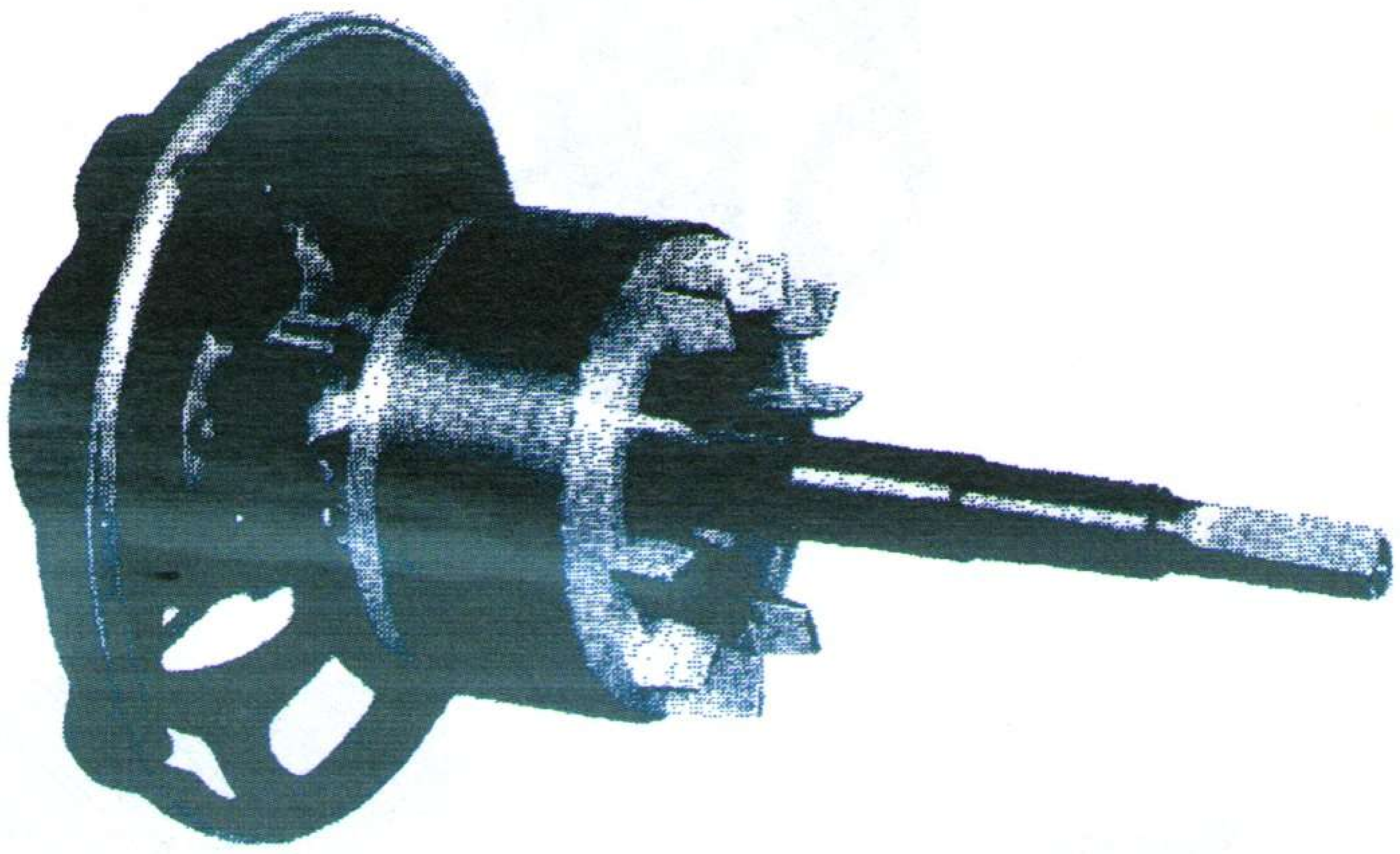


FIG. 1-2.—A complete rotor of a split-phase motor. (*Wagner Electric Co.*)

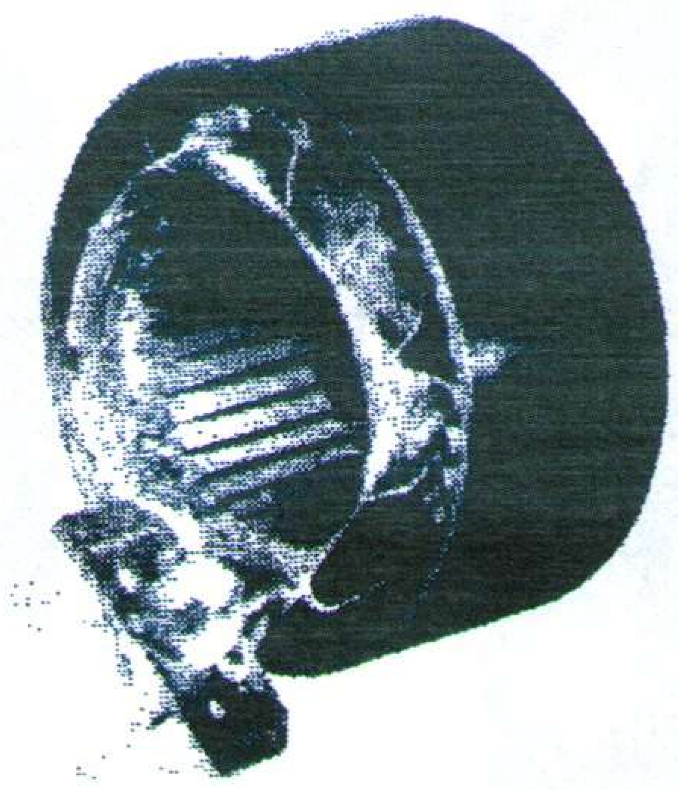


FIG. 1-3.—A stator of a split-phase motor mounted inside the frame. (*General Electric Company.*)

G158(65)

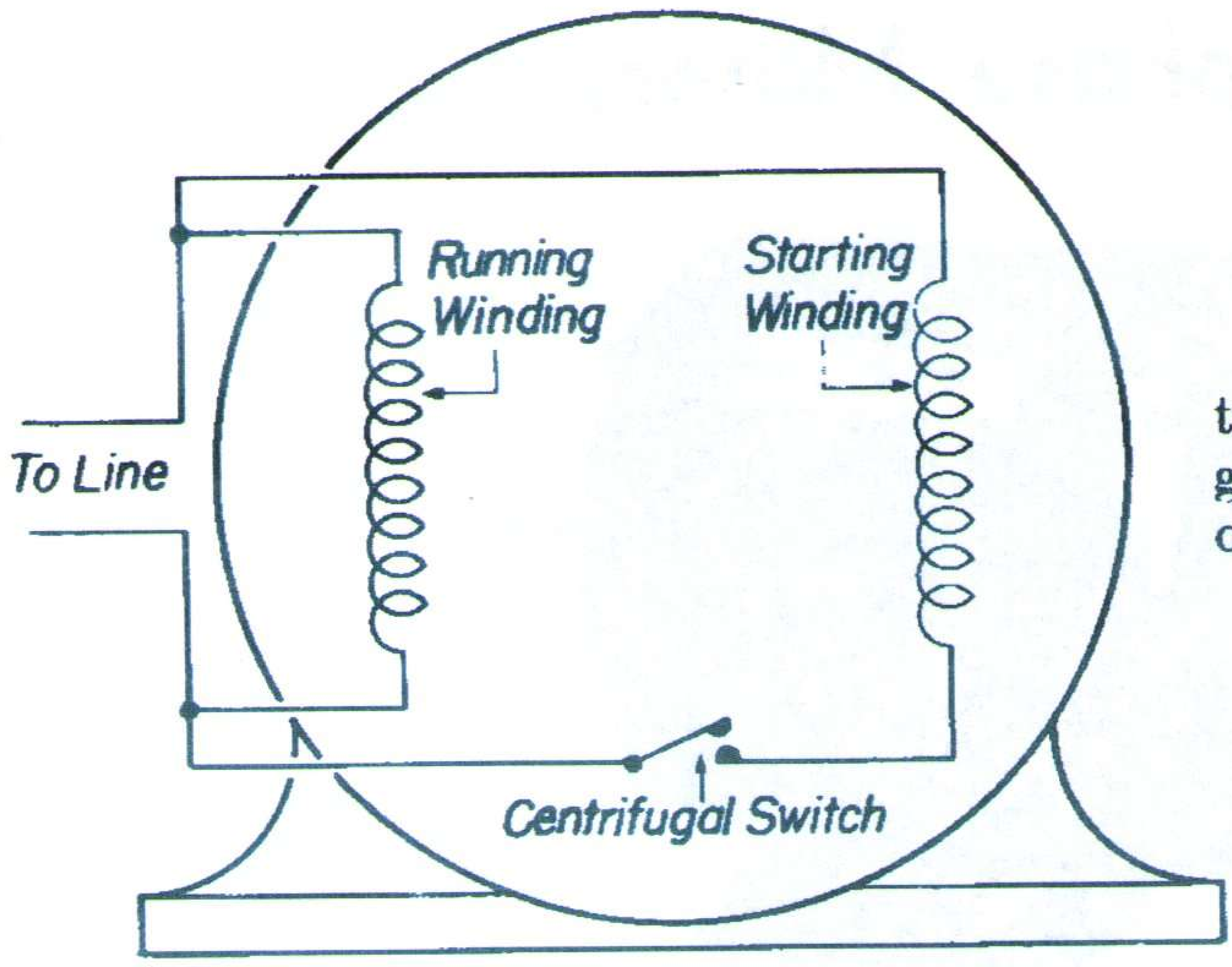
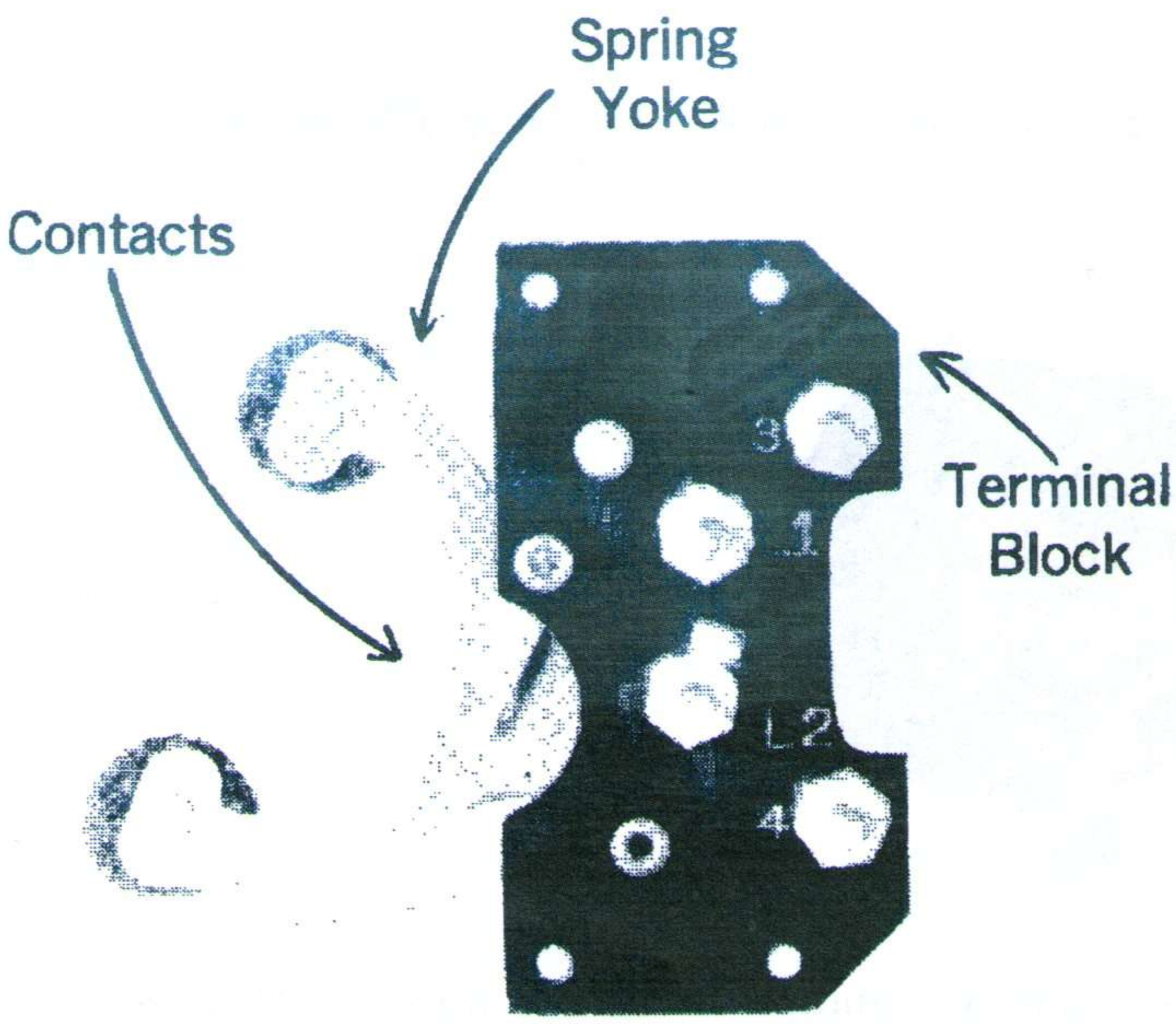


FIG. 1-4.—A circuit of the two windings and the centrifugal switch when the motor is operating at full speed.

FIG. 1-5.—One end plate of a fractional-horsepower a-c motor. (*General Electric Company.*)



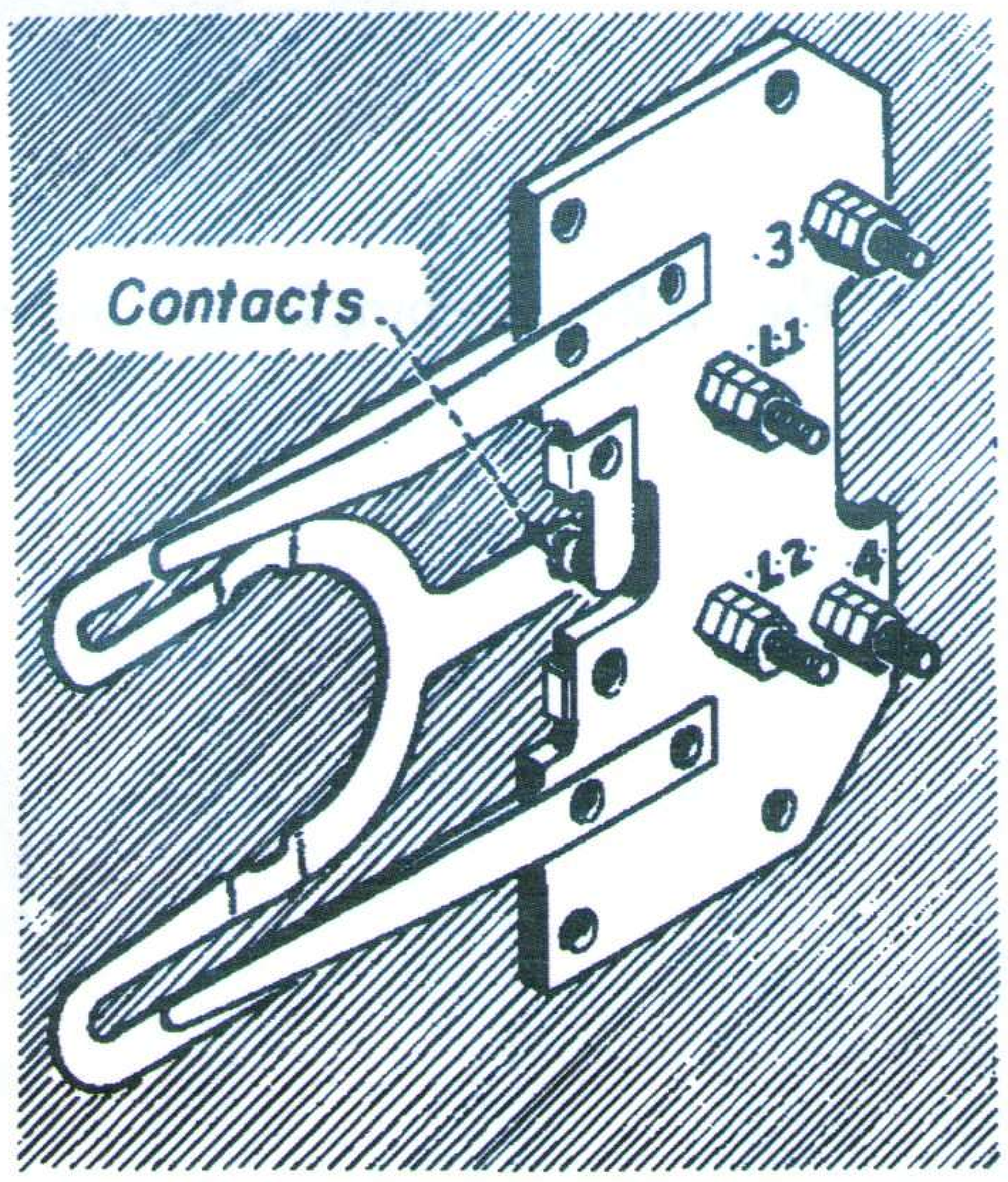


FIG. 1-6.—Two variations of the stationary section of one type of centrifugal switch which consist of a U-shaped yoke mounted on a terminal block.

G158(66)

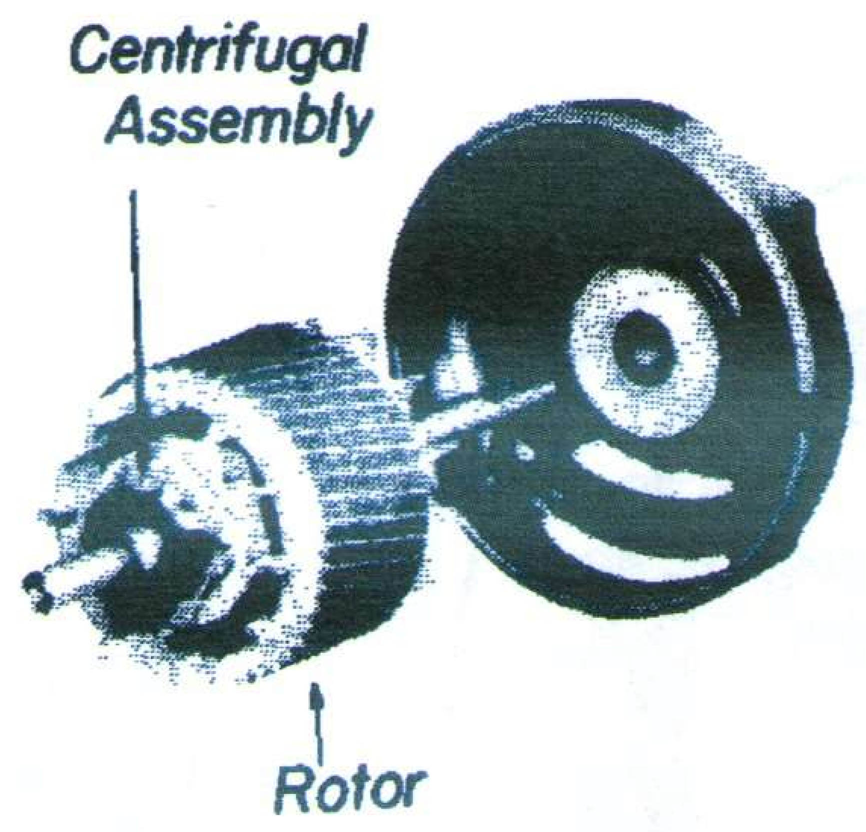
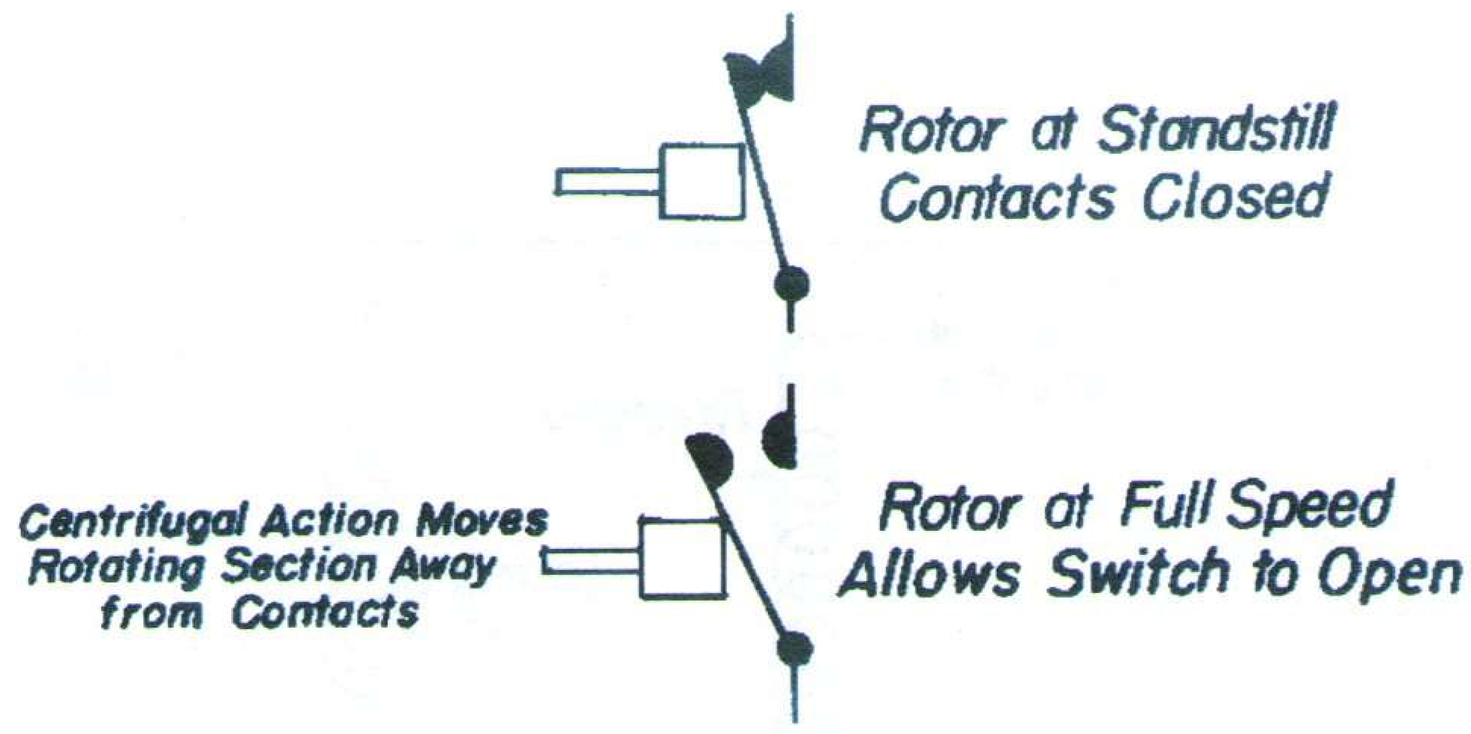


FIG. 1-7.—The rotating mechanism of a centrifugal switch. (*General Electric Company.*)

FIG. 1-8.—Steps in the operation of a centrifugal switch.



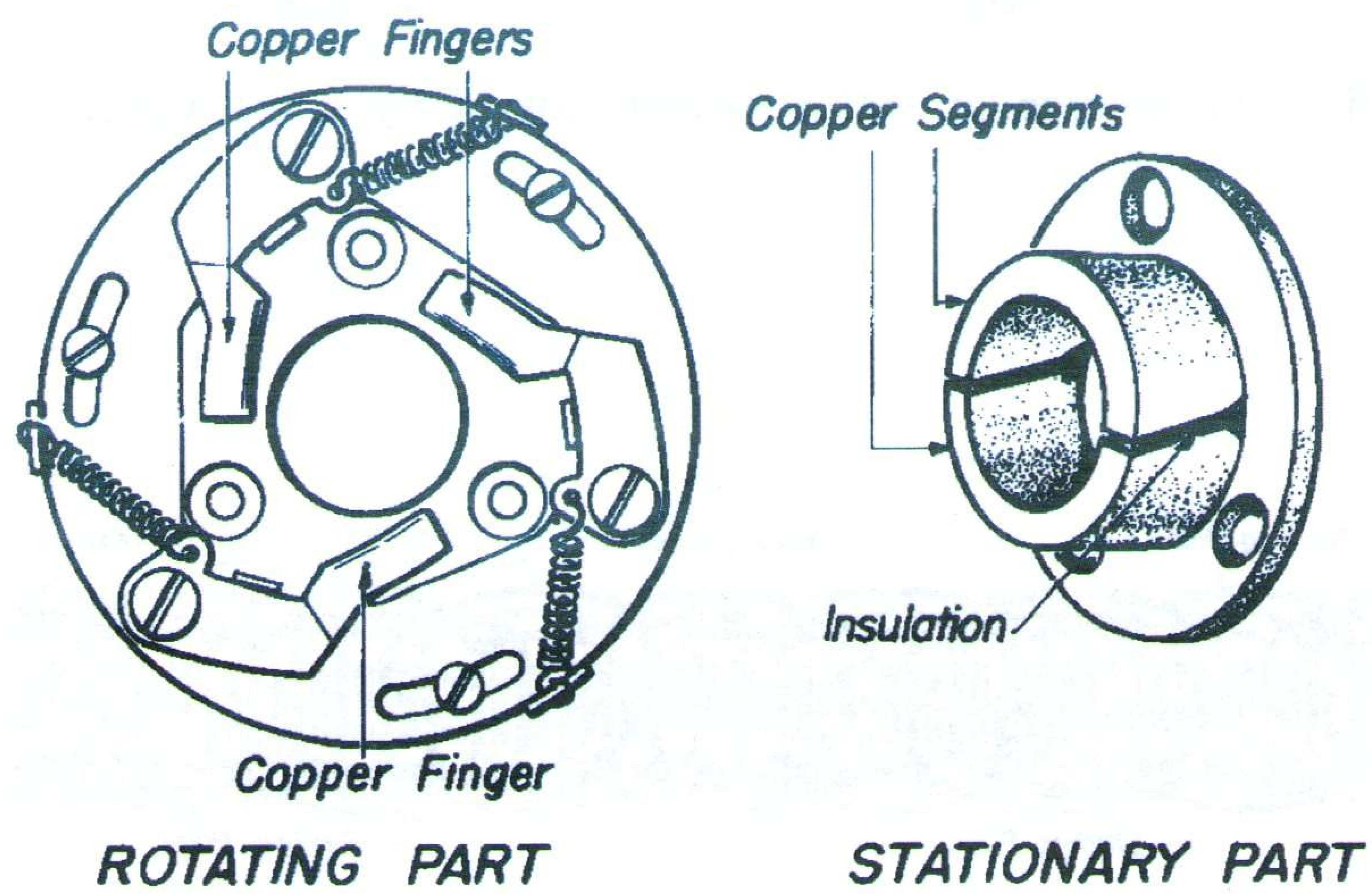


FIG. 1-9.—The rotating and stationary parts of one type of centrifugal switch.

G158(67)

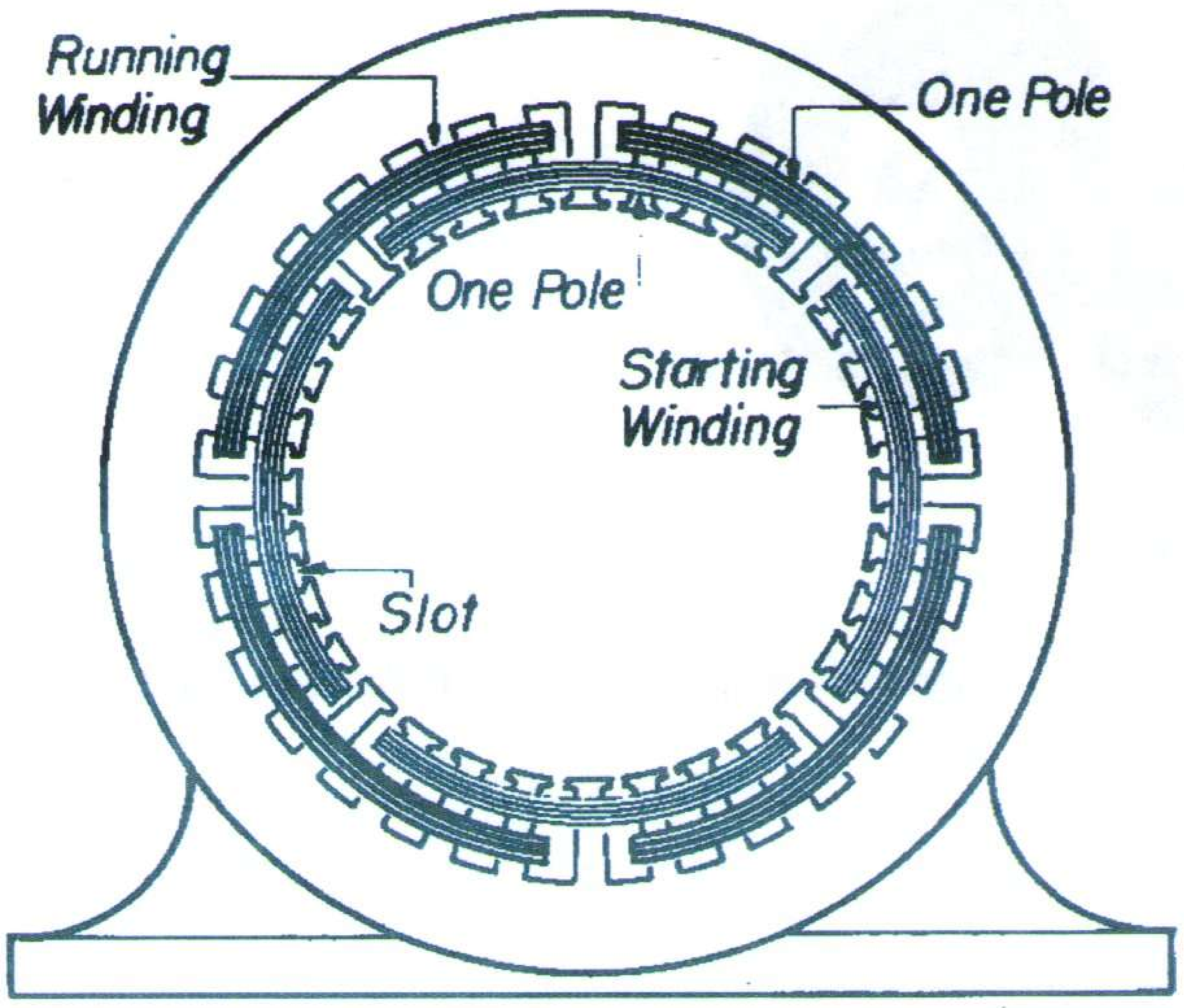


FIG. 1-10.—The two windings of a split-phase motor. Note the four sections or poles in each winding.

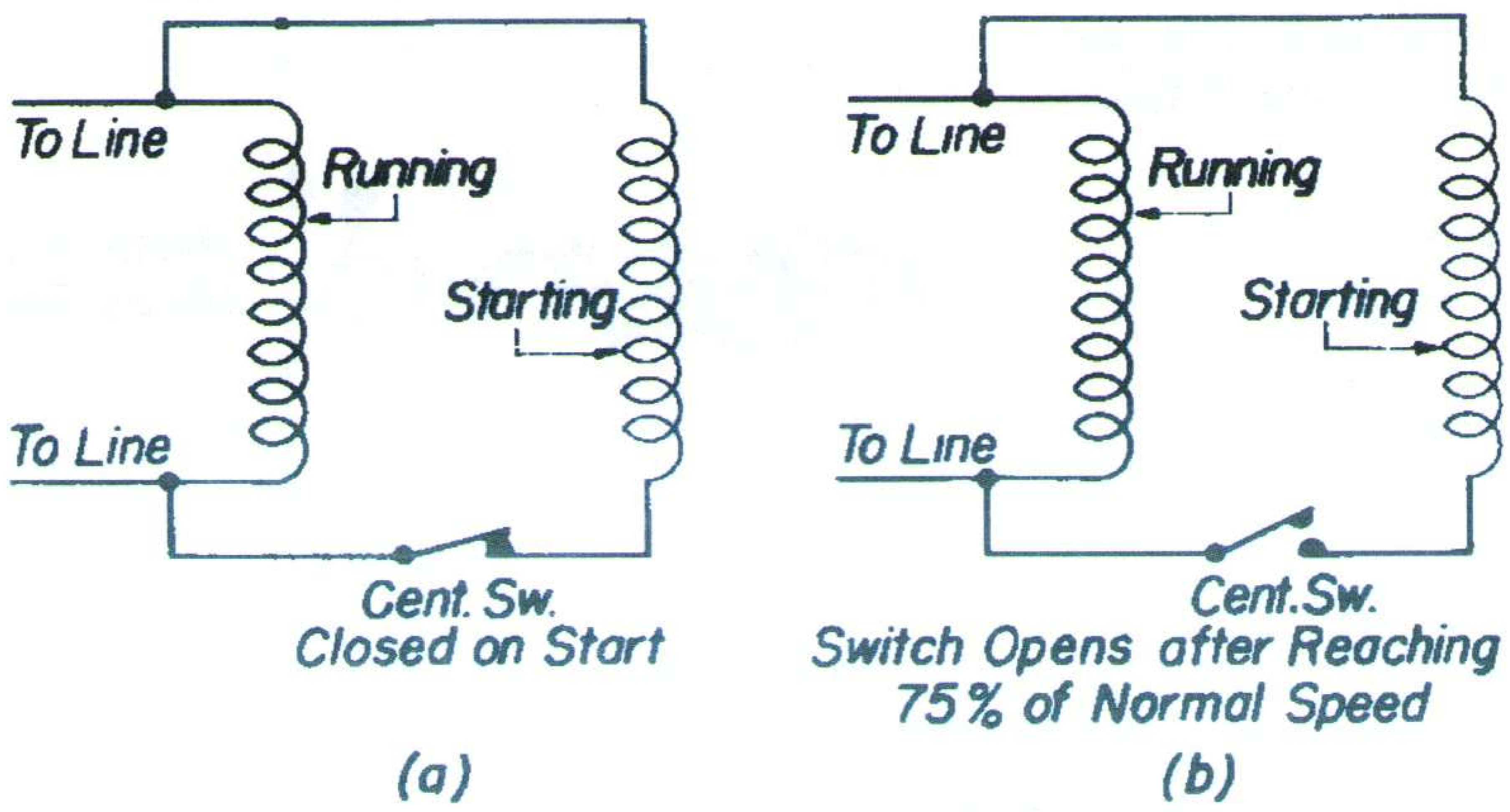


FIG. 1-11.—The change in motor circuit caused by a centrifugal switch.

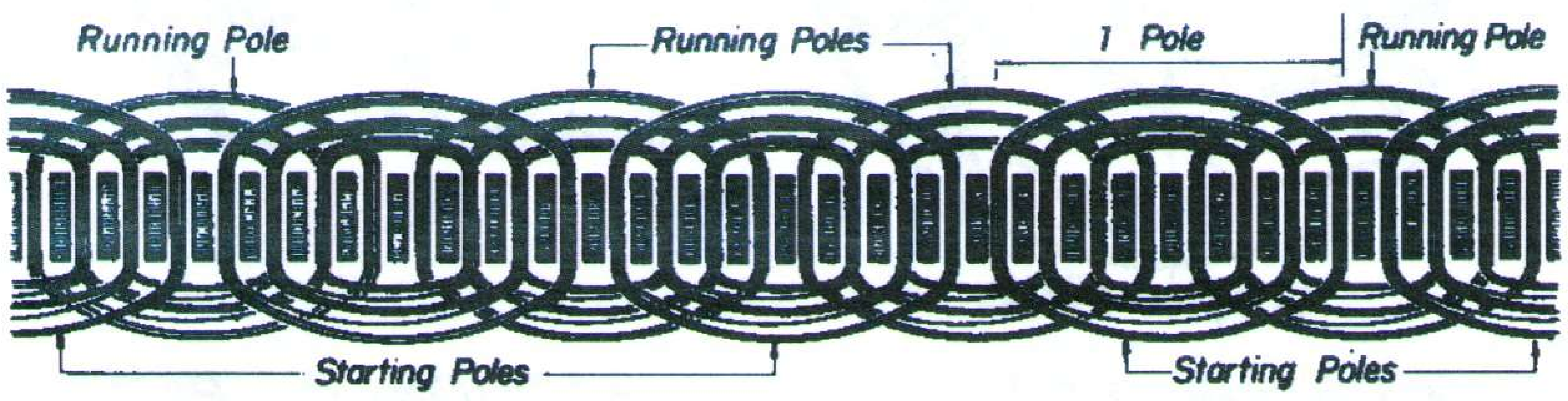


FIG. 1-12.—A diagram of the stator in Fig. 10 with slots and windings shown as they would look if rolled flat. The starting-winding poles are located between two running-winding poles.

Figures 1-10; 1-11; 1-12

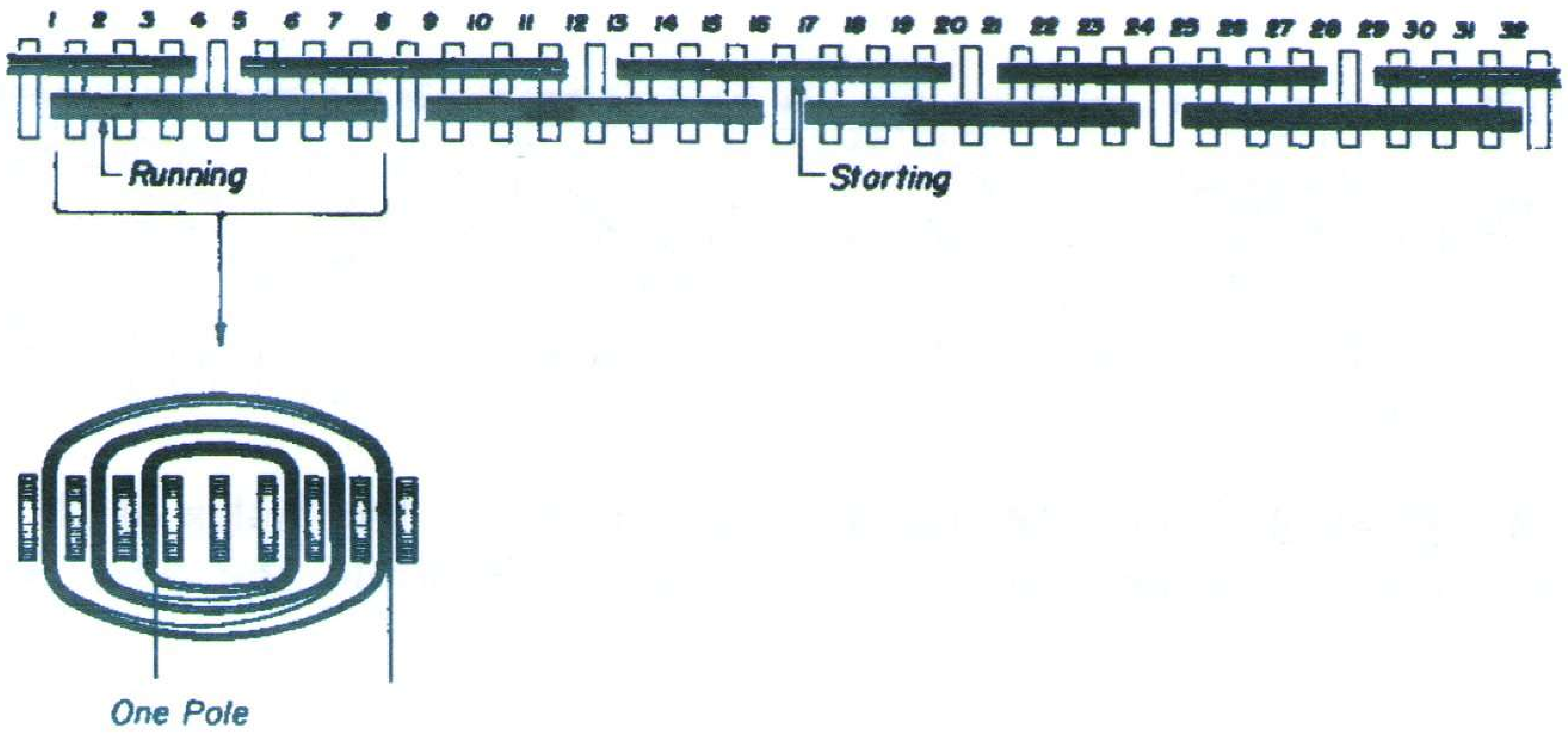


FIG. 1-13.—Each pole consists of three coils, and each coil is wound in two slots separated by other slots.

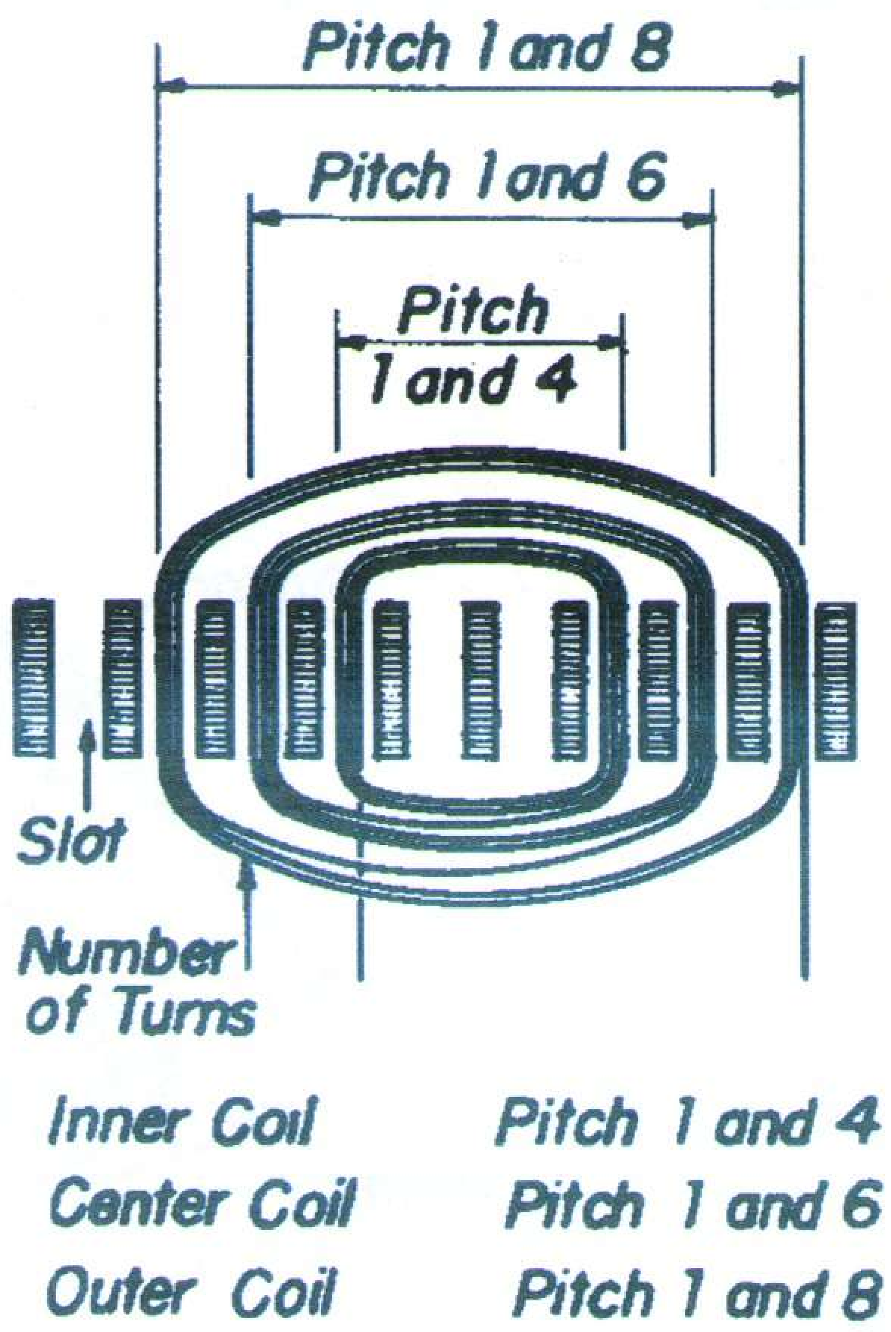


FIG. 1-14.—The pitch, or span, of the three coils forming one pole.

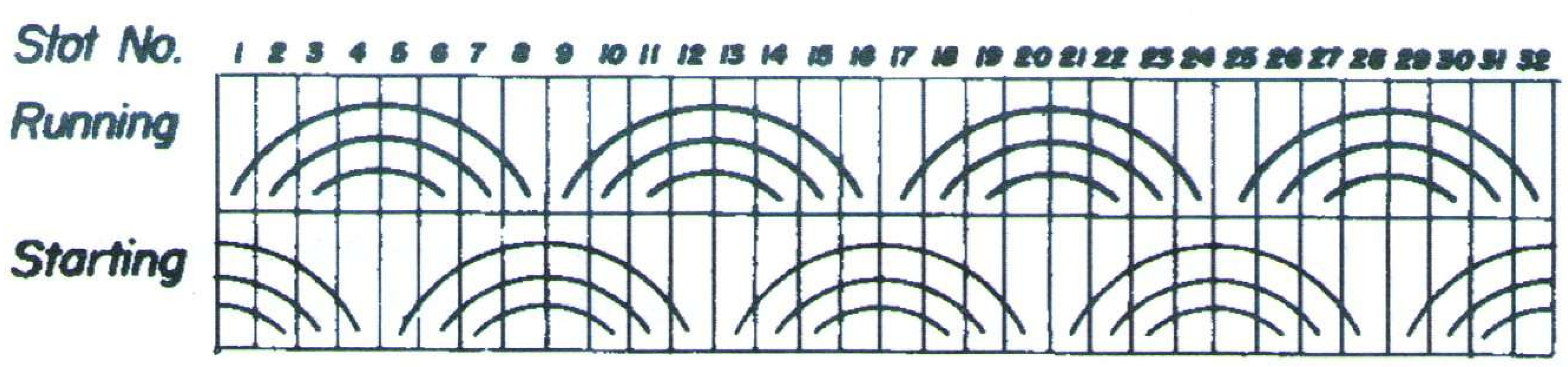


FIG. 1-15.—The method of recording the pitch of the coils in a 32-slot, four-pole motor. The number of turns in each coil can be recorded alongside each coil in the diagram if so desired.

G158 (69)

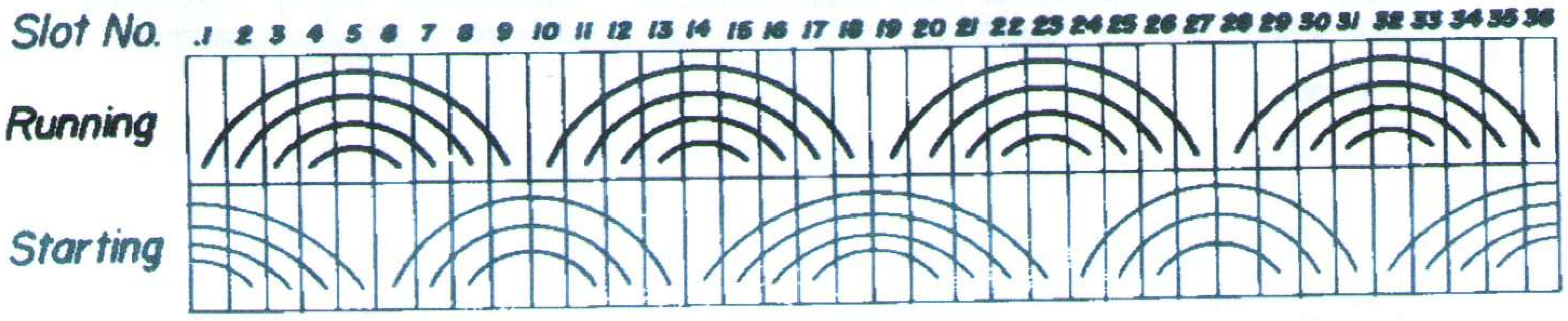


FIG. 1-16.—Pitch data of a 36-slot, four-pole motor. The poles of the starting winding are not the same; one pole has four coils while the next has three.

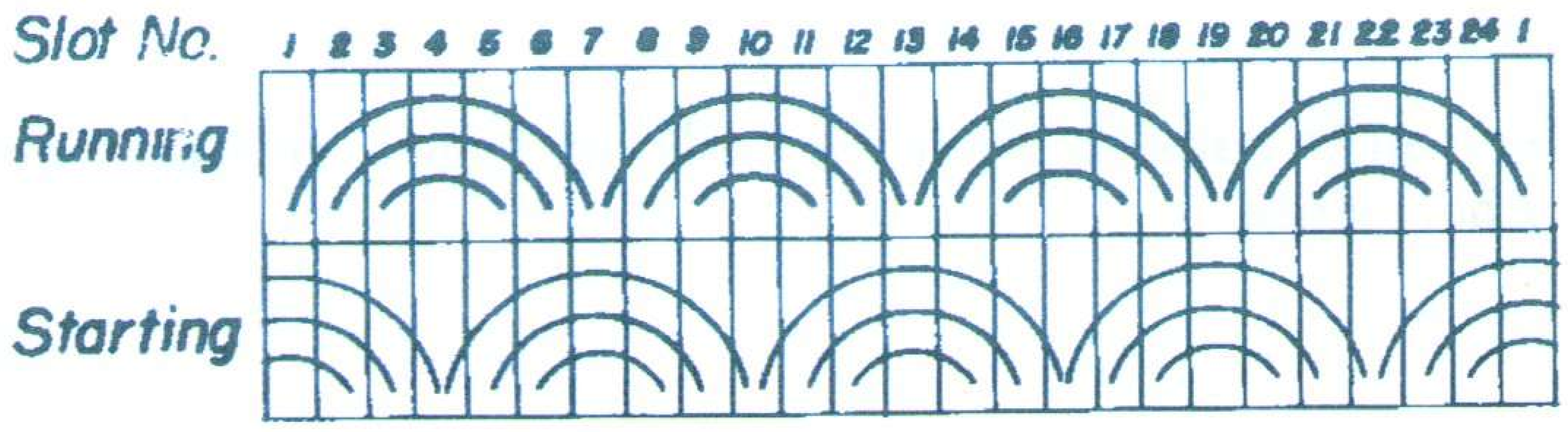


FIG. 1-17.—Pitch data of a 24-slot, four-pole motor. The outer coils of adjacent poles are in the same slot.

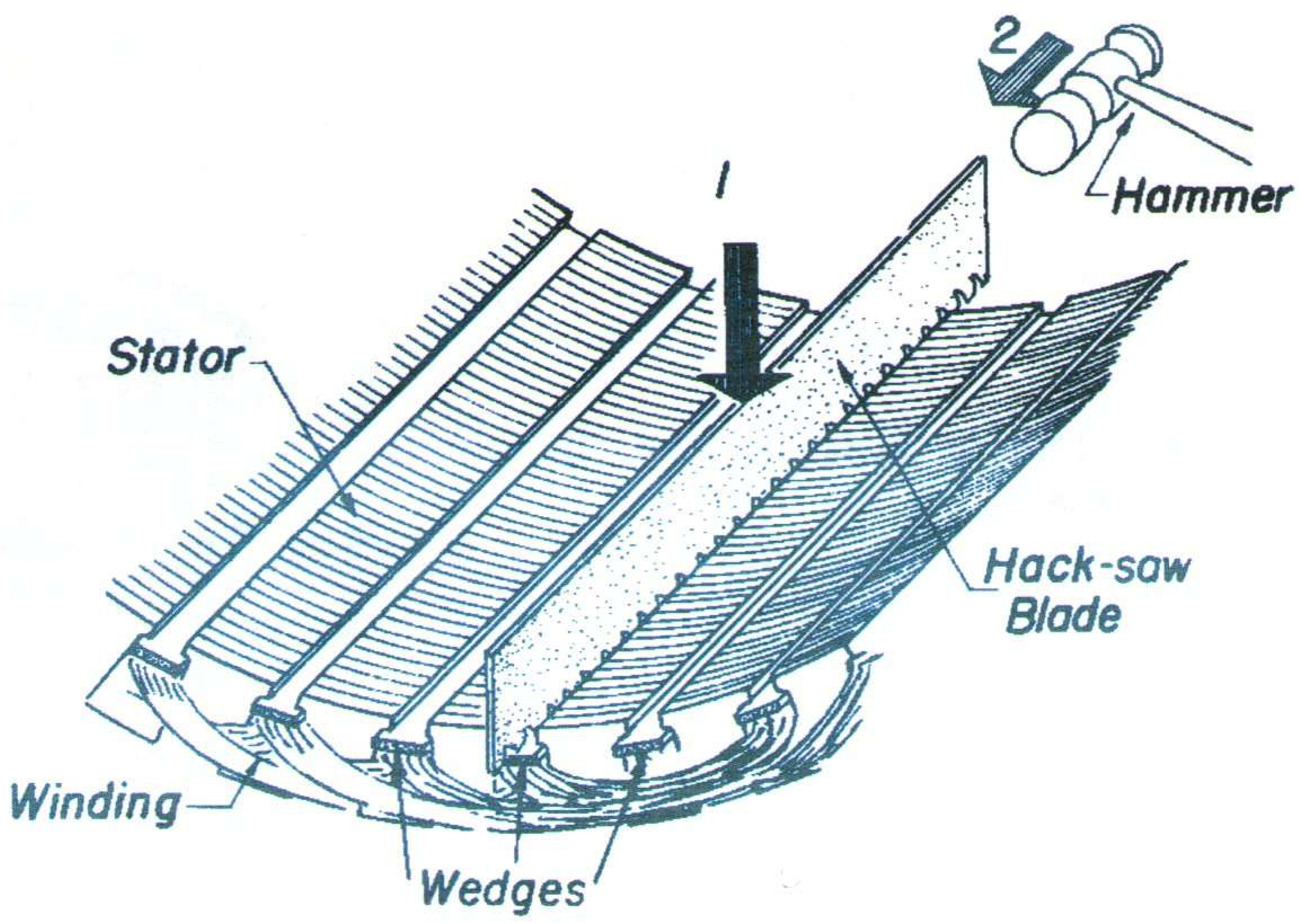


FIG. 1-18.—The method of forcing a hack-saw blade into a wedge.

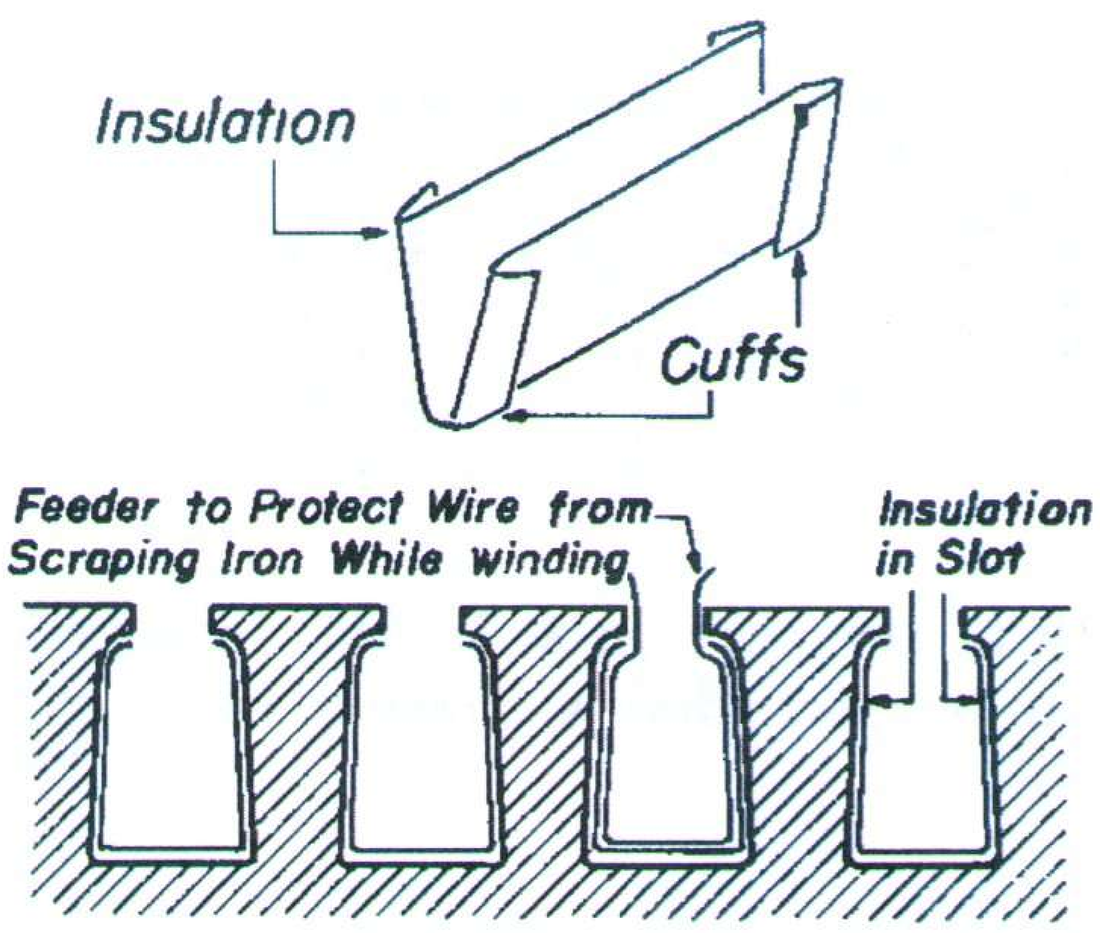


FIG. 1-19.—An insulating strip and its placement in slot before winding.

Figures 1-16; 1-17; 1-18; 1-19

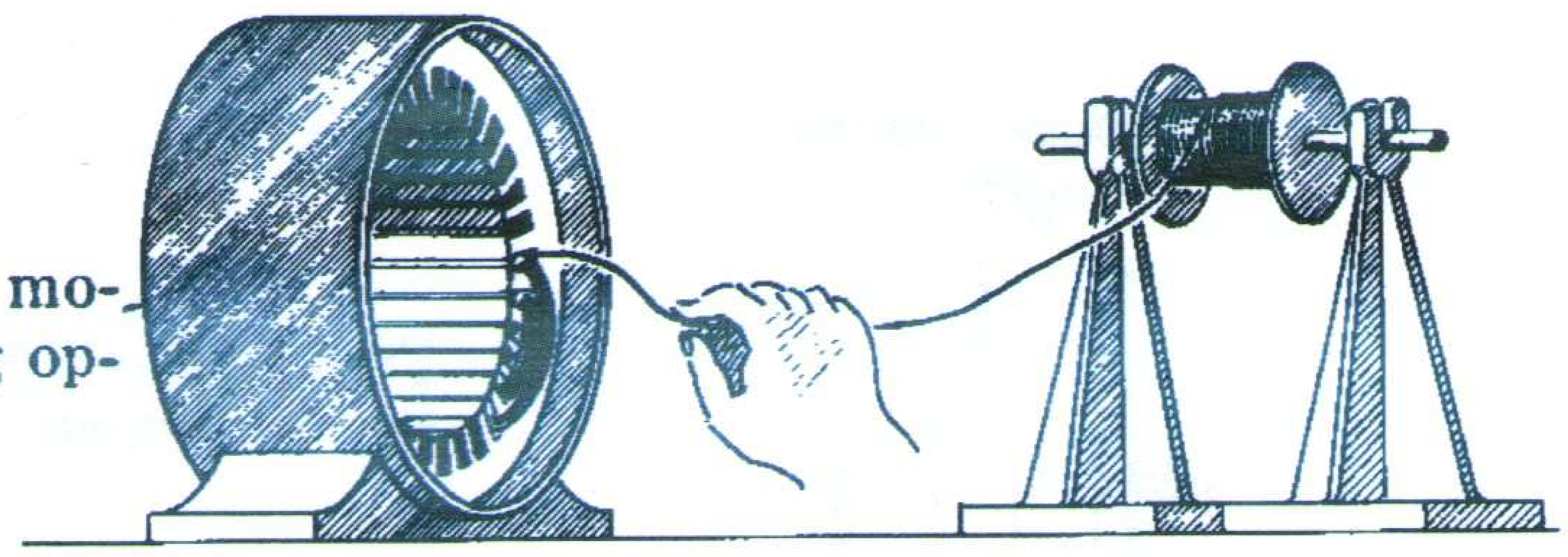


Fig. 1-20.—The position of the motor and wire spool during winding operation.

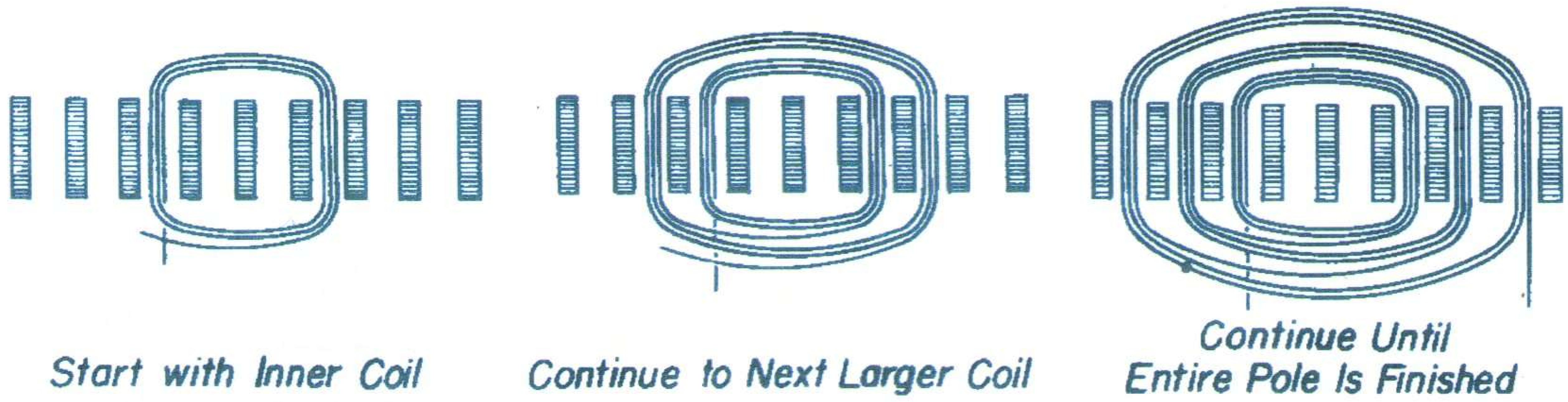


Fig. 1-21.—The procedure for winding one stator pole by hand.

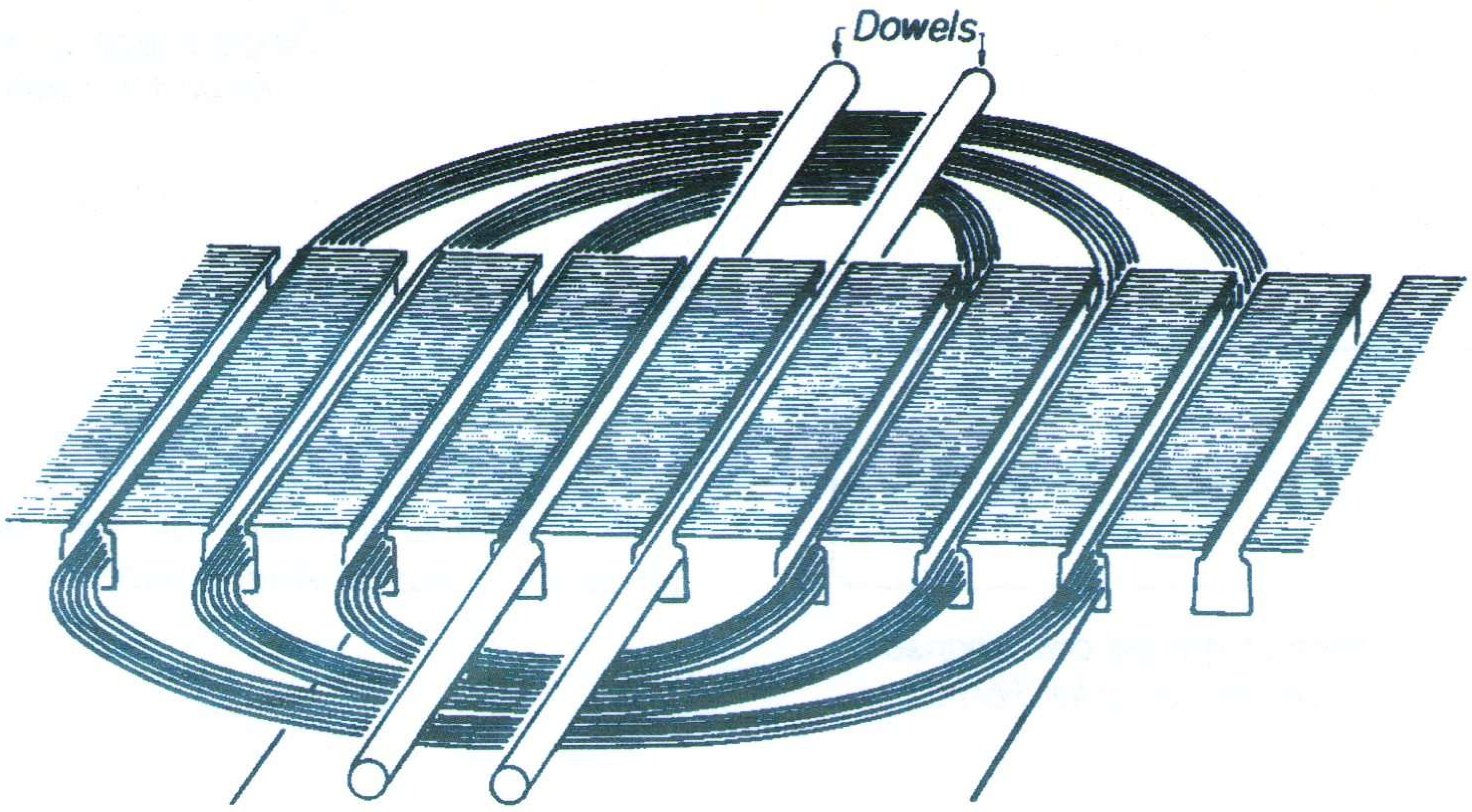


Fig. 1-22.—Wooden dowels may be placed in empty slots to hold coils in position while winding.

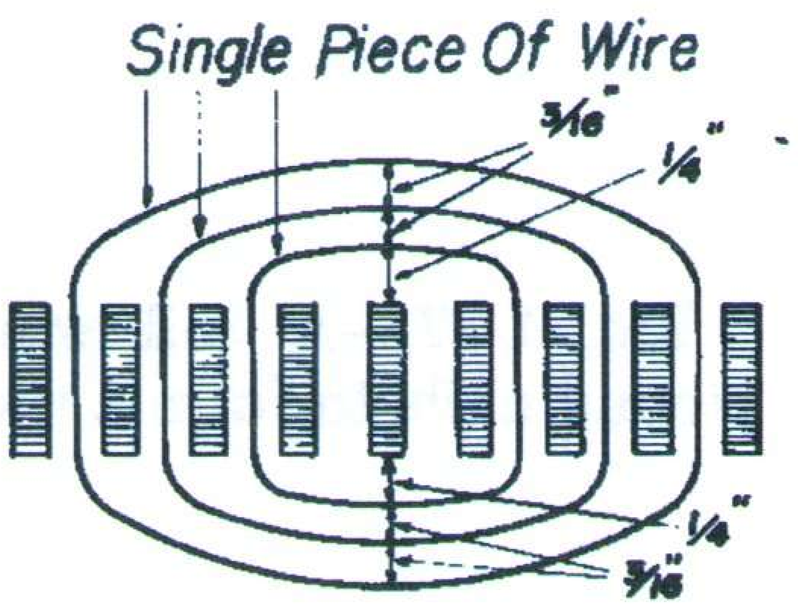


Fig. 1-23.—Properly spaced single turns of wire determine the size of the wooden forms shown in Fig. 1-24.

G158(71)

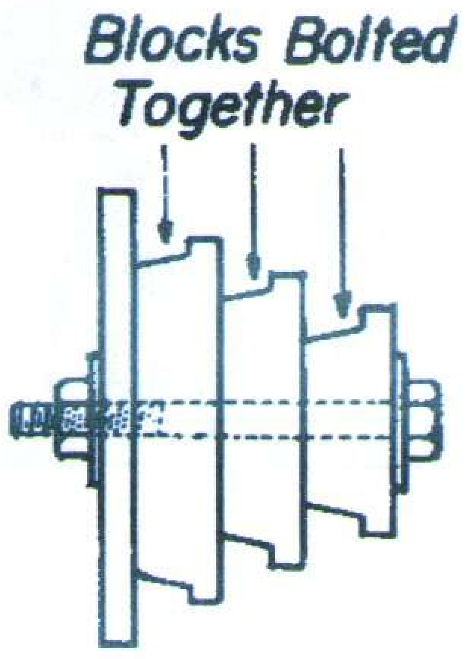


FIG. 1-24.—Wooden blocks provide forms on which to wind coils.

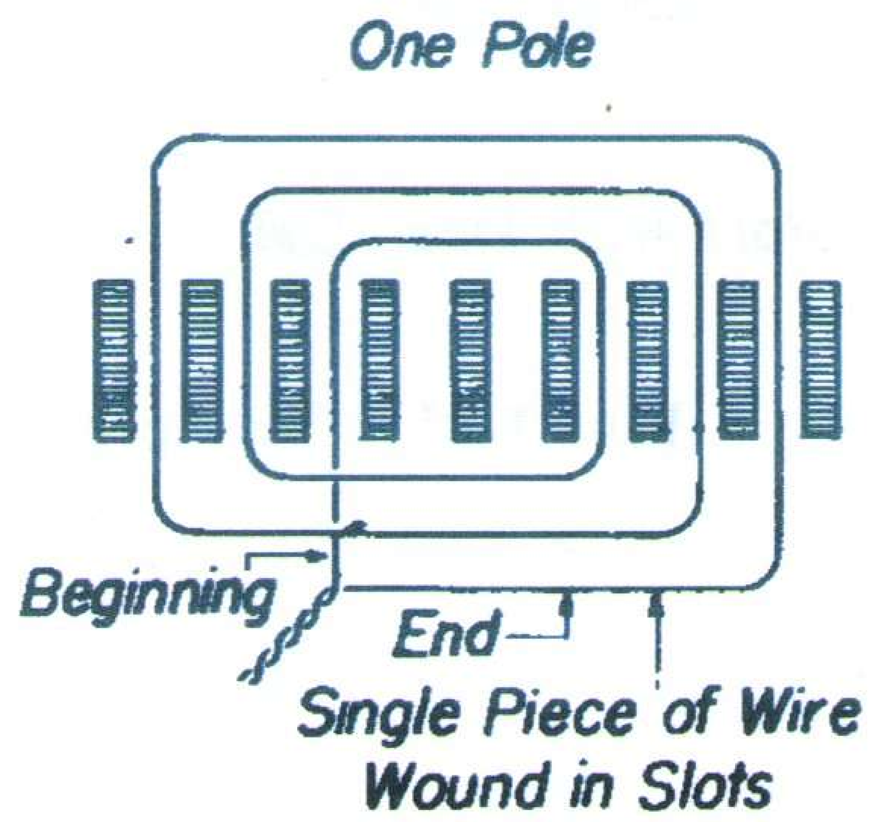


FIG. 1-25.—The method of determining the size of the skein.

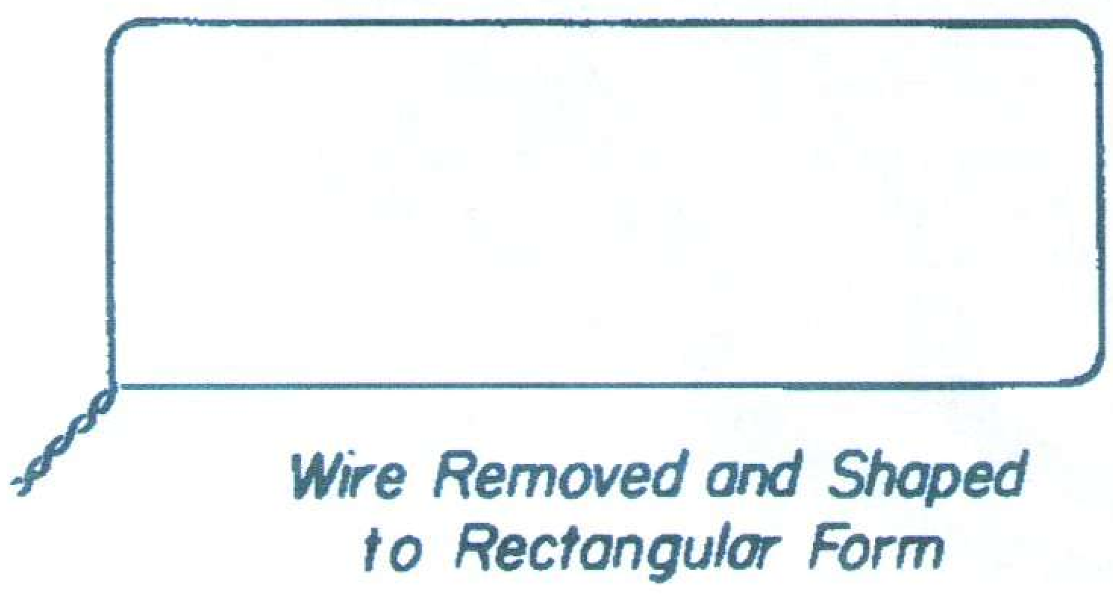


FIG. 1-26.—The size of the skein obtained from a single wire.

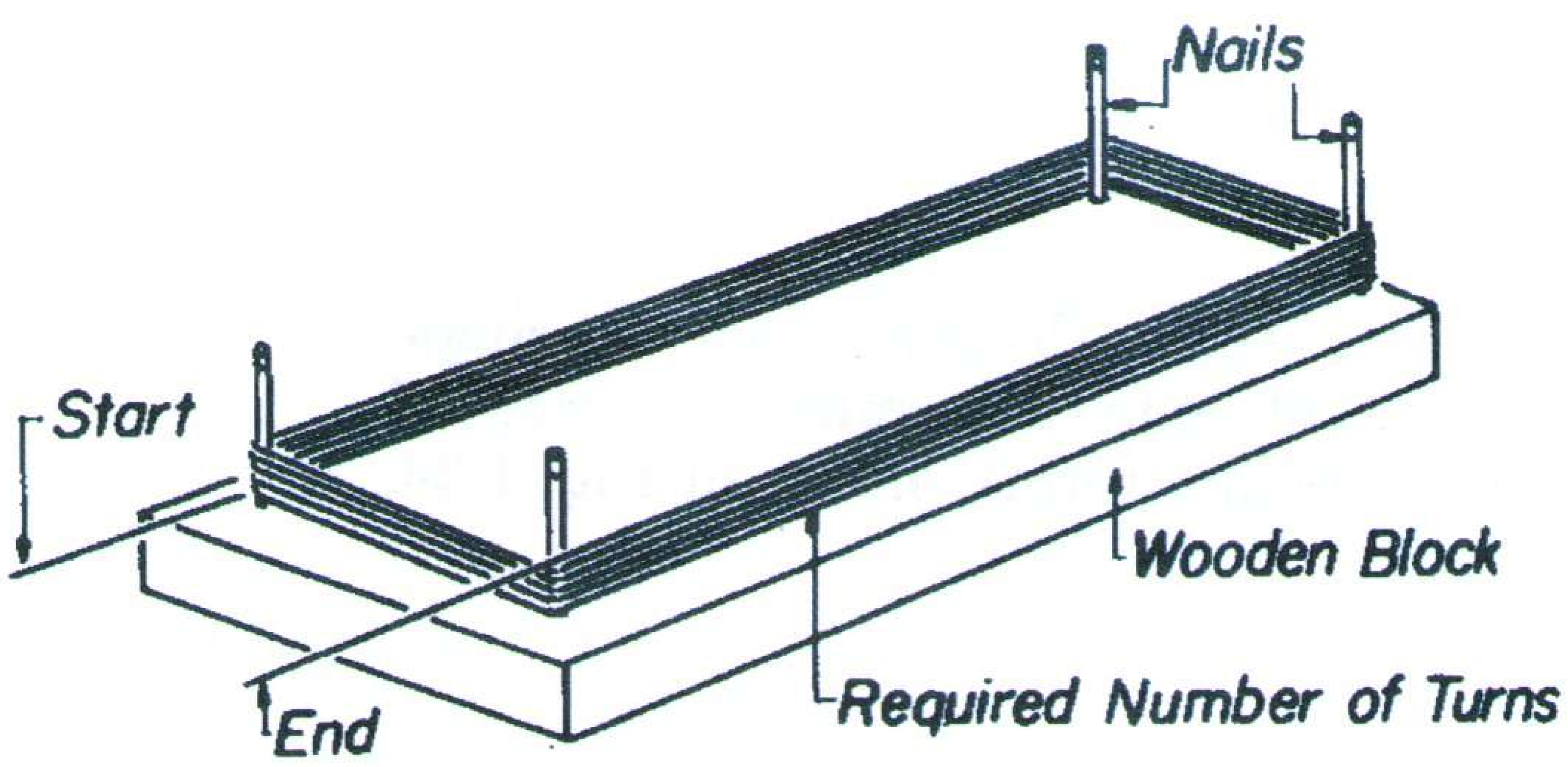


FIG. 1-27.—A coil wound around nails to form a skein.

Figures 1-24; 1-25; 1-26; 1-27

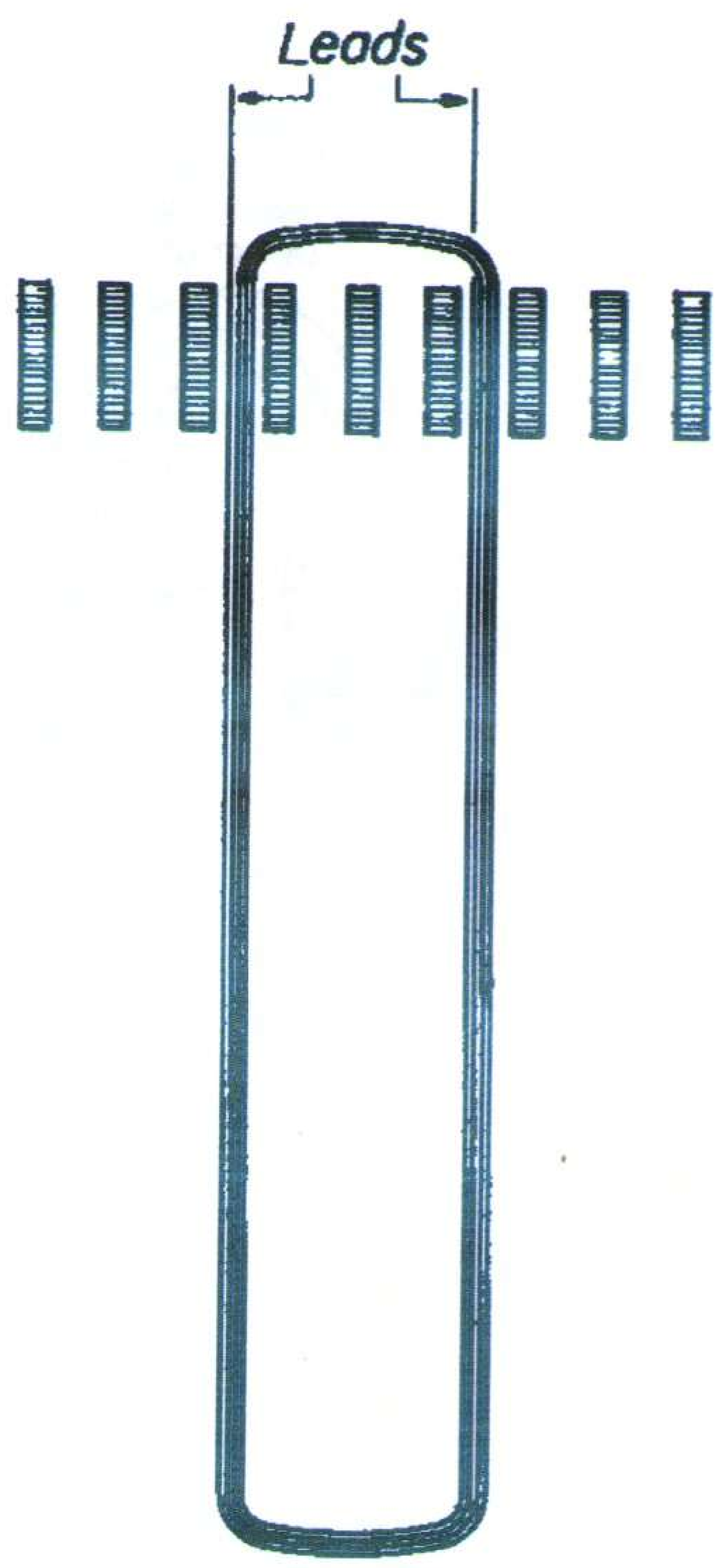


FIG. 1-28.—After it is removed from the nails, the skein is placed in slots of the lowest pitch.

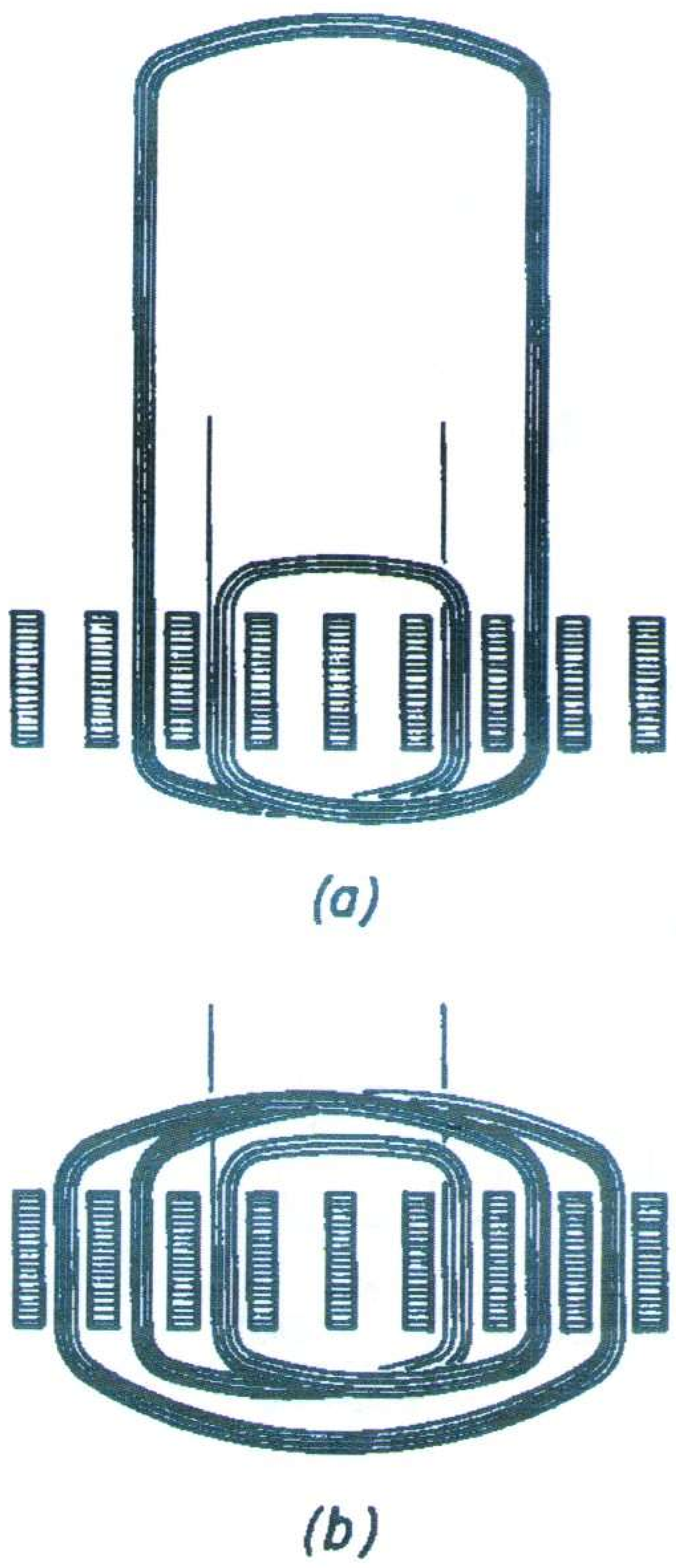
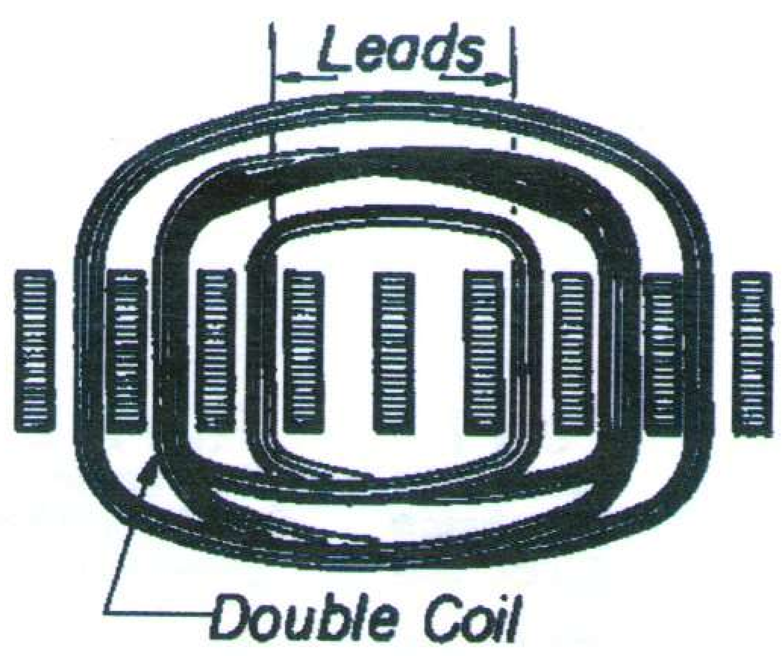


FIG. 1-29.—The skein is twisted and placed in the slot of next pitch (*a*) and twisted again to form final pole (*b*).

FIG. 1-30.—A skein winding with a double coil in the center.



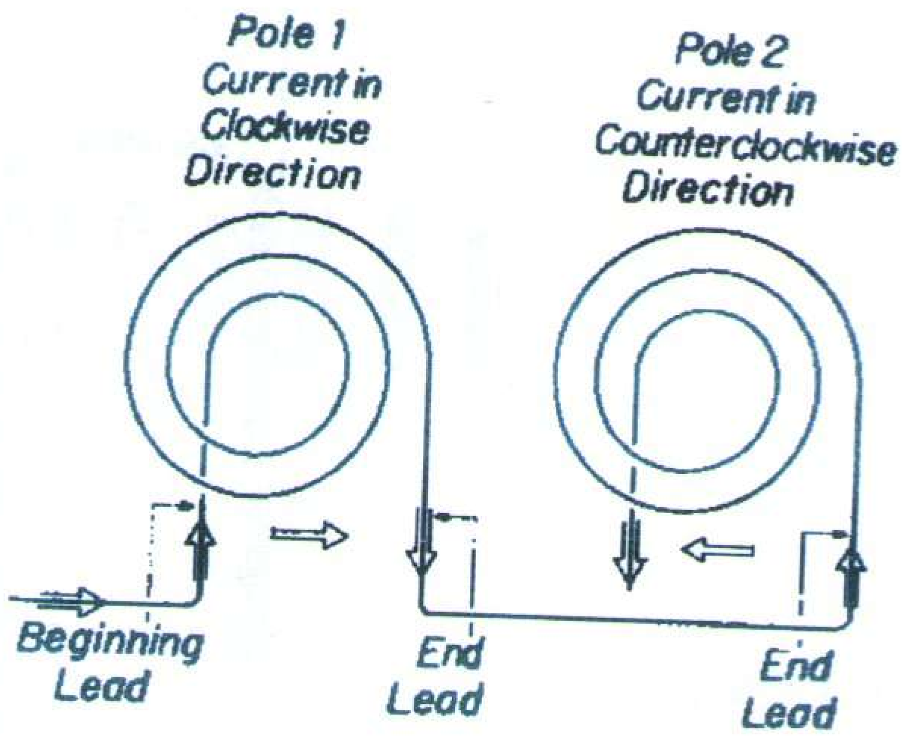


FIG. 1-31.—The connection of adjacent poles to obtain opposite polarity.

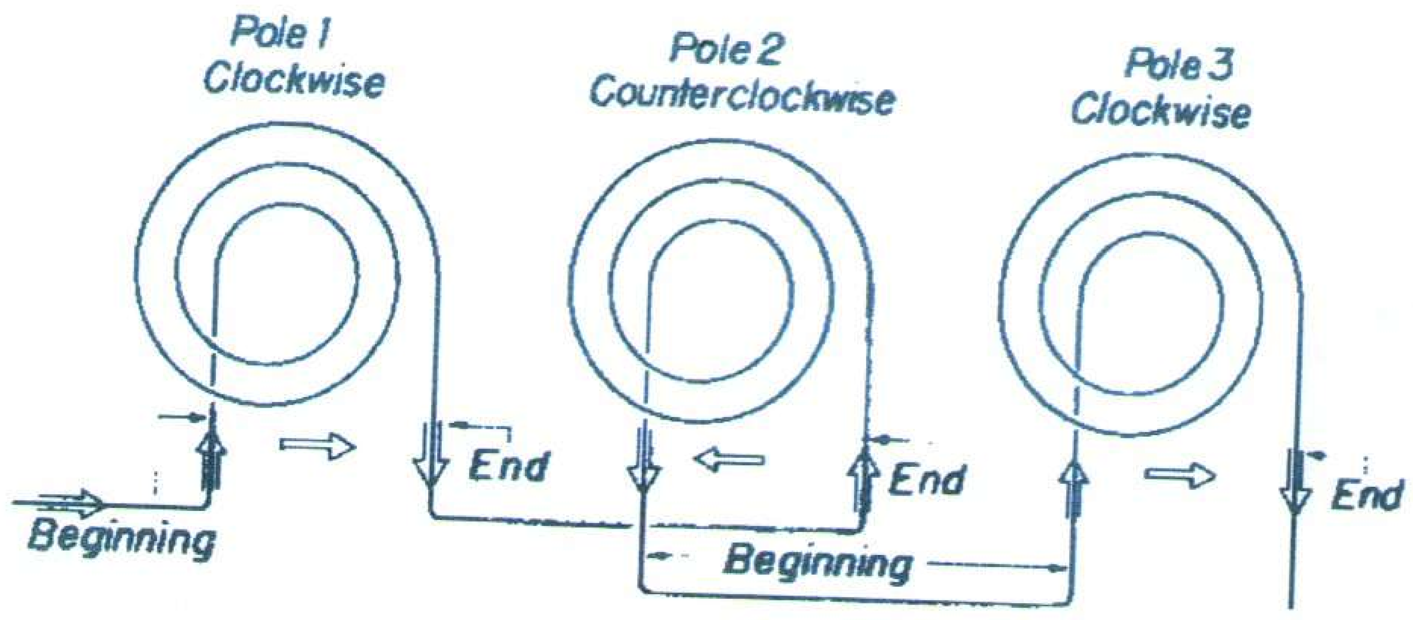


FIG. 1-32.—The connections of three poles.

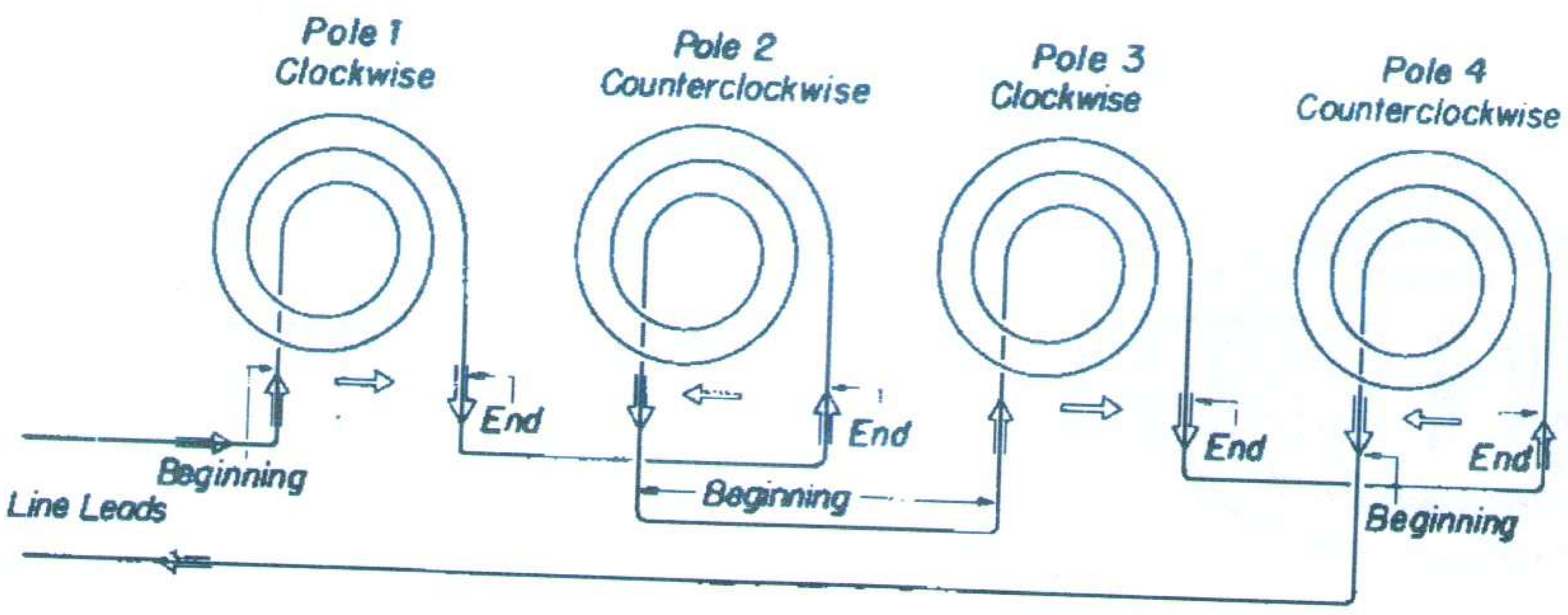


FIG. 1-33.—Four poles connected together and to the line.

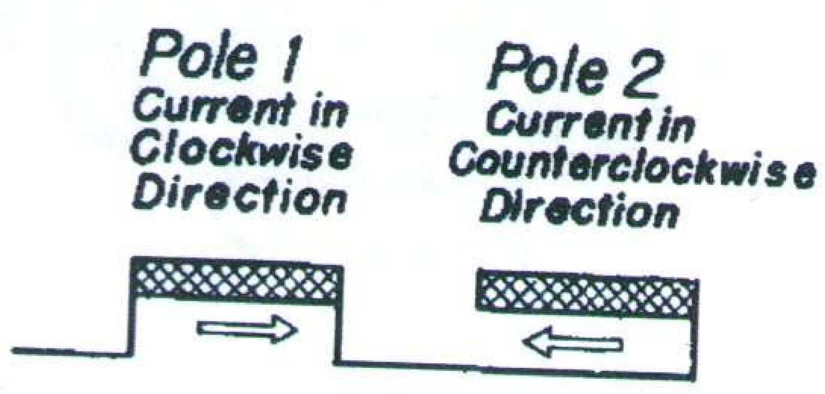
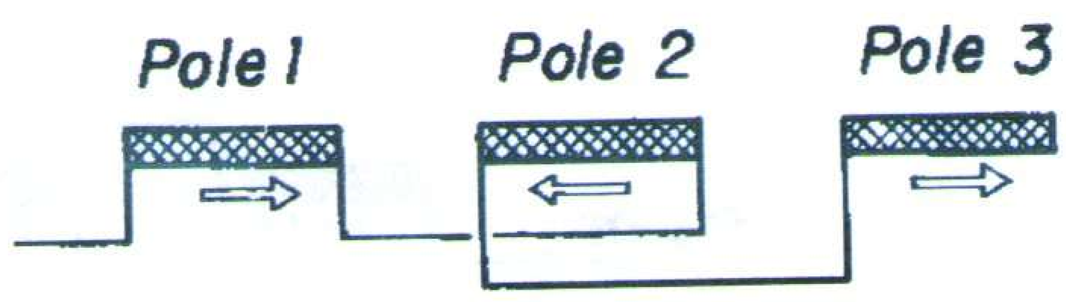


FIG. 1-34.—A block diagram of circuit of Fig. 1-31.

Figures 1-31; 1-32; 1-33; 1-34

FIG. 1-35.—Continued from Fig. 1-34. The beginning of pole *2* connects to the beginning of pole *3*.



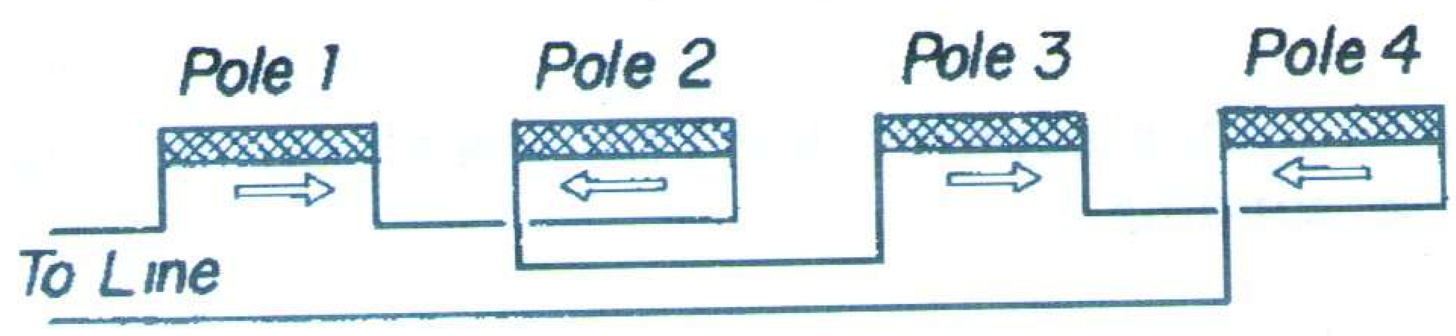


FIG. 1-36.—The end of pole *3* connects to the end of pole *4*. The line is connected to the beginning of pole *1* and pole *4*.

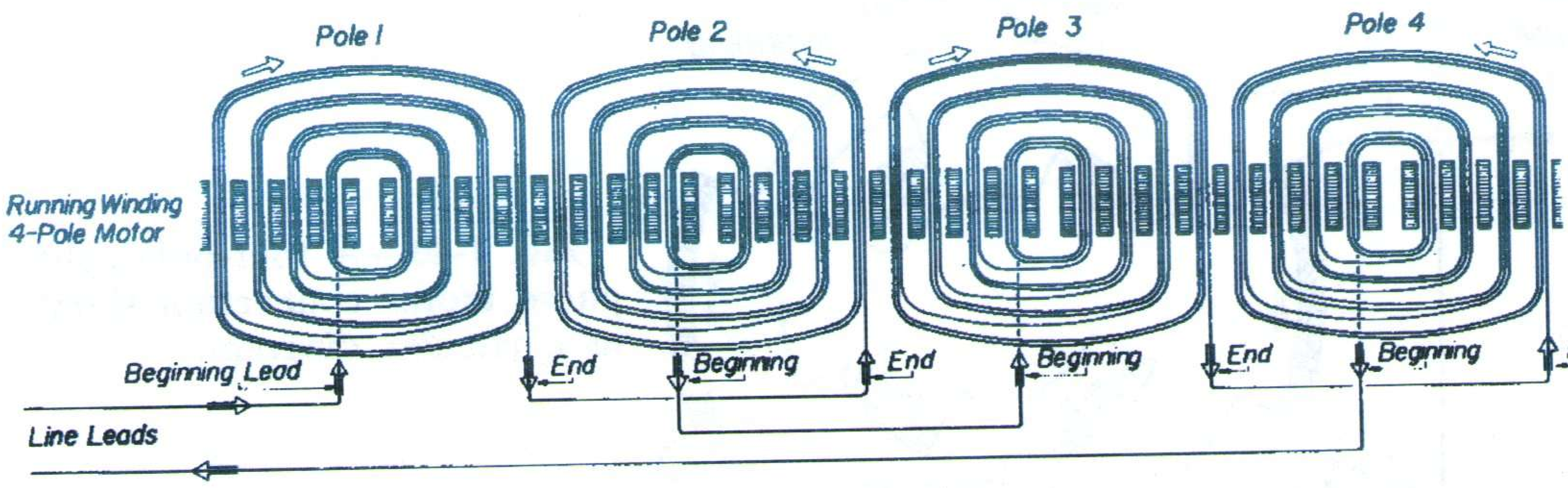
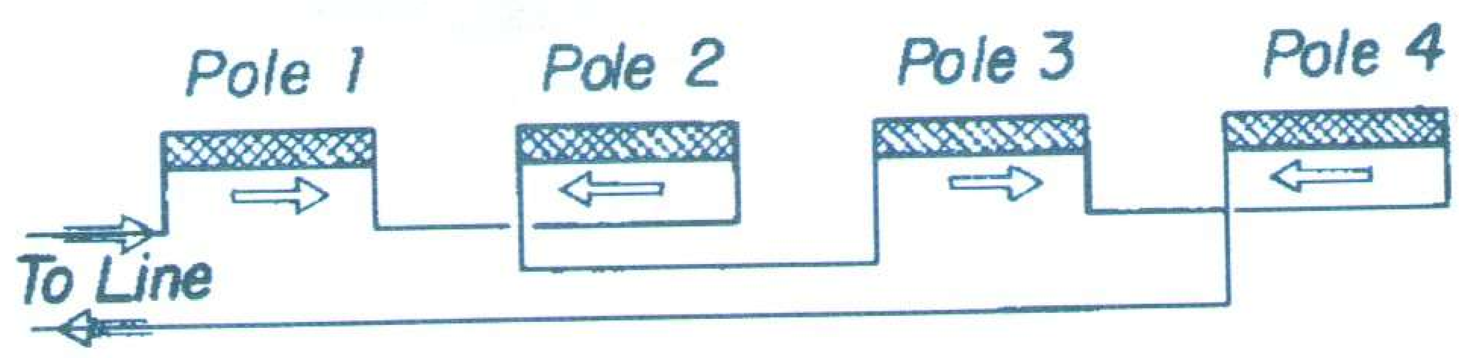


FIG. 1-37.—Four poles of the running winding. The poles are connected so that the current through pole *1* is in a clockwise direction; through pole *2*, in a counterclockwise direction; pole *3*, clockwise; pole *4*, counterclockwise.



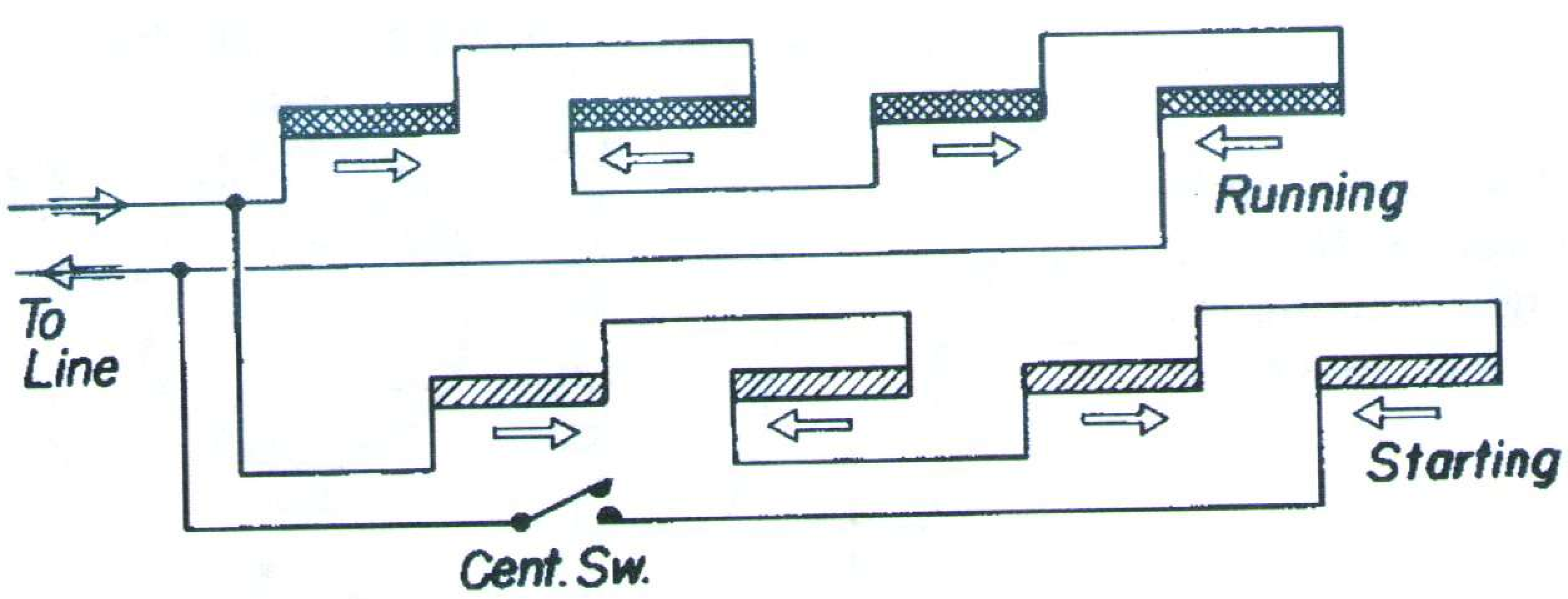


FIG. 1-38.—A four-pole split-phase motor connection.

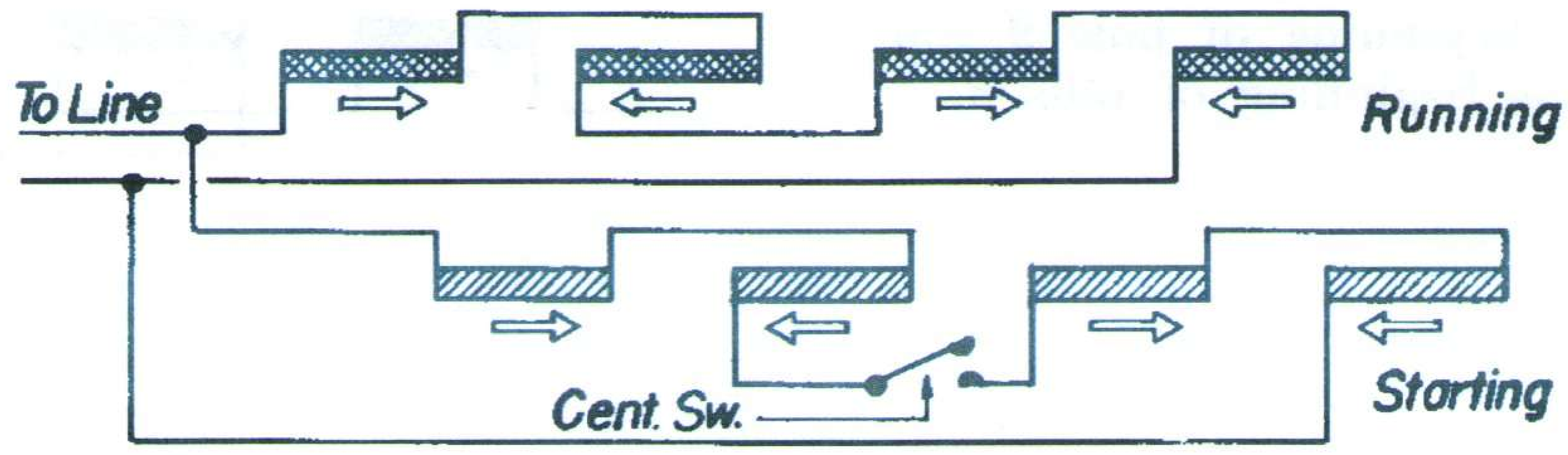


FIG. 1-39.—A four-pole, split-phase motor showing the centrifugal switch connected in the center of the starting winding.

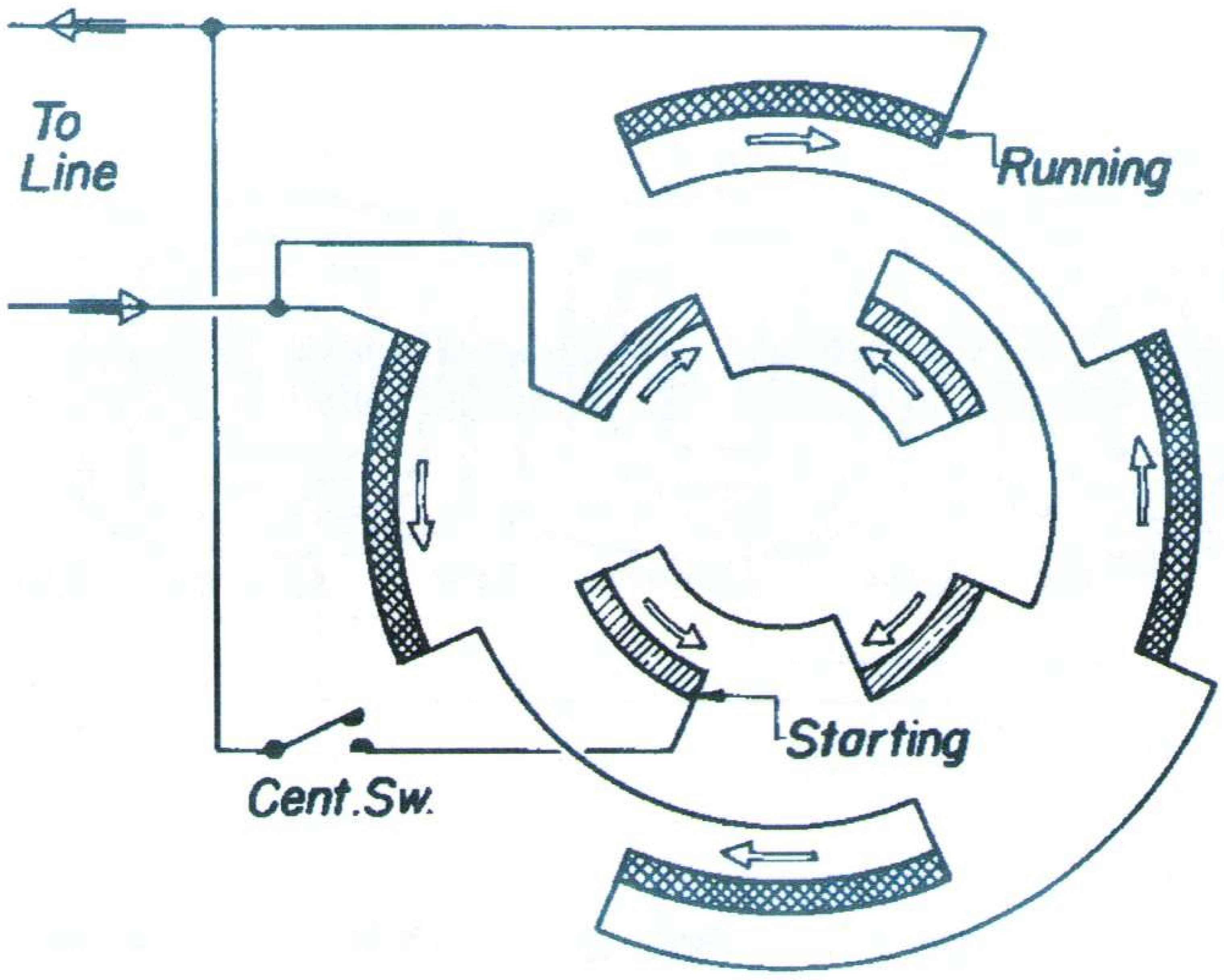


FIG. 1-40.—A four-pole split-phase motor connection shown in a circular diagram.

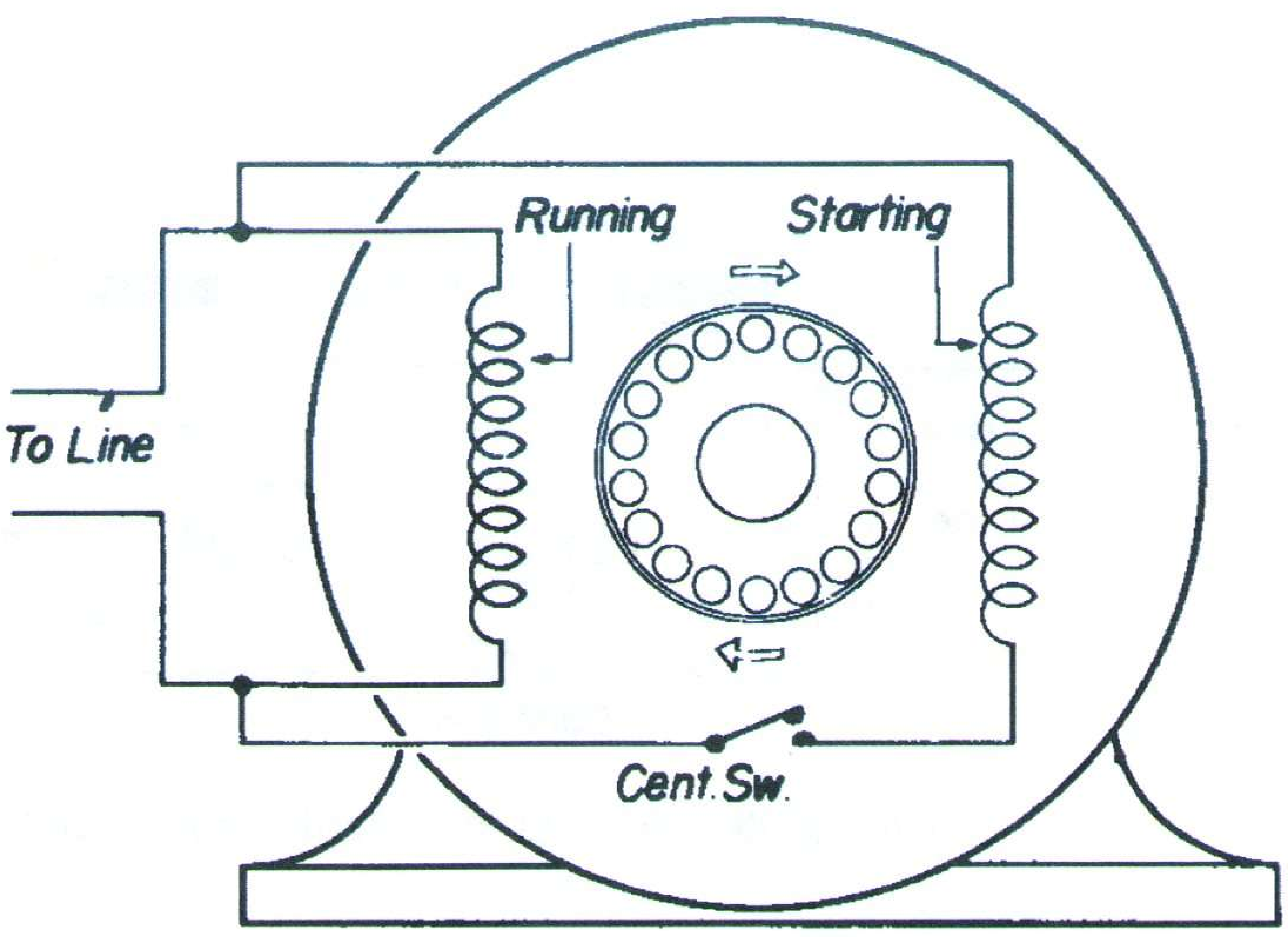


FIG. 1-41.—A split-phase motor with four leads brought outside the frame for reversing.

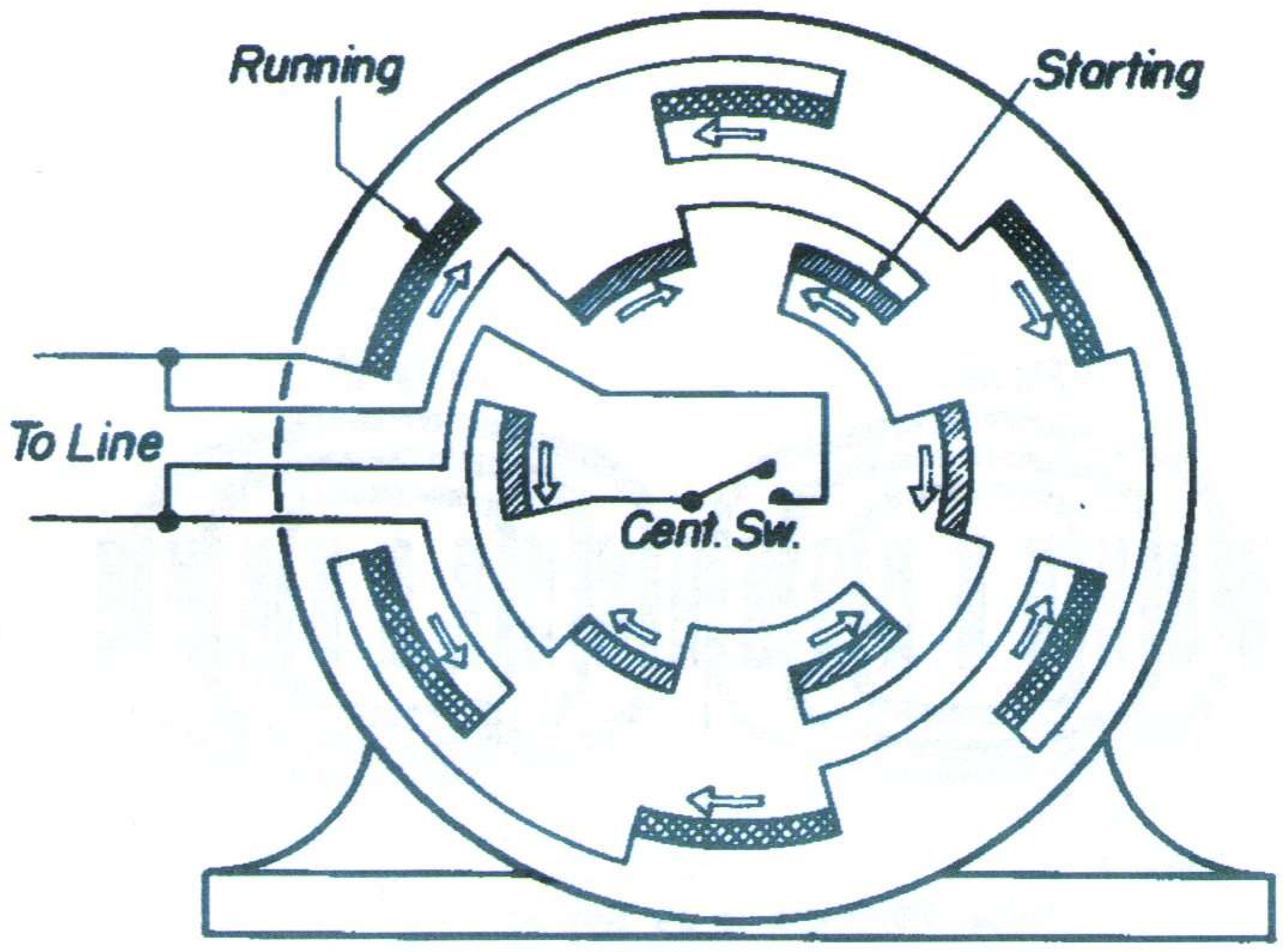


FIG. 1-42.—The connections of a six-pole split-phase motor.

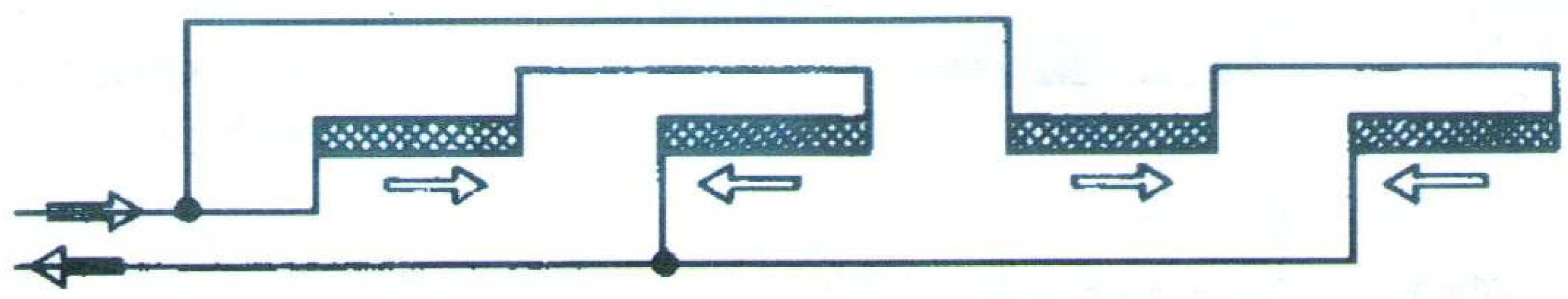


FIG. 1-43.—A two-circuit connection of a four-pole running winding.

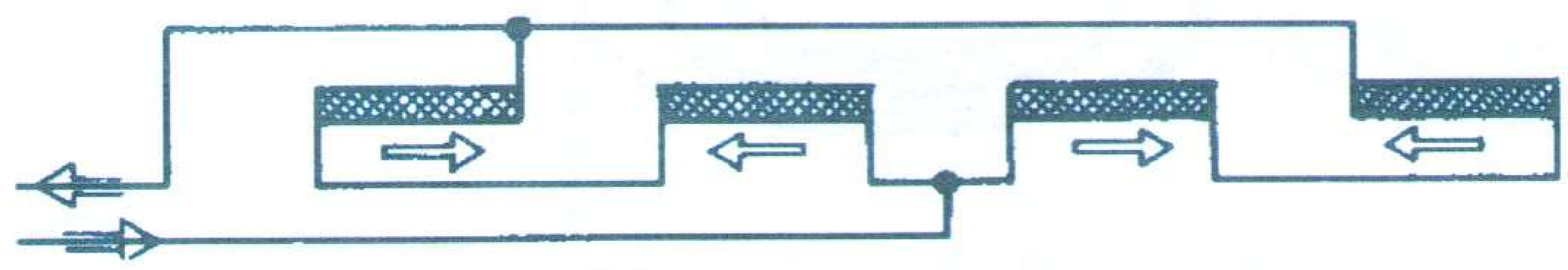


FIG. 1-44.—Another method for connecting a two-circuit, four-pole running winding.

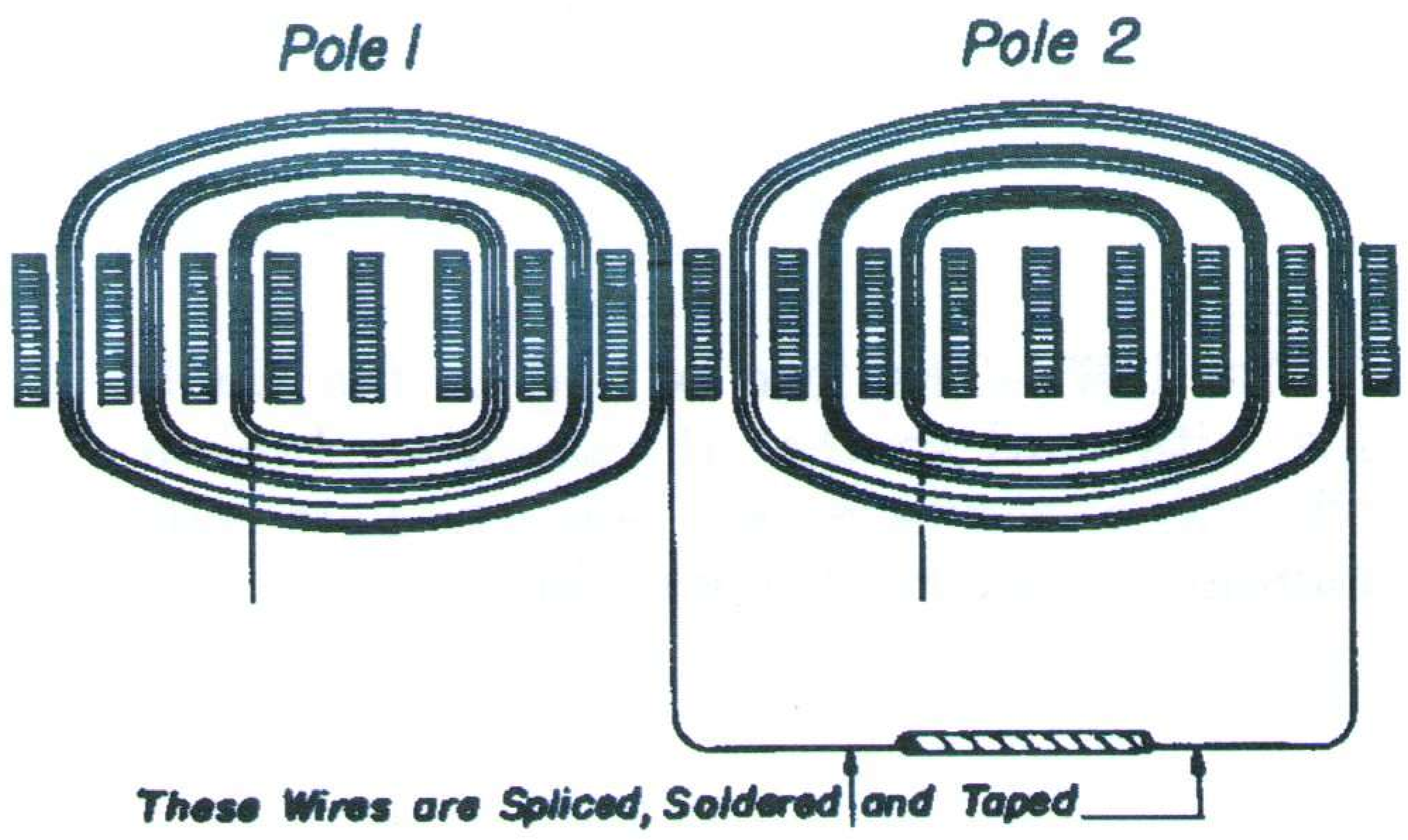


FIG. 1-45.—One method of connecting wires between poles.

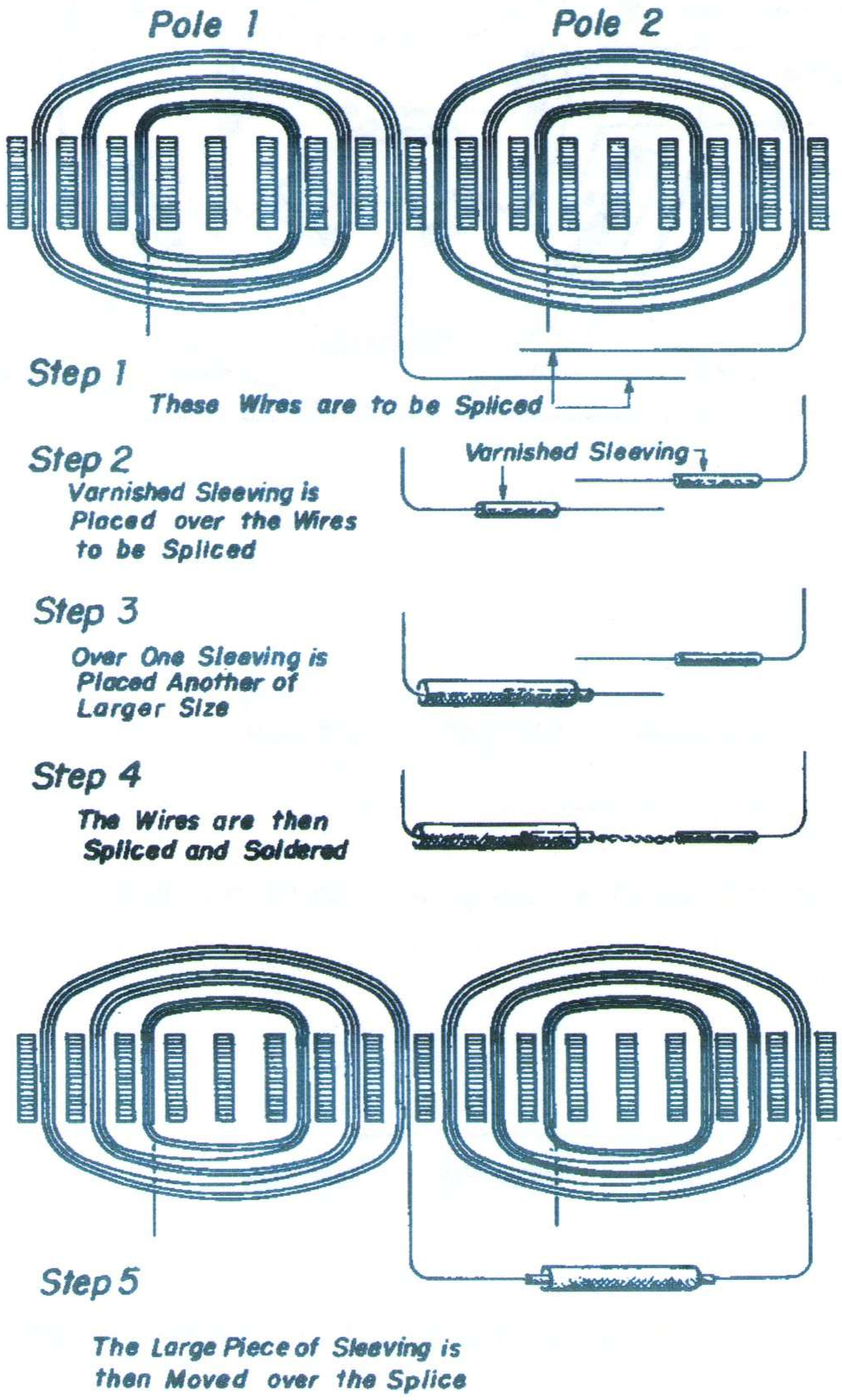
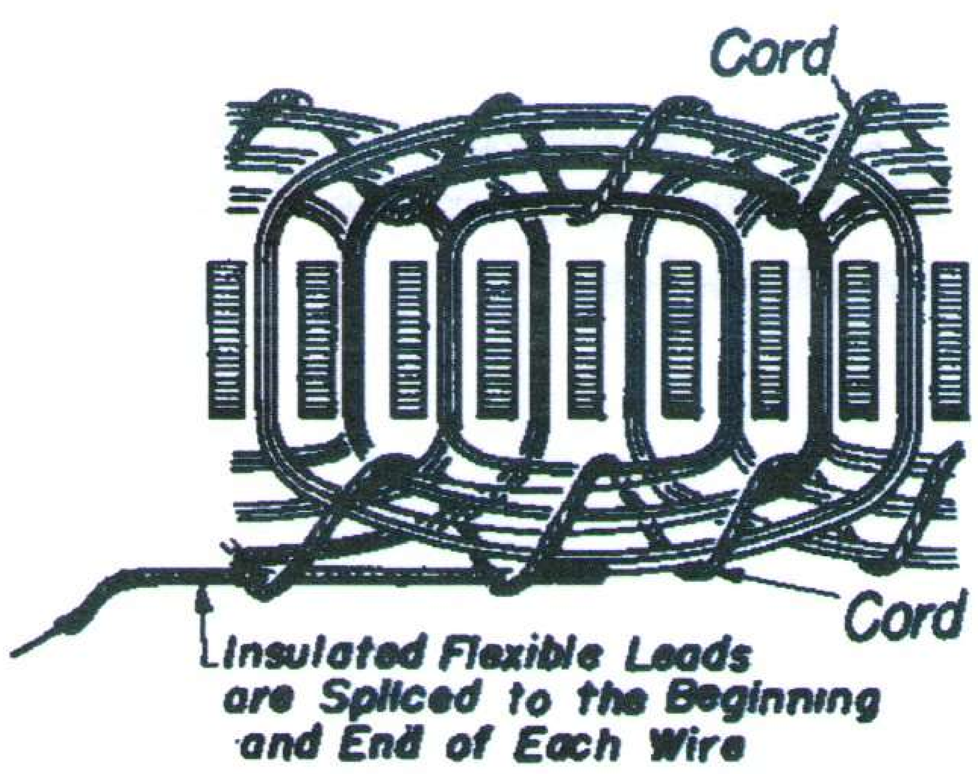


FIG. 1-46.—A method of connecting leads together.

FIG. 1-47.—The lead is tied to the winding with cord so that it cannot be broken off. The windings are also tied to one another to prevent unraveling.



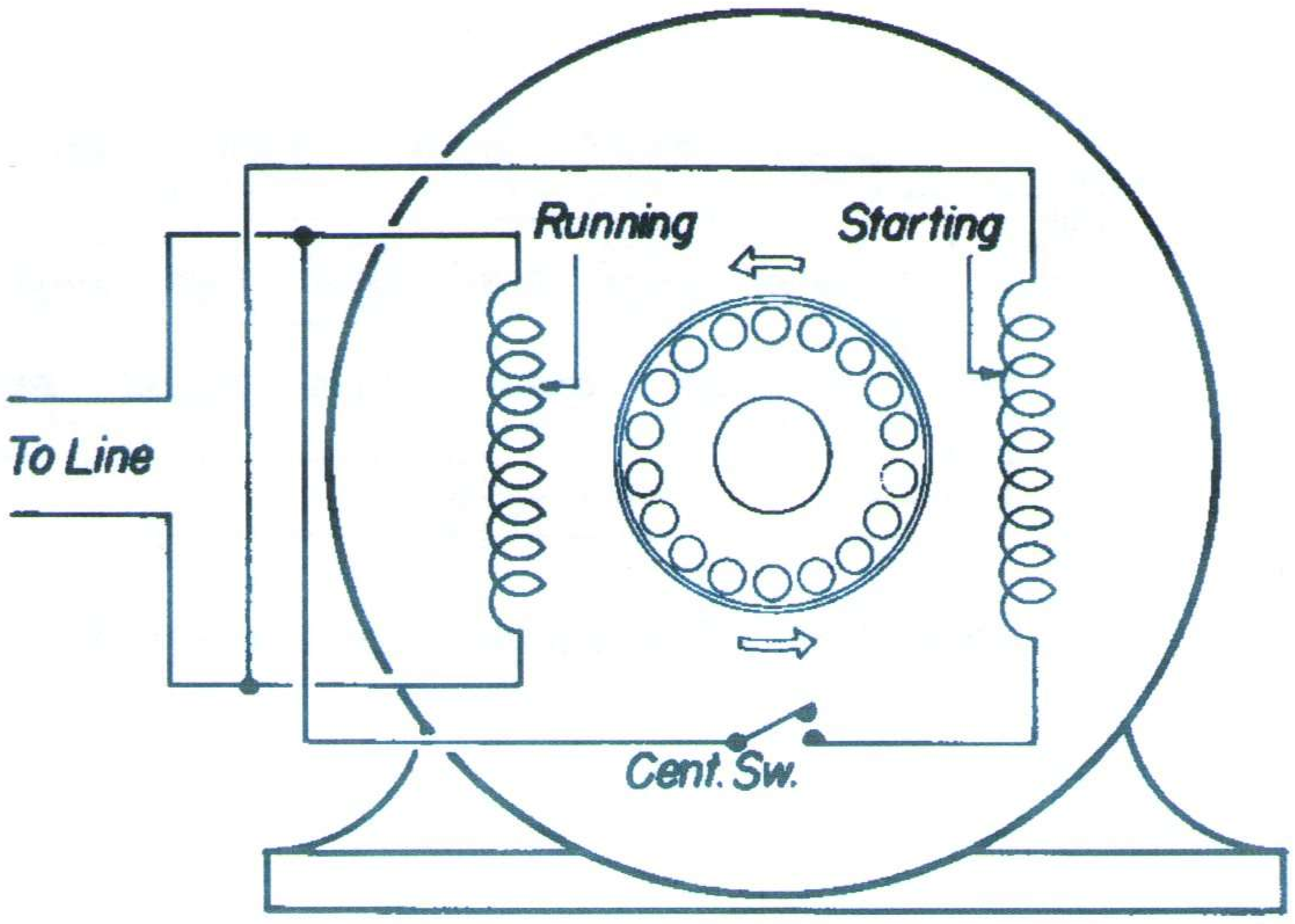


FIG. 1-48.—The motor shown in Fig. 1-41 connected for reversed rotation.

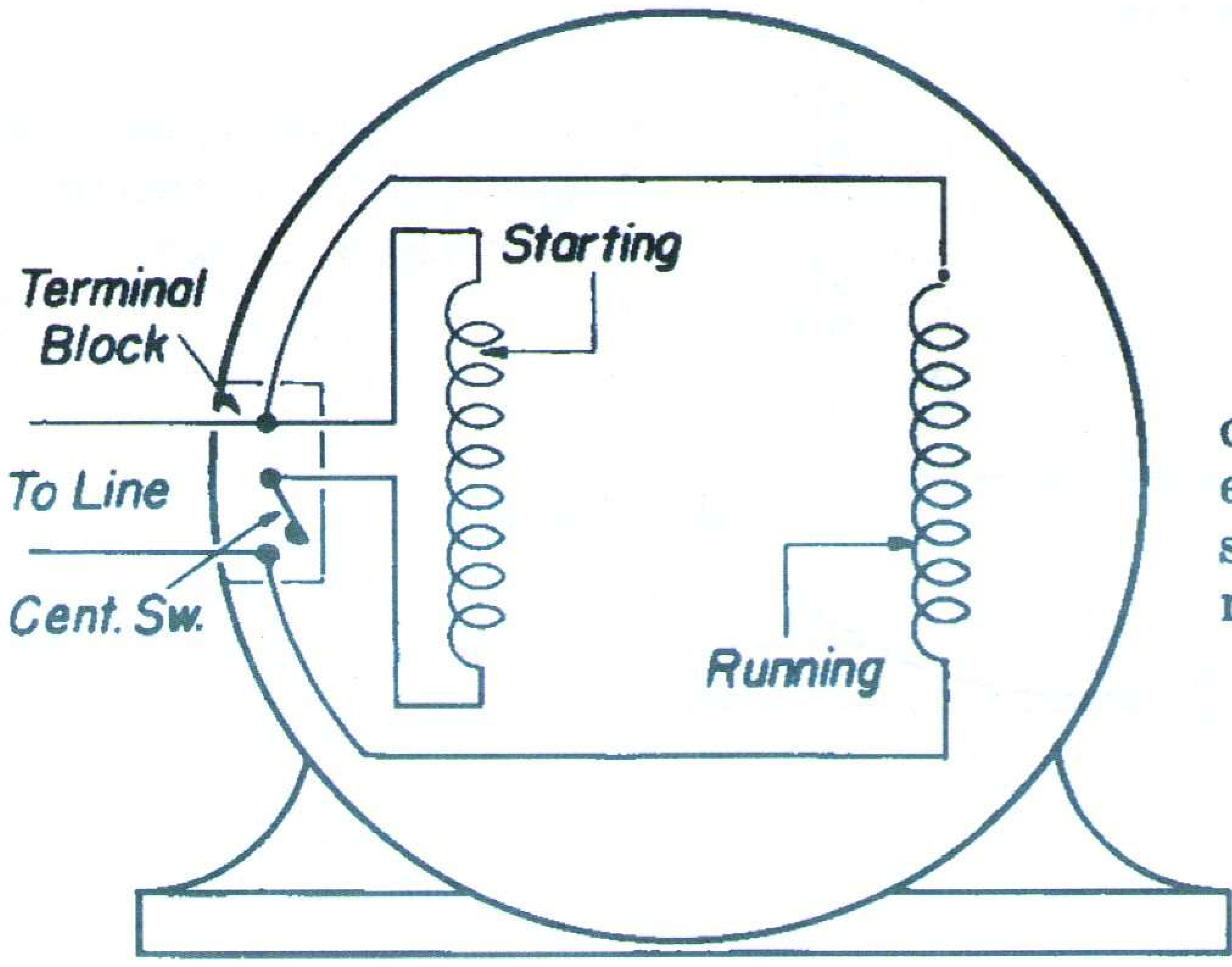


FIG. 1-49.—The connections of the terminal block on the end plate. The centrifugal switch is mounted on the terminal block.

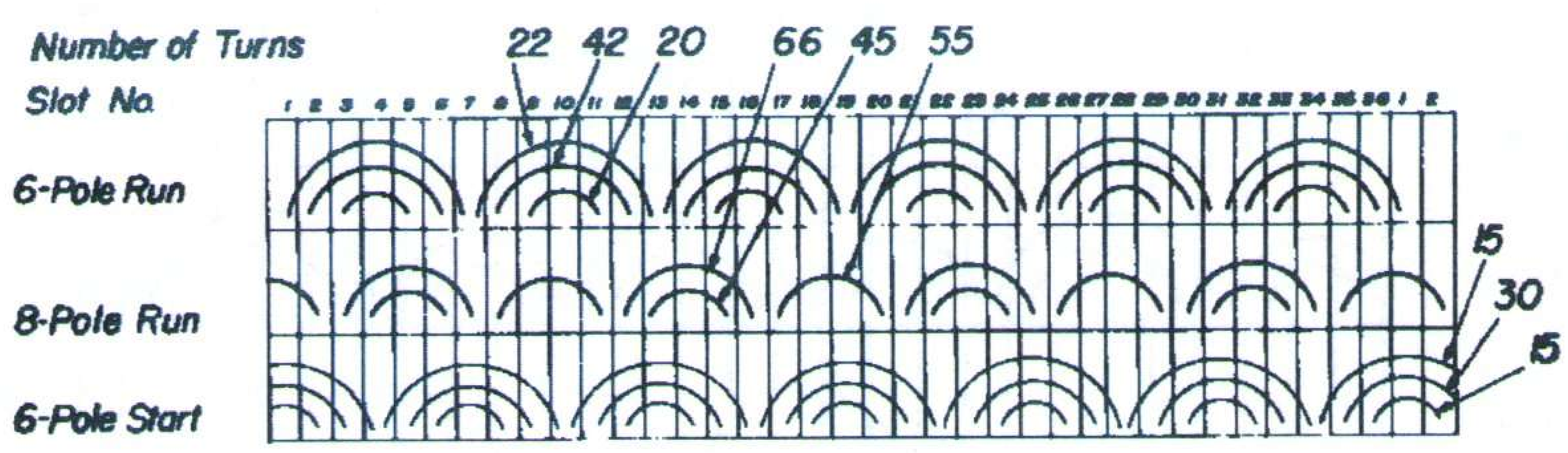


FIG. 1-50.—A coil layout of a two-speed, three-winding split-phase motor.

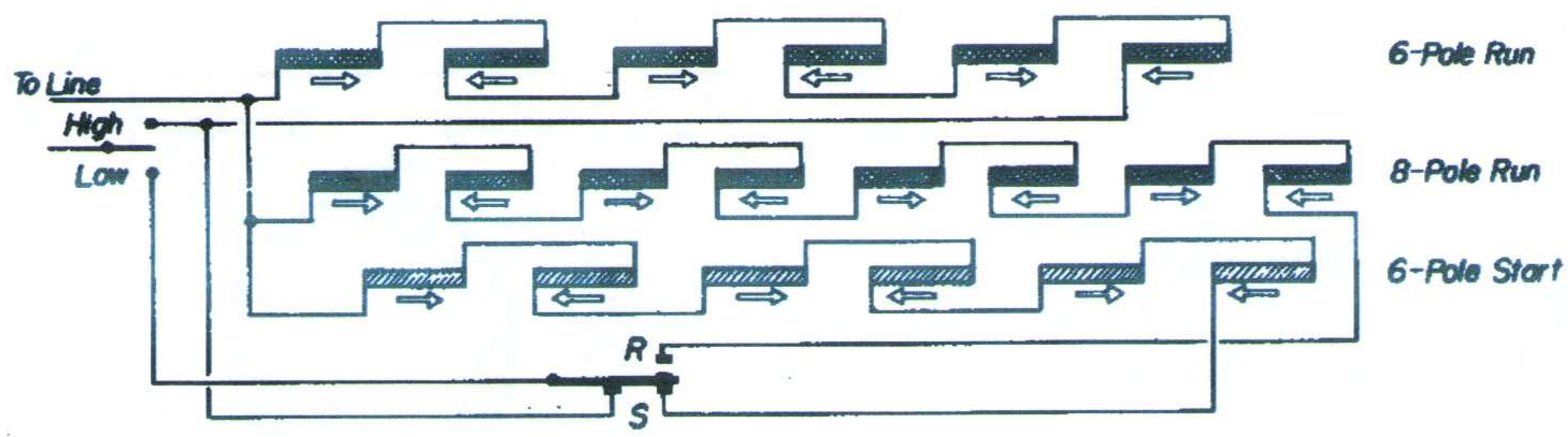


FIG. 1-51.—The wiring of a two-speed split-phase motor.

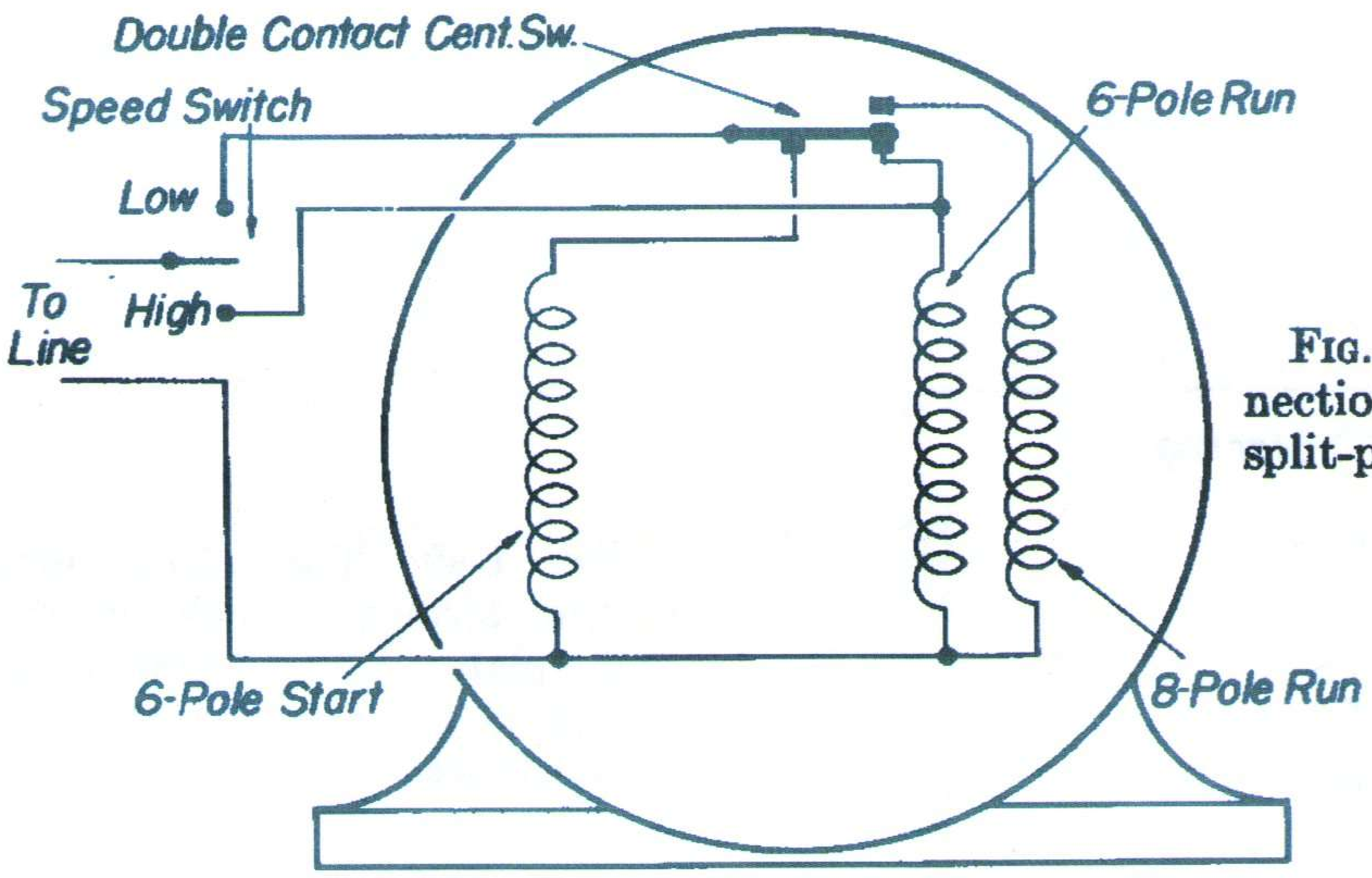


FIG. 1-52.—The connections of a two-speed split-phase motor.

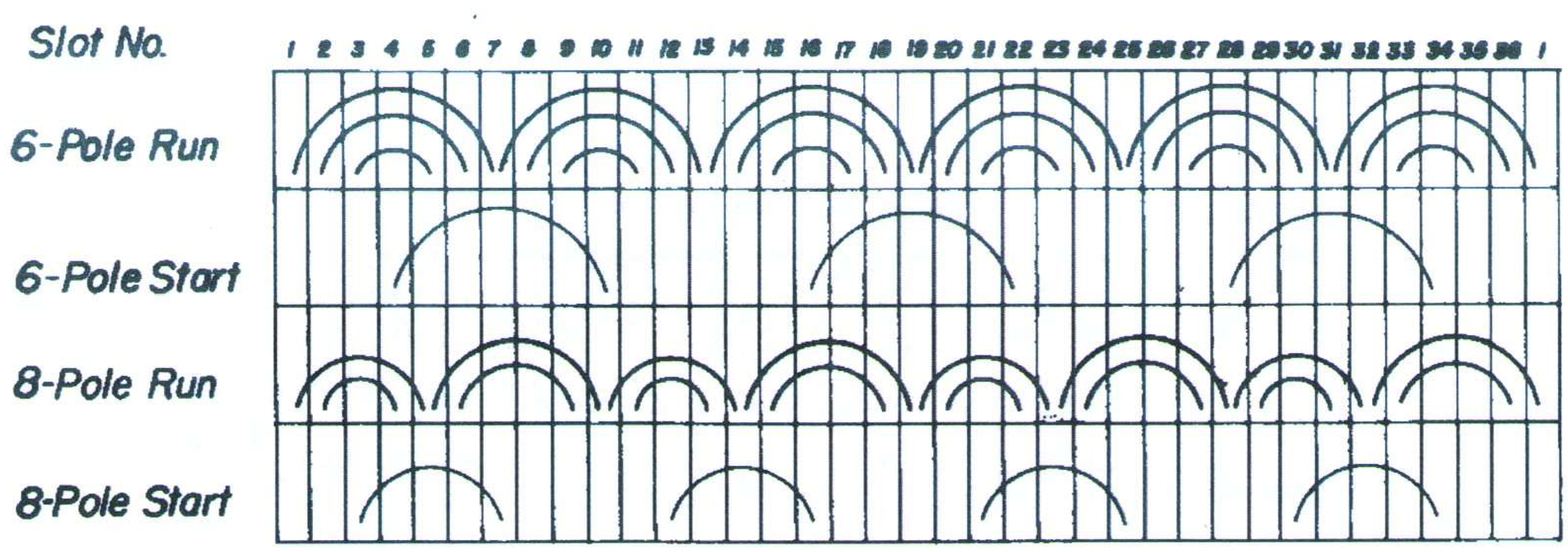


FIG. 1-53.—A typical layout of a two-speed split-phase motor using four windings. The starting windings are consequent pole connected.

Figures 1-51; 1-52; 1-53

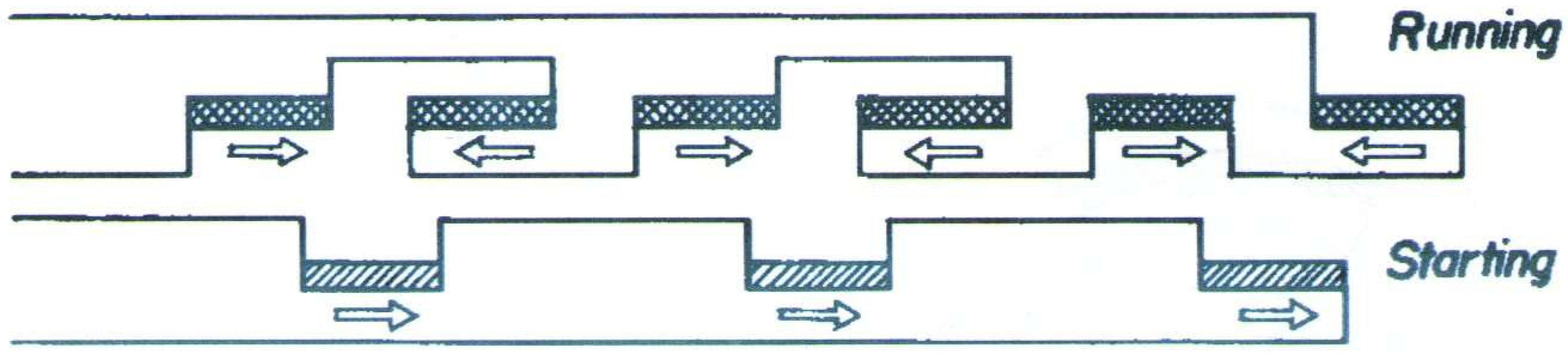


FIG. 1-54.—The starting and running winding of the six-pole part of a two-speed motor. The starting-winding poles are connected for like polarity. There are only three wound poles; three more poles of opposite polarity are formed in the stator frame.

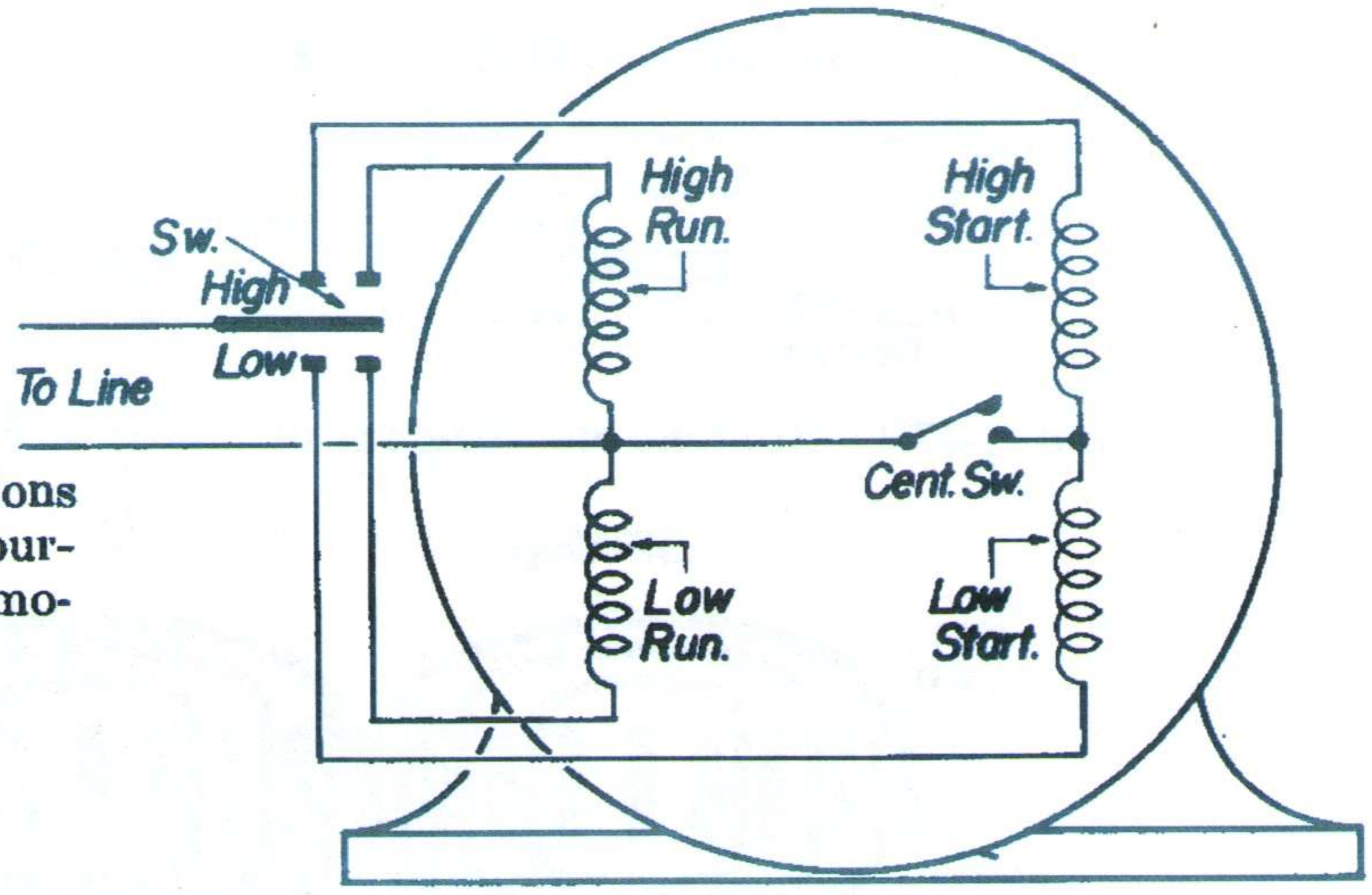


FIG. 1-55.—Connections of a two-speed, four-winding split-phase motor.

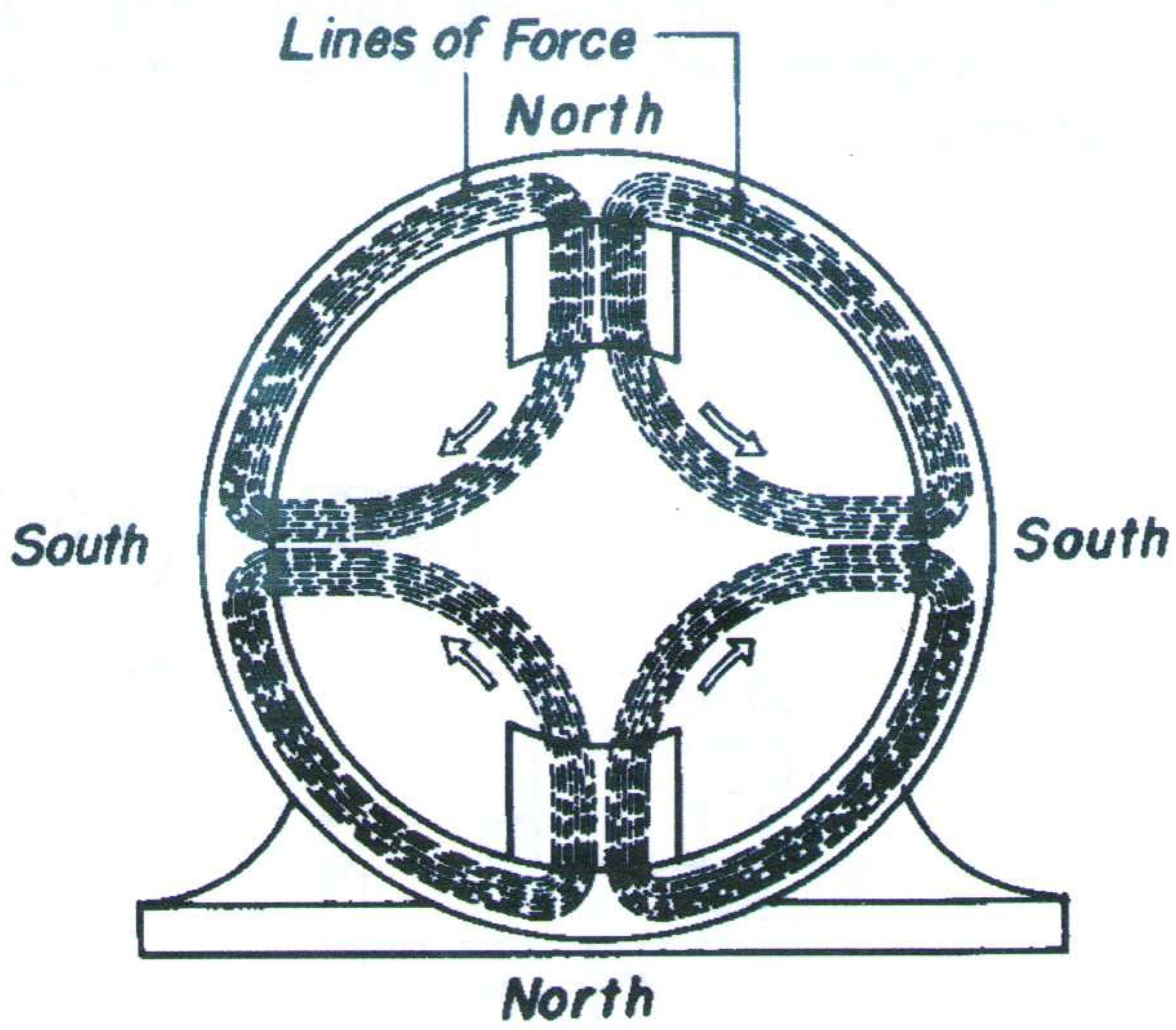


FIG. 1-56.—If the two poles of a two-pole motor are connected so that like polarity results, two more poles will be formed by the lines of force entering the frame.

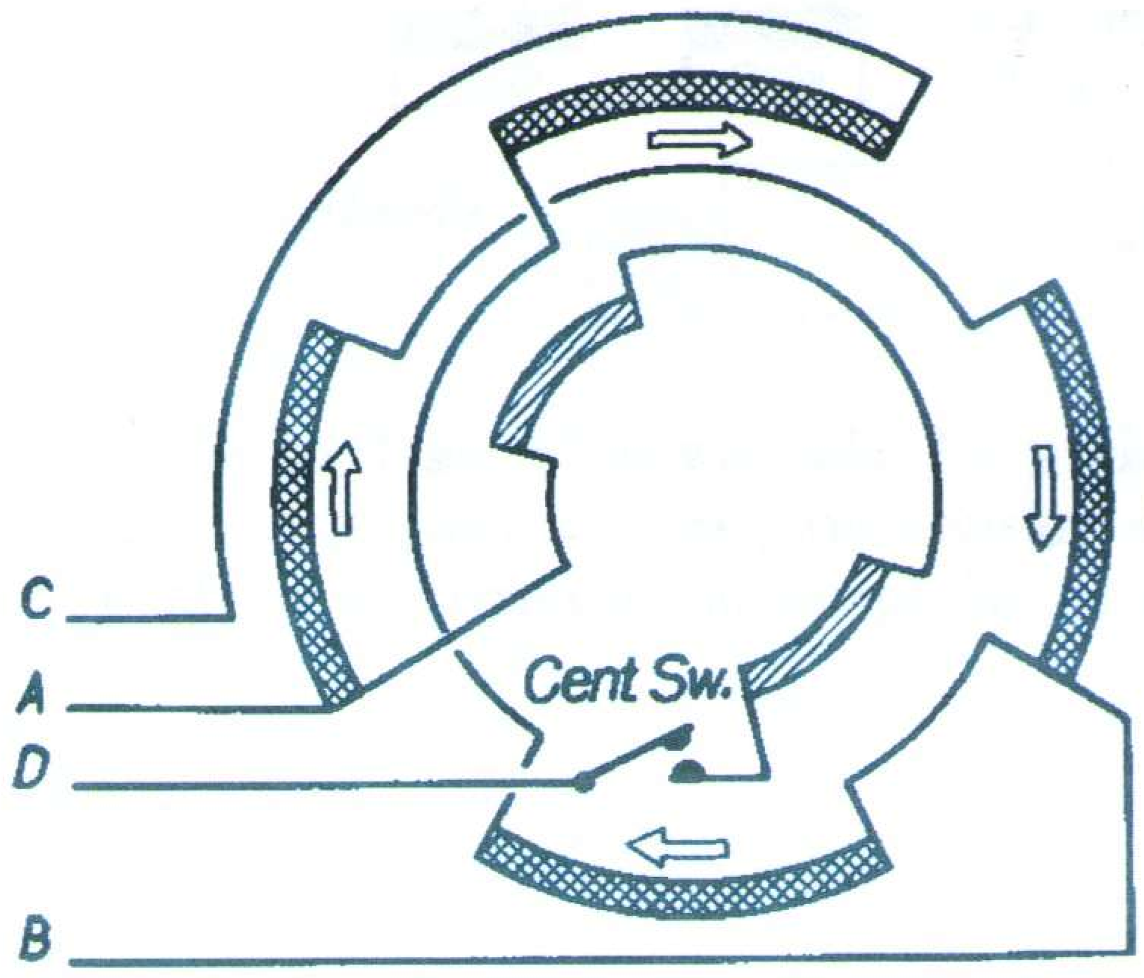


FIG. 1-57*A*.—Circular diagram of a two-speed, two-winding, split-phase motor.

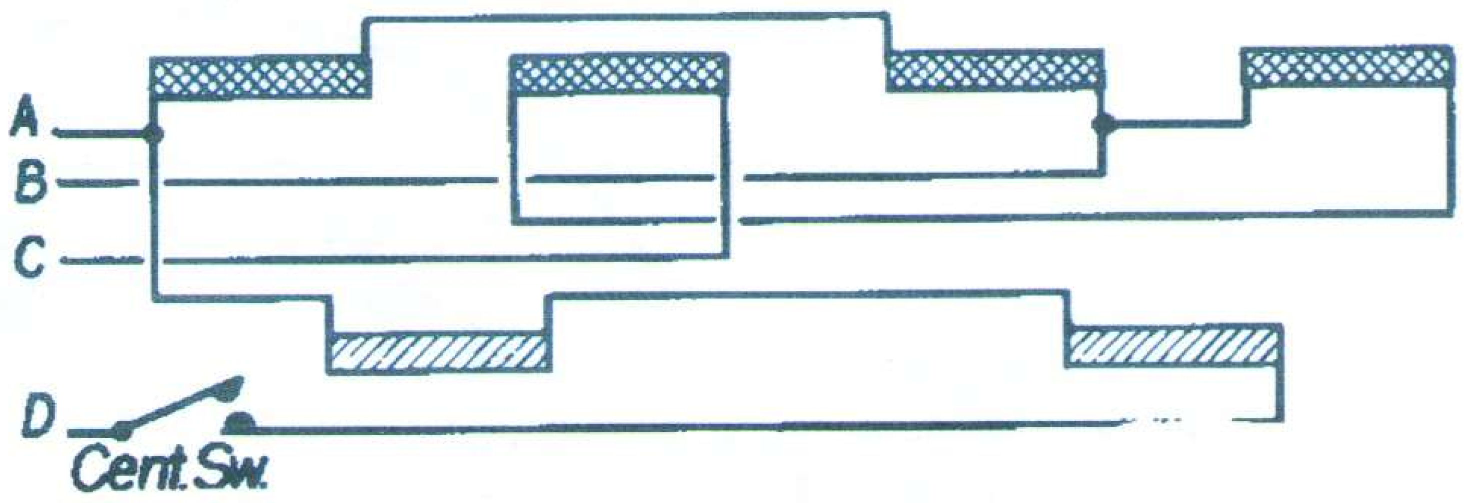


FIG. 1-57*B*.—Straight-line diagram of motor of Figure 1-57*A*.

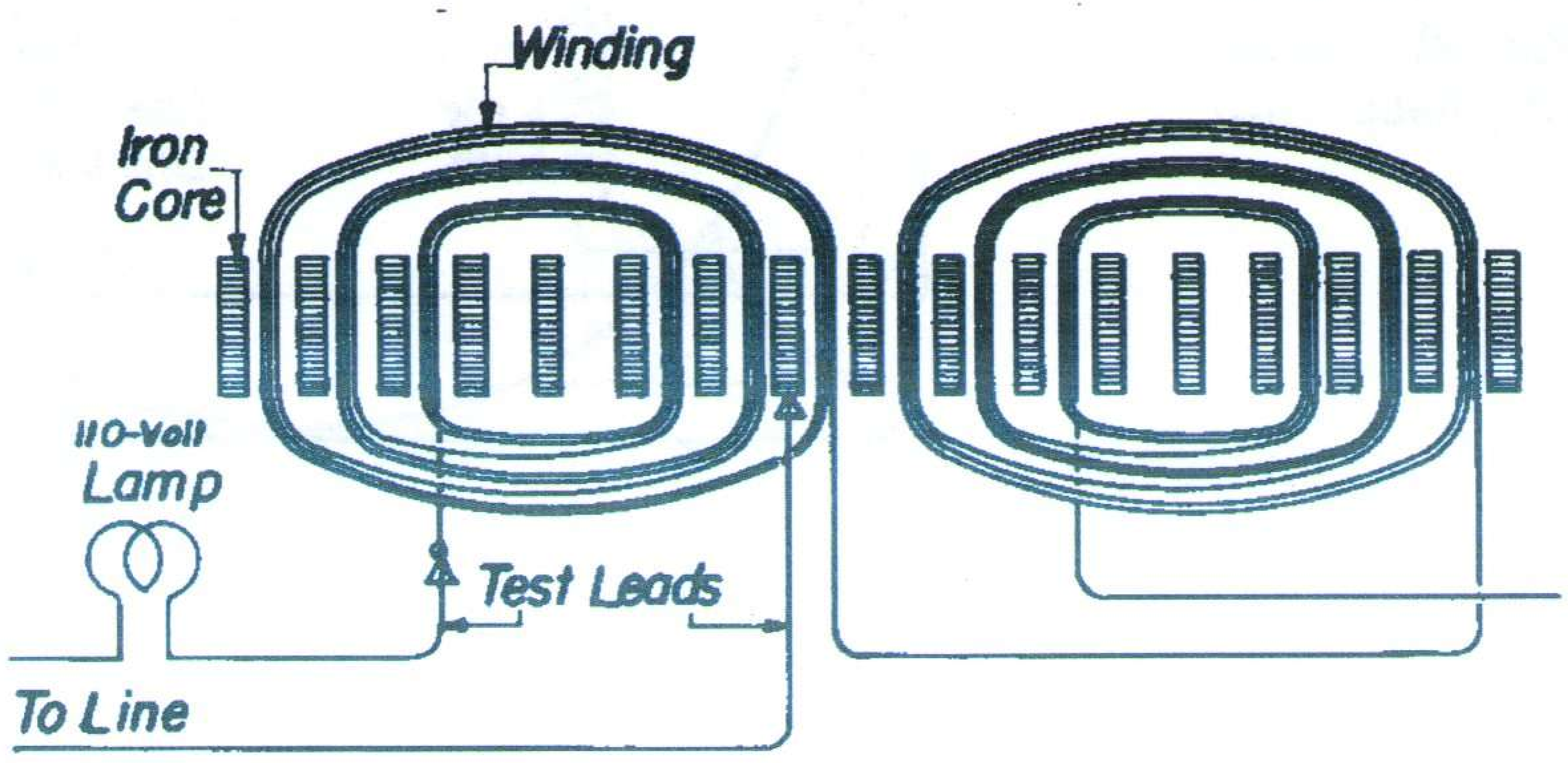


FIG. 1-58.—To determine whether winding is grounded, connect one test lead to the winding and the other test lead to the core. The lighted lamp indicates a ground.

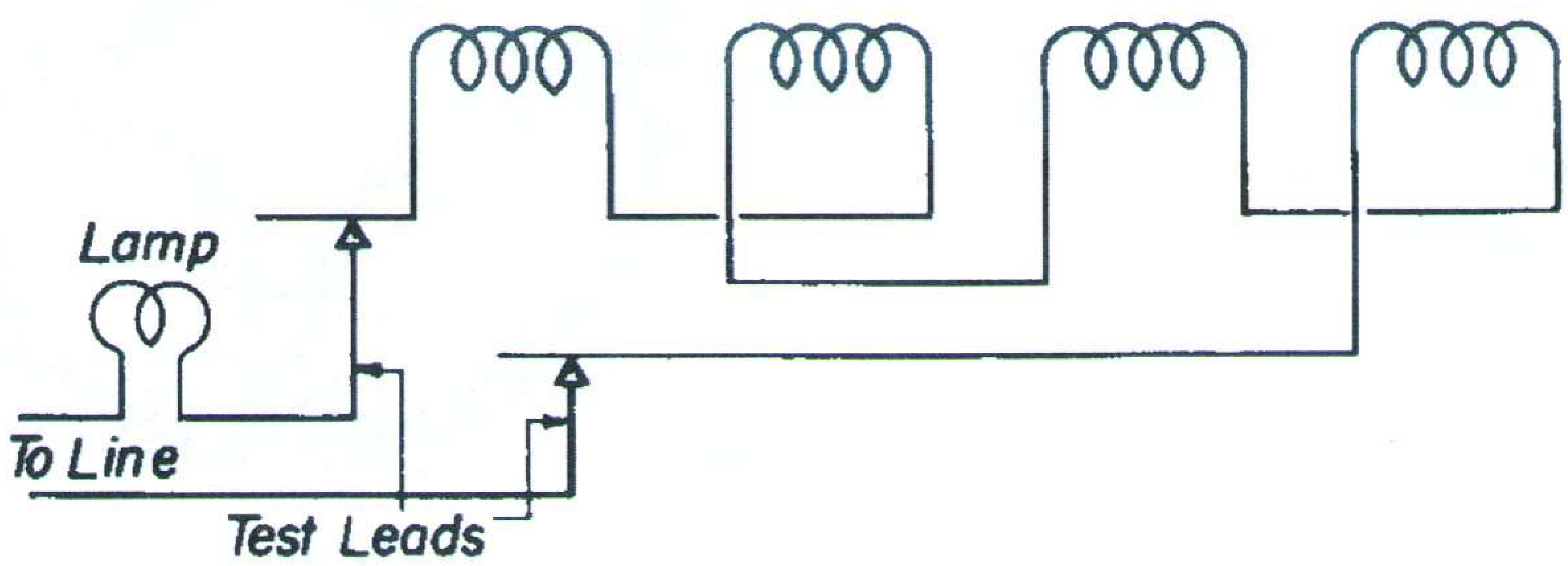


FIG. 1-59.—A circuit for testing winding for opens.

G158(82)

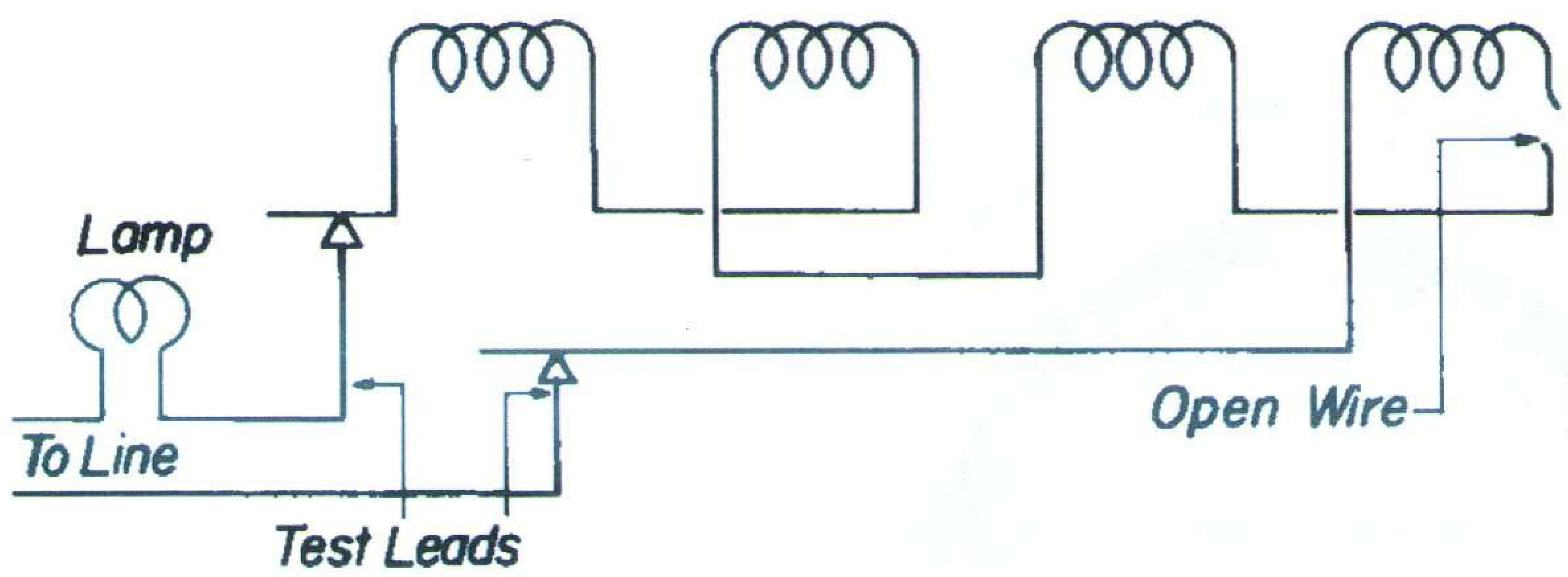


FIG. 1-60.—The effect of a defective pole. If the circuit is open, the lamp will not light.

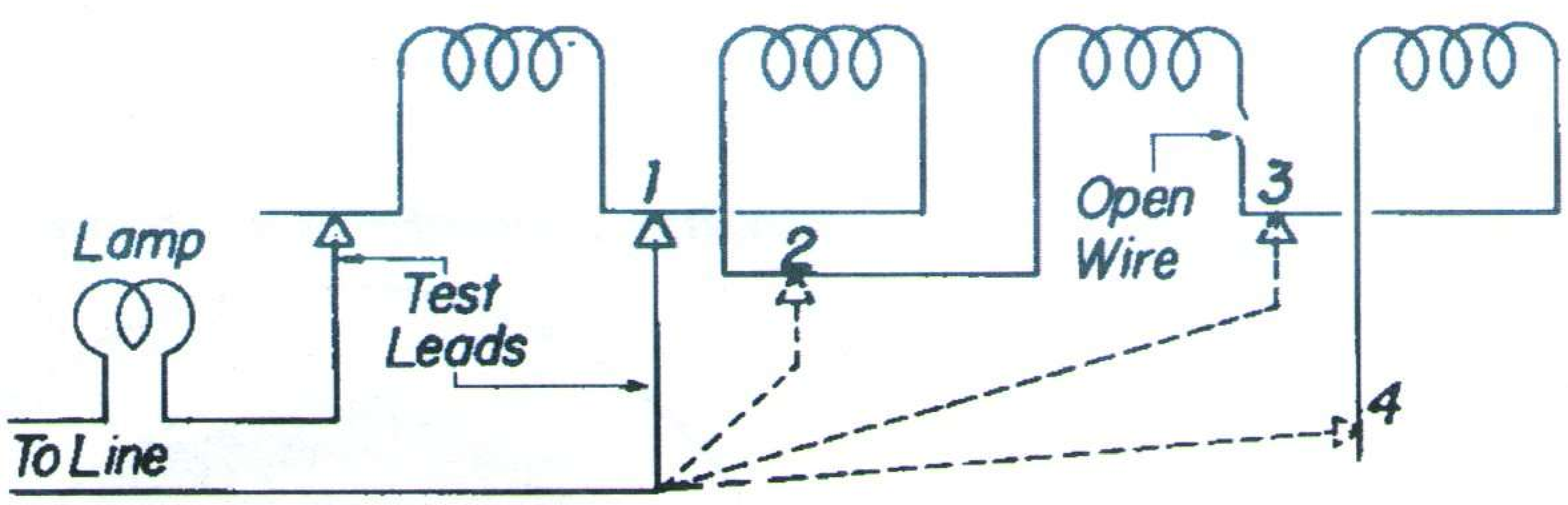


FIG. 1-61.—The method of determining which pole is open-circuited.

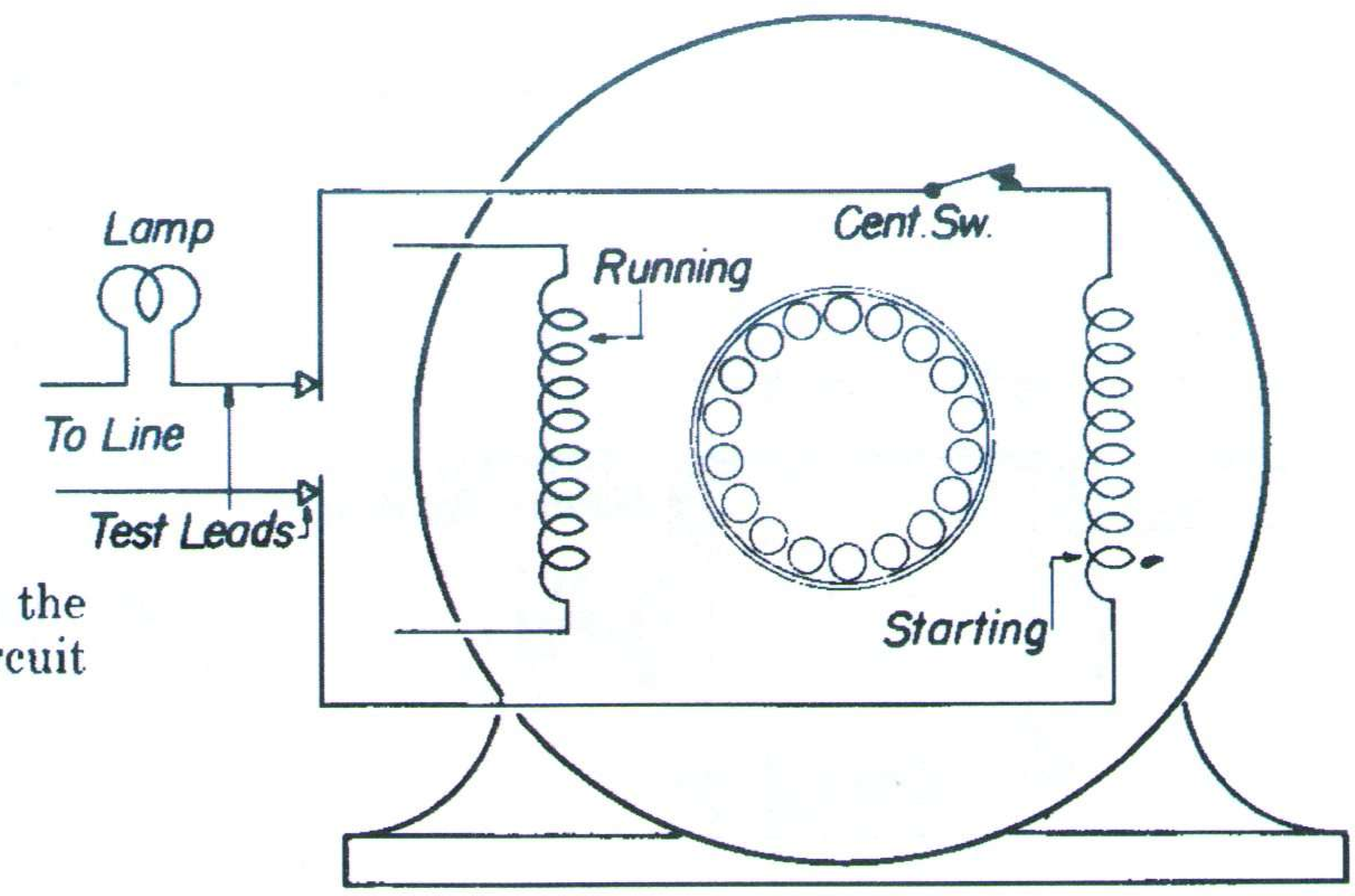


FIG. 1-62.—Testing the starting-winding circuit for opens.

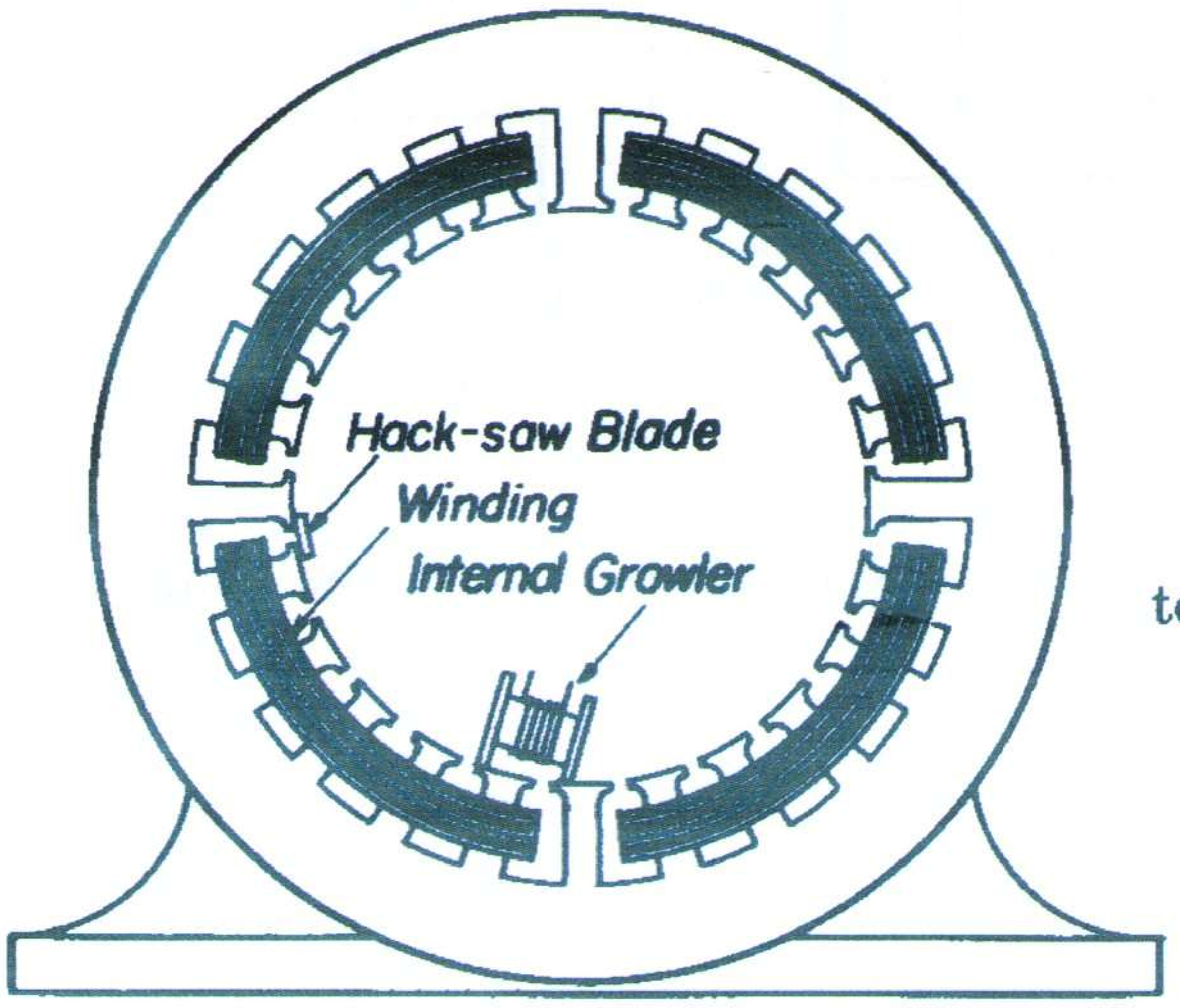


FIG. 1-63.—The growler method of testing for shorts in the stator.

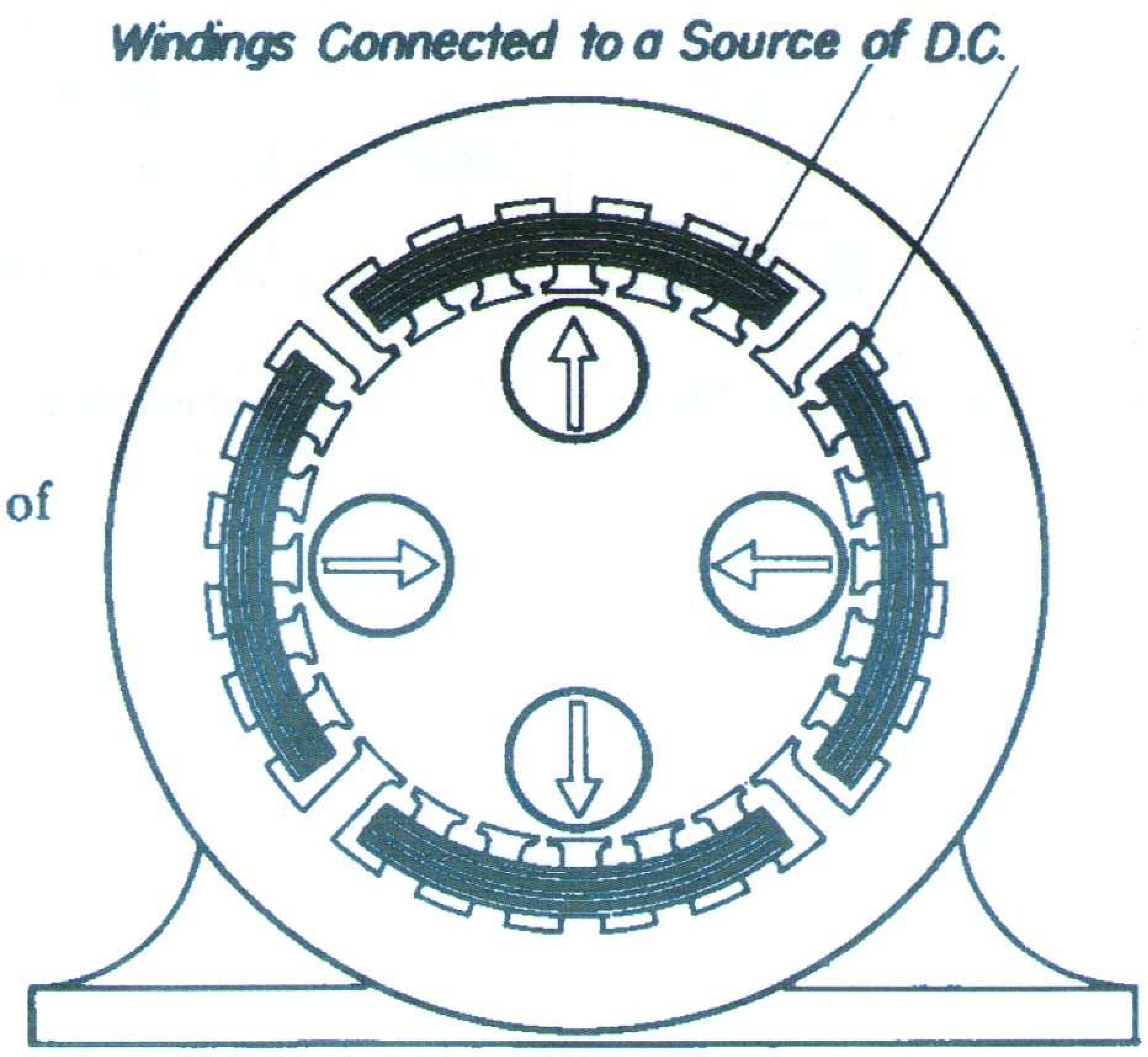


FIG. 1-64.—The compass method of testing for reversed poles.

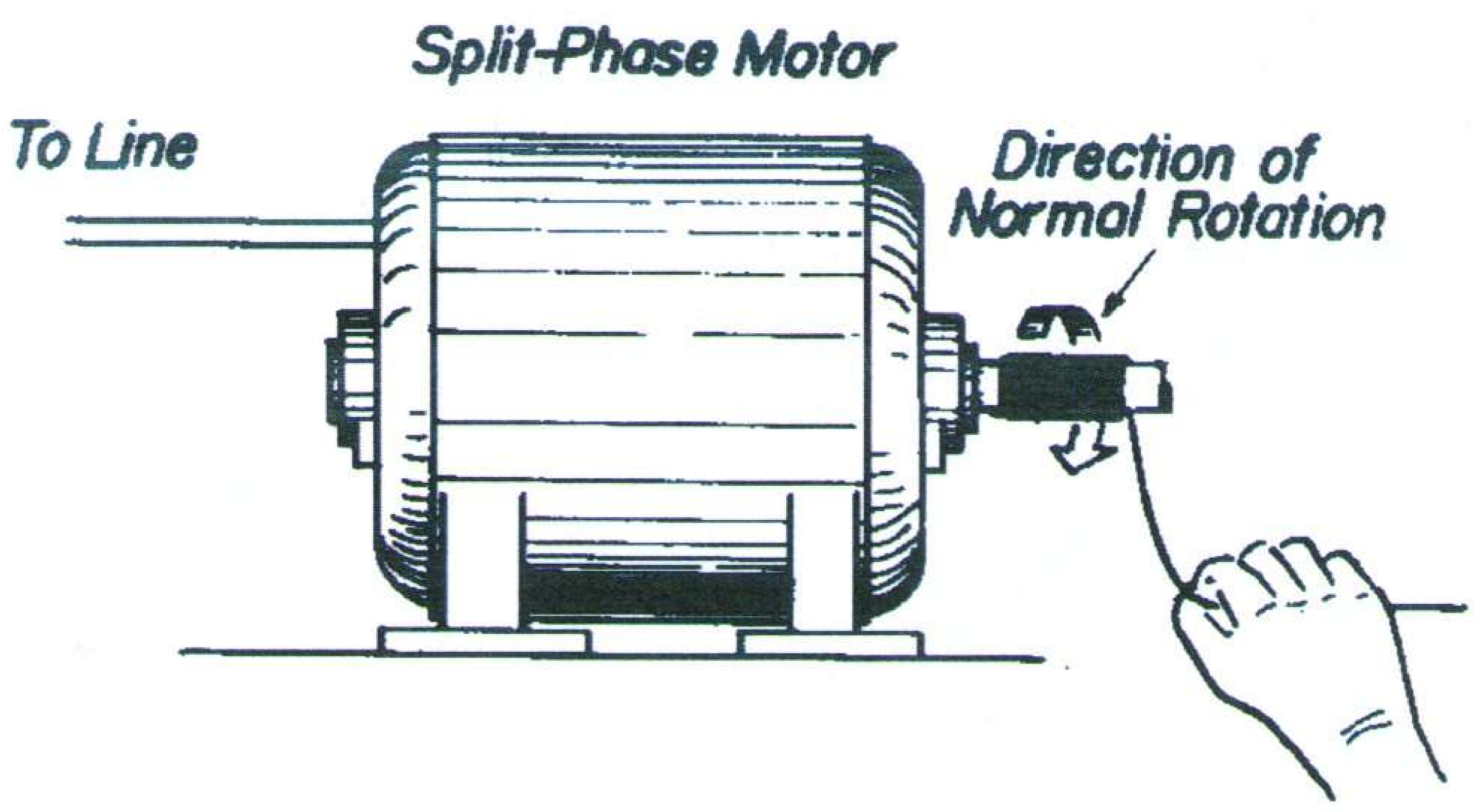


FIG. 1-65.—Starting the motor by mechanical means.

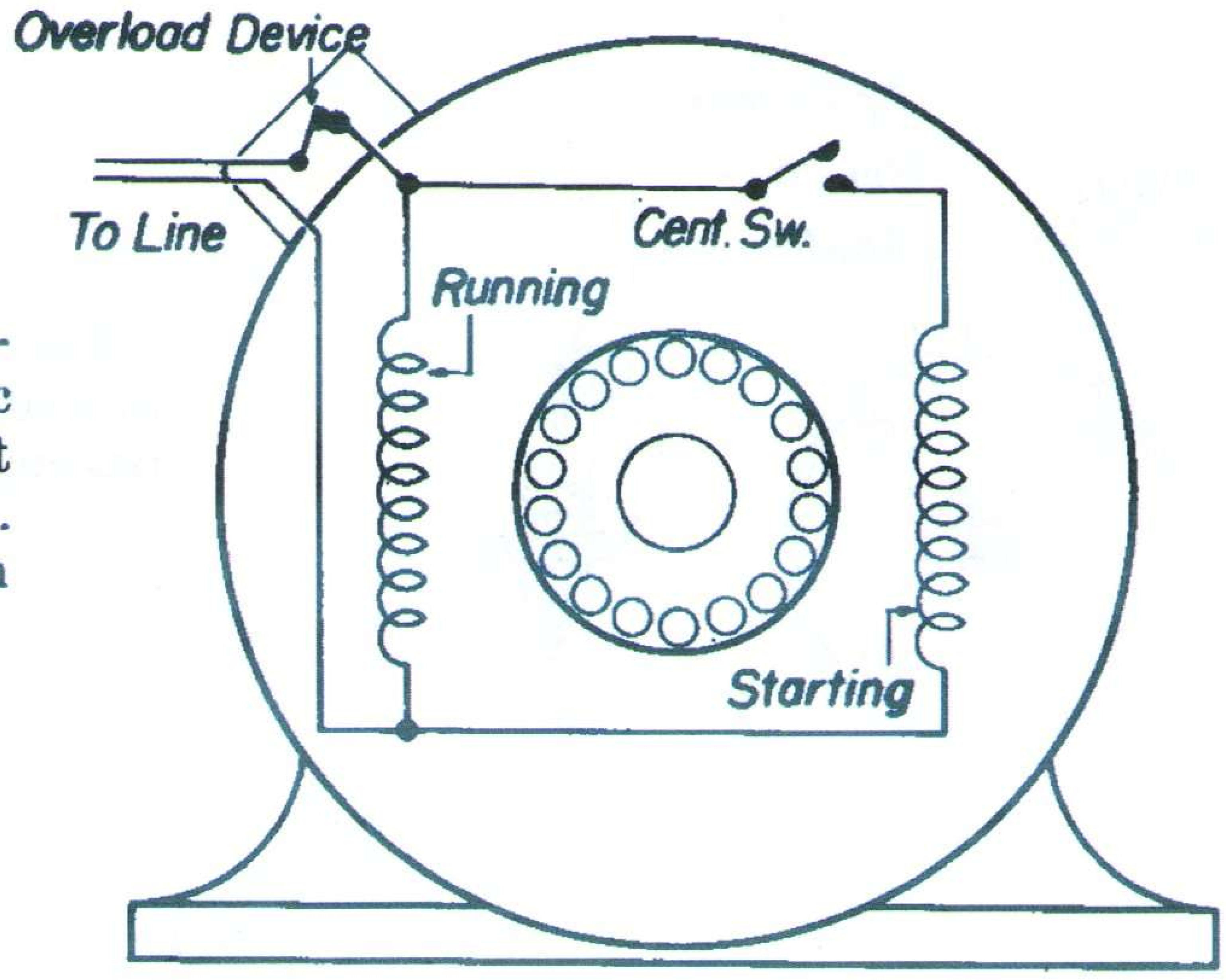


FIG. 1-66.—An overload device, consisting of a bimetallic element that will open circuit on overload or short circuit. It is connected in series with the line.

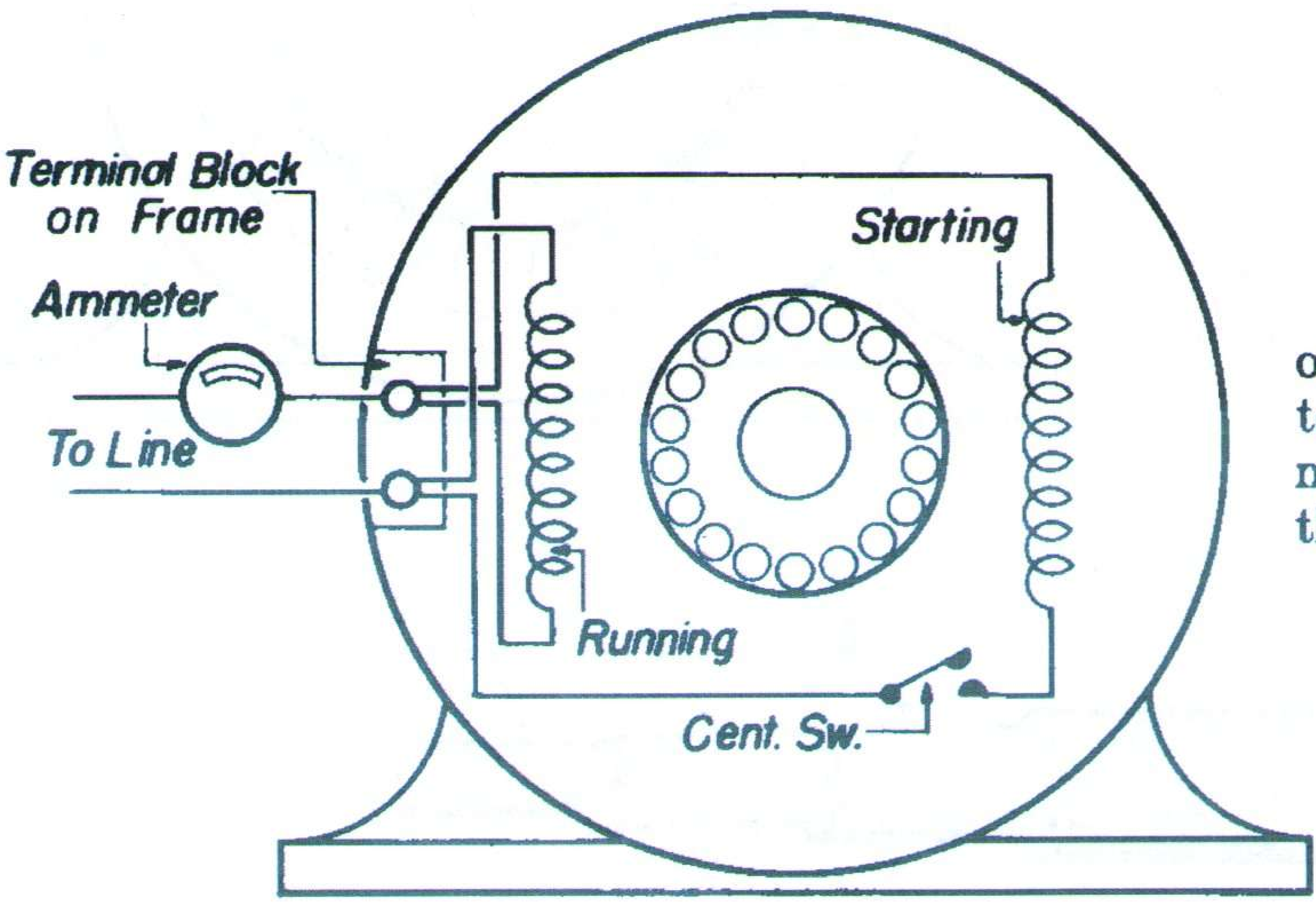


FIG. 1-67.—The method of connecting an ammeter in circuit to determine the current flowing through the motor.

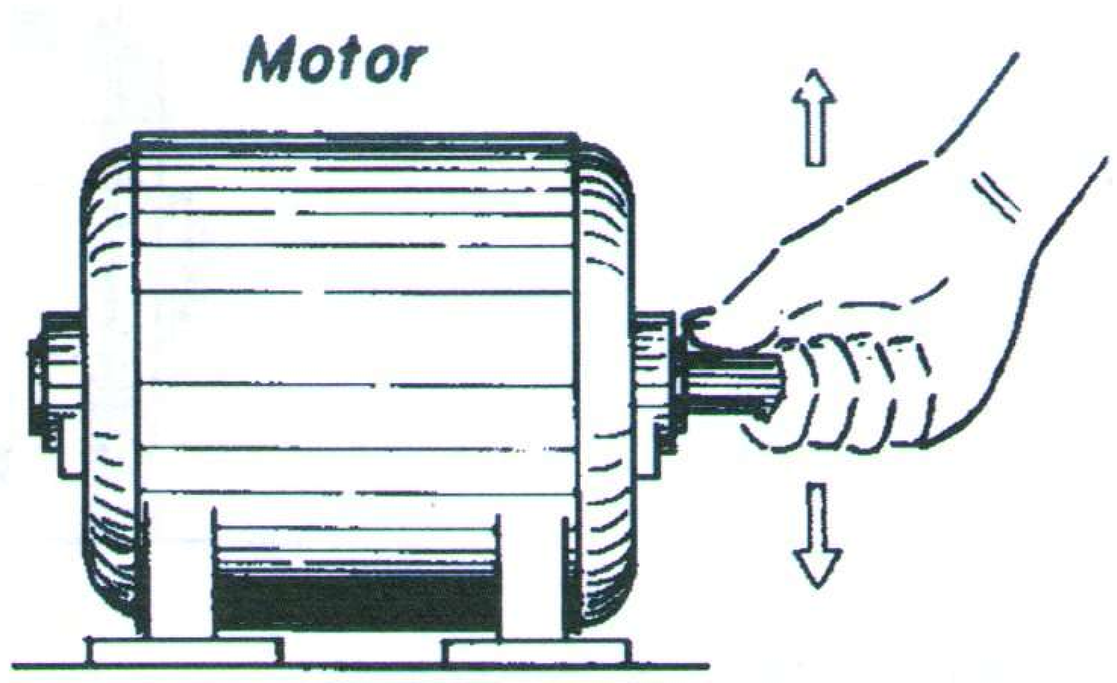


FIG. 1-68.—The bearings are tested by trying to move the shaft vertically.

G158(85)

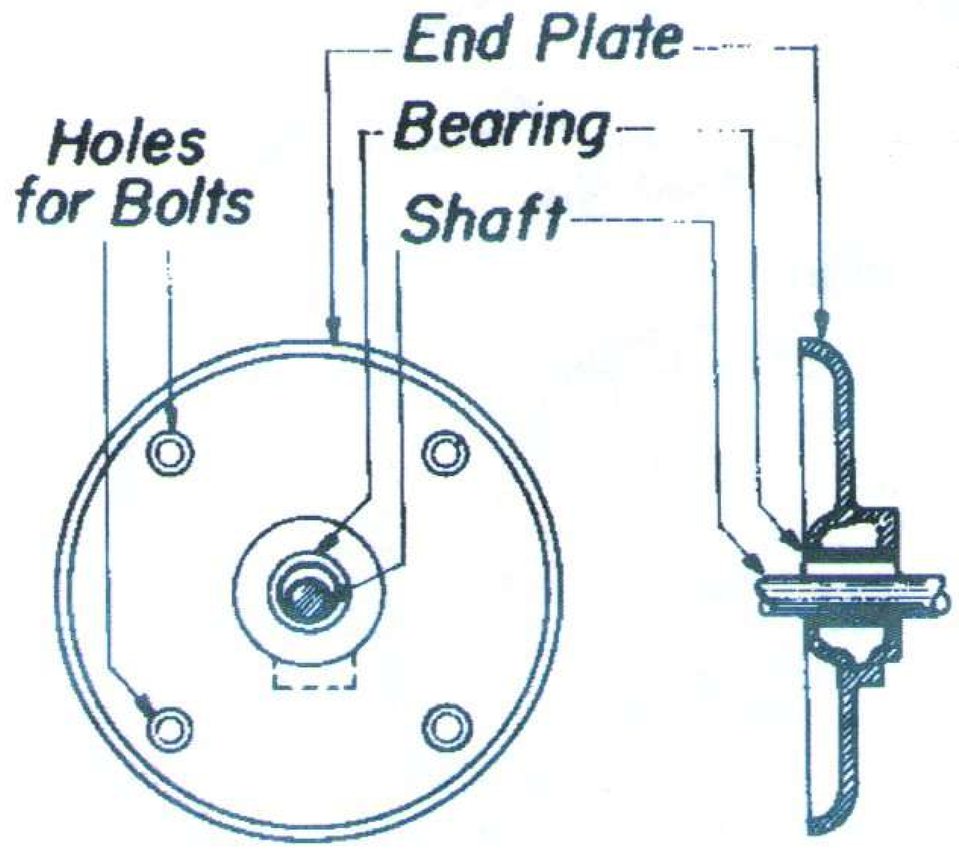


Fig. 1-69.—If the shaft can be moved vertically, it indicates a worn bearing or worn rotor shaft.

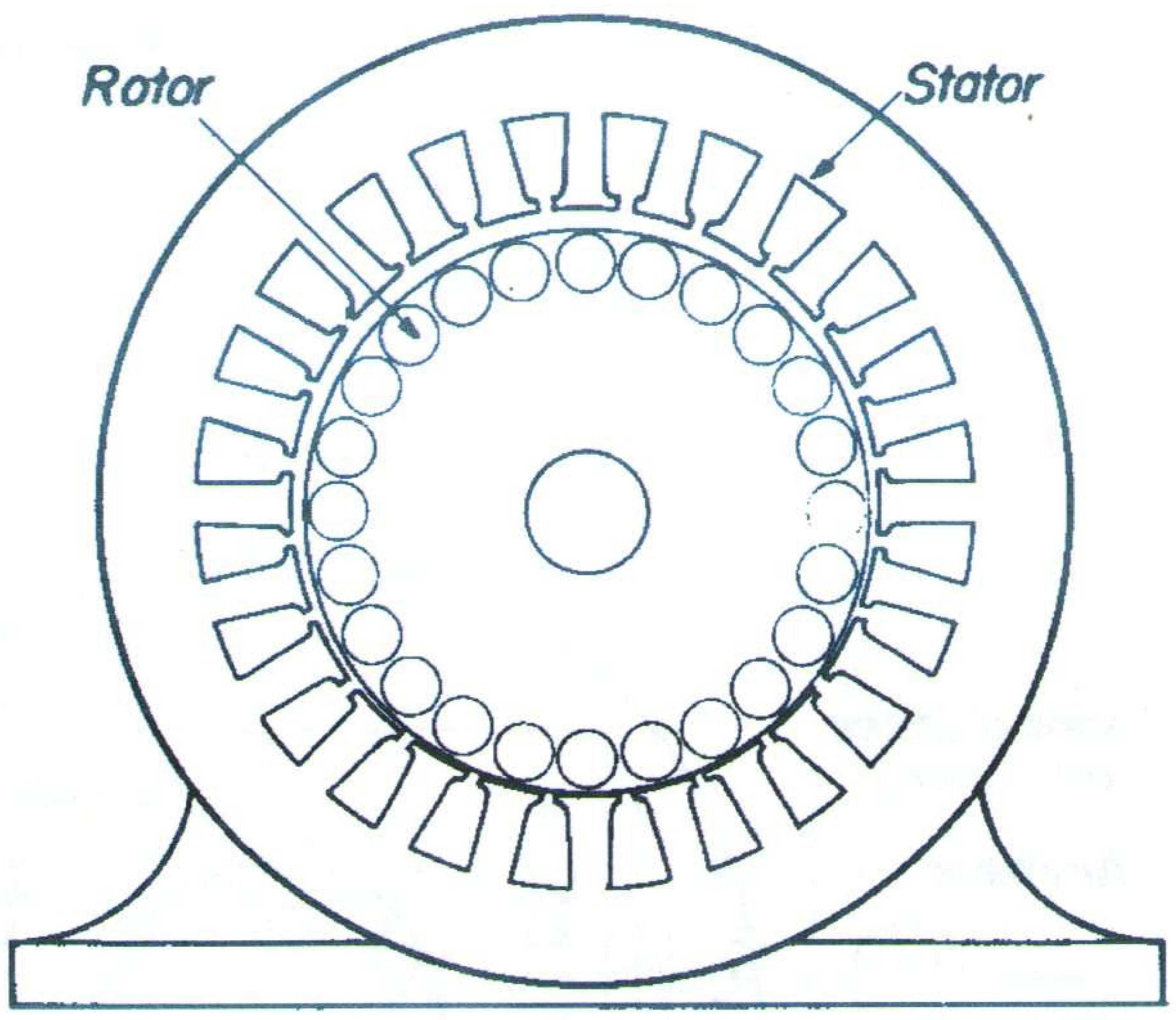


Fig. 1-70.—A worn bearing may cause the rotor to rub on the stator core.

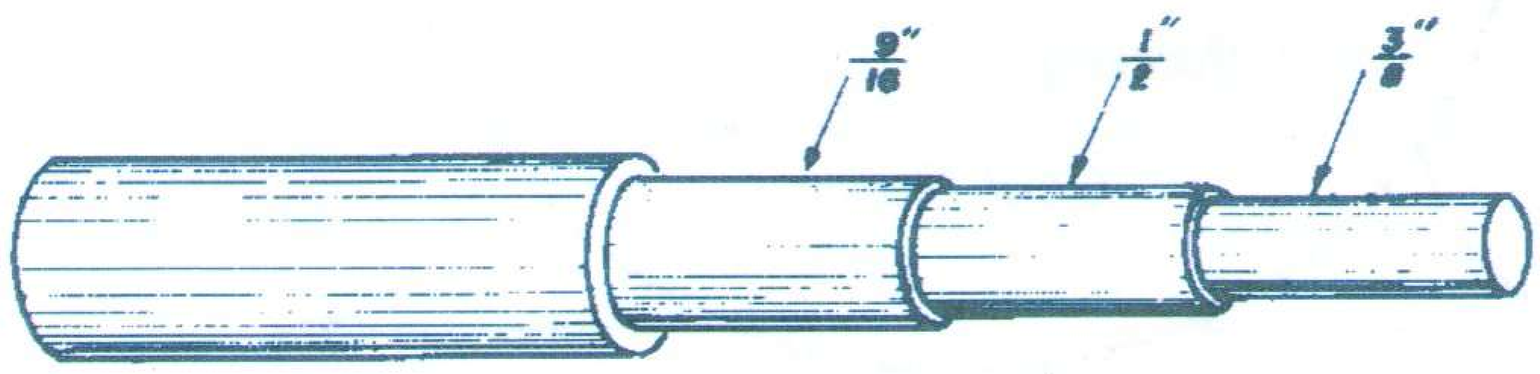


Fig. 1-71.—The tool used for forcing bearings out of end plates.

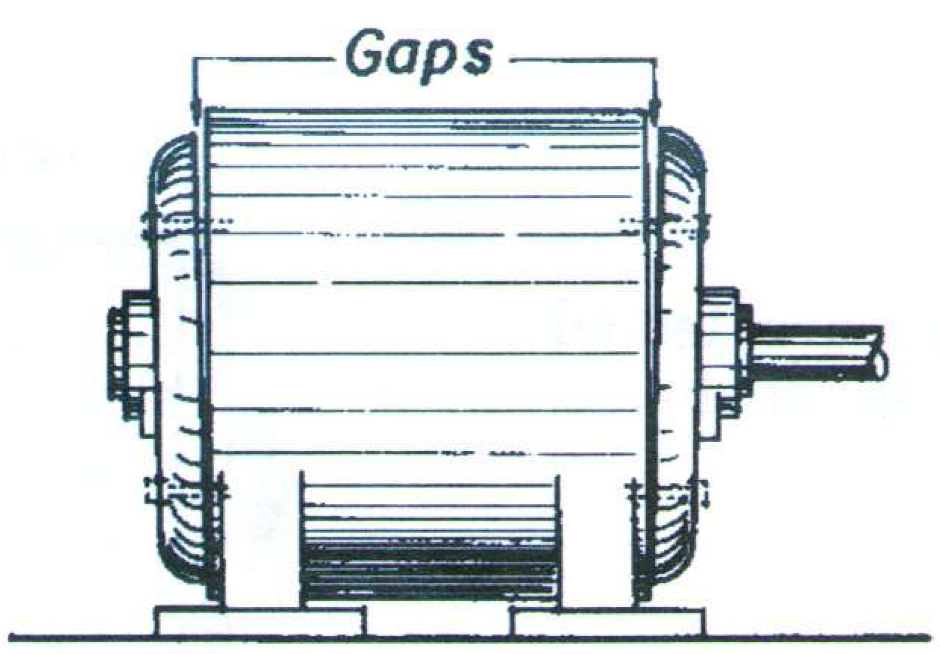


Fig. 1-72.—A motor showing end plates not mounted properly. This prevents the rotor from turning. Use a mallet to tap plates into position.

Figures 1-69; 1-70; 1-71; 1-72

9158(86)

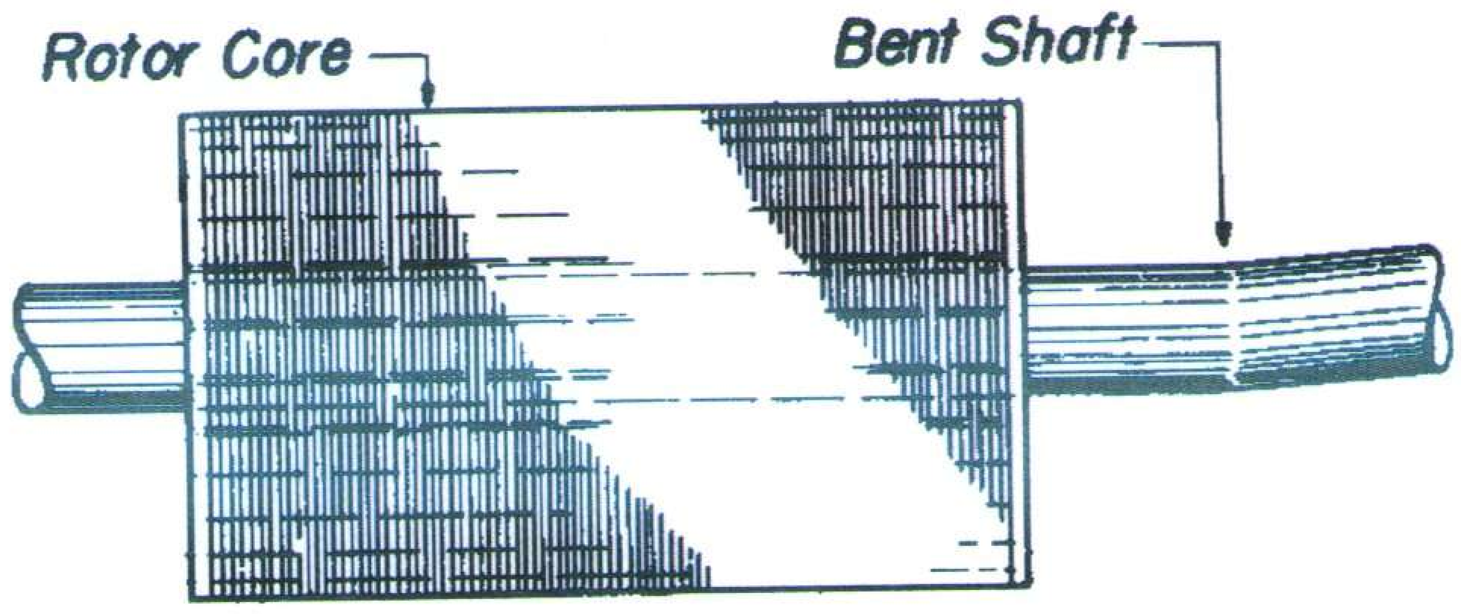


FIG. 1-73.—The bent shaft of a rotor.

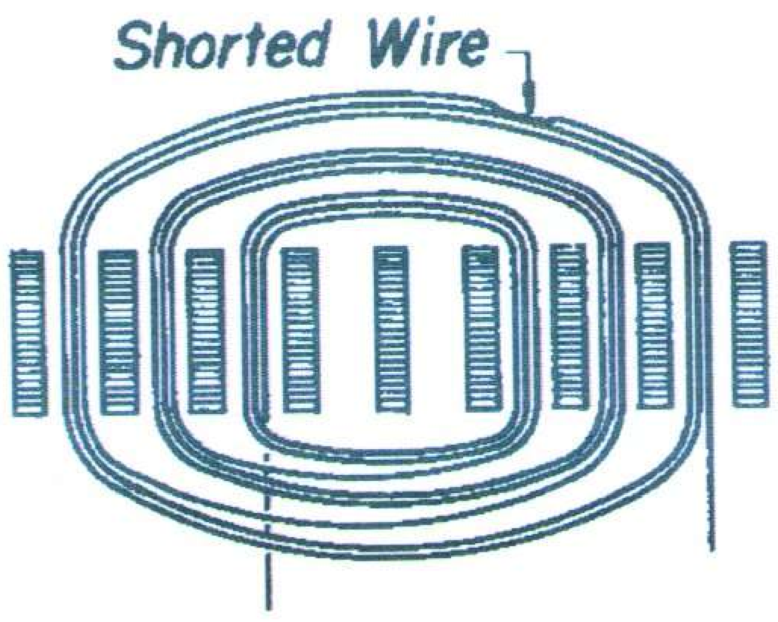


FIG. 1-74.—Two coils making electrical contact.

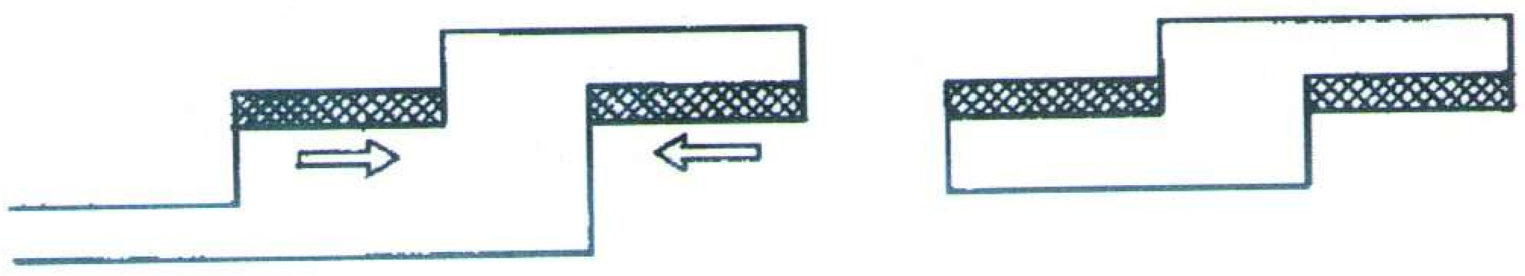


FIG. 1-75.—A connection mistake often made by beginners.

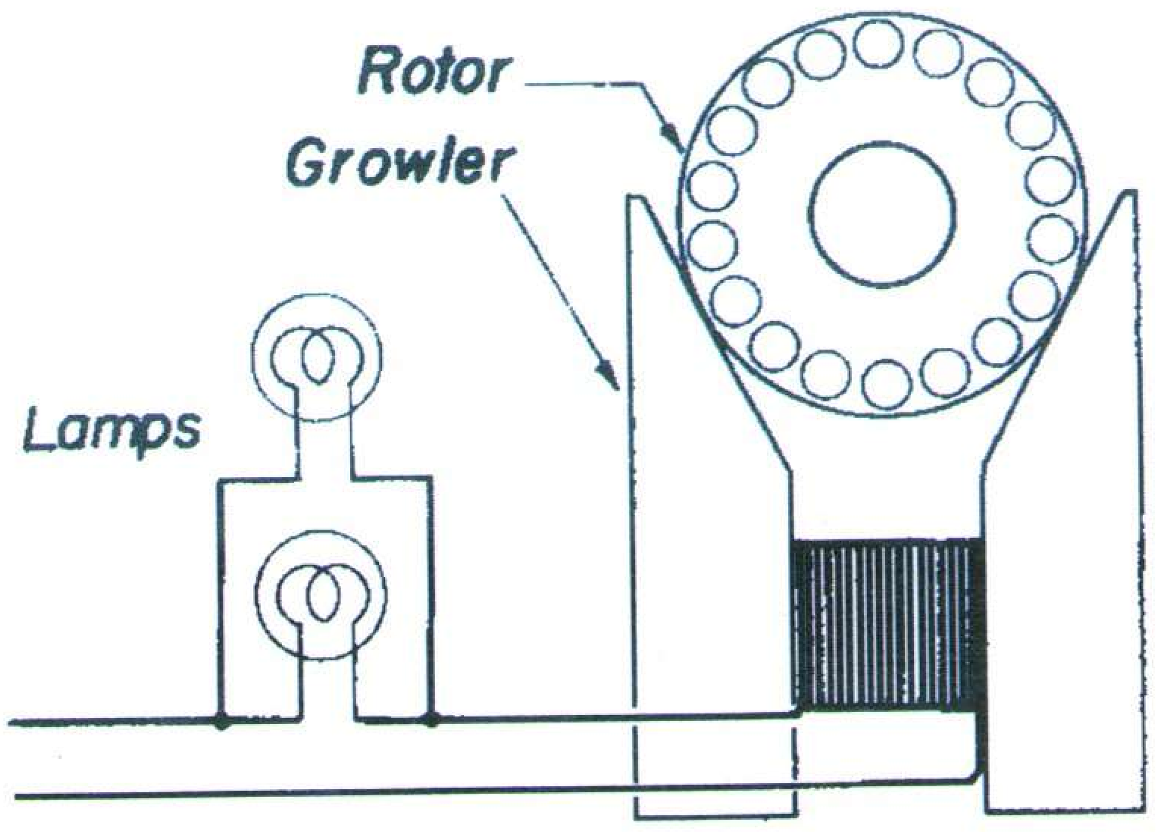


FIG. 1-76.—The rotor under test placed between the open ends of the growler core.

Figures 1-73; 1-74; 1-75; 1-76

Chapter 4

Armature Testing

MUCH has been written about the winding of armatures but little about the methods of checking up on the work as it progresses. The winding of armatures is clean work and exceedingly interesting to those who like it until some form of trouble turns up. Nothing can ruin the day for an armature winder like a "bug" in the winding; one that stubbornly resists all efforts to locate it. Because he has been so close to the work, the winder himself may have difficulty in finding his own mistake; a mistake that may be obvious to a fellow workman. In the larger shops, the foreman, or another winder, may be called upon to do the trouble shooting, but the winder who works alone must depend on testing methods to insure accurate results.

In the usual course of winding, the winder goes about the task more or less automatically, having de-

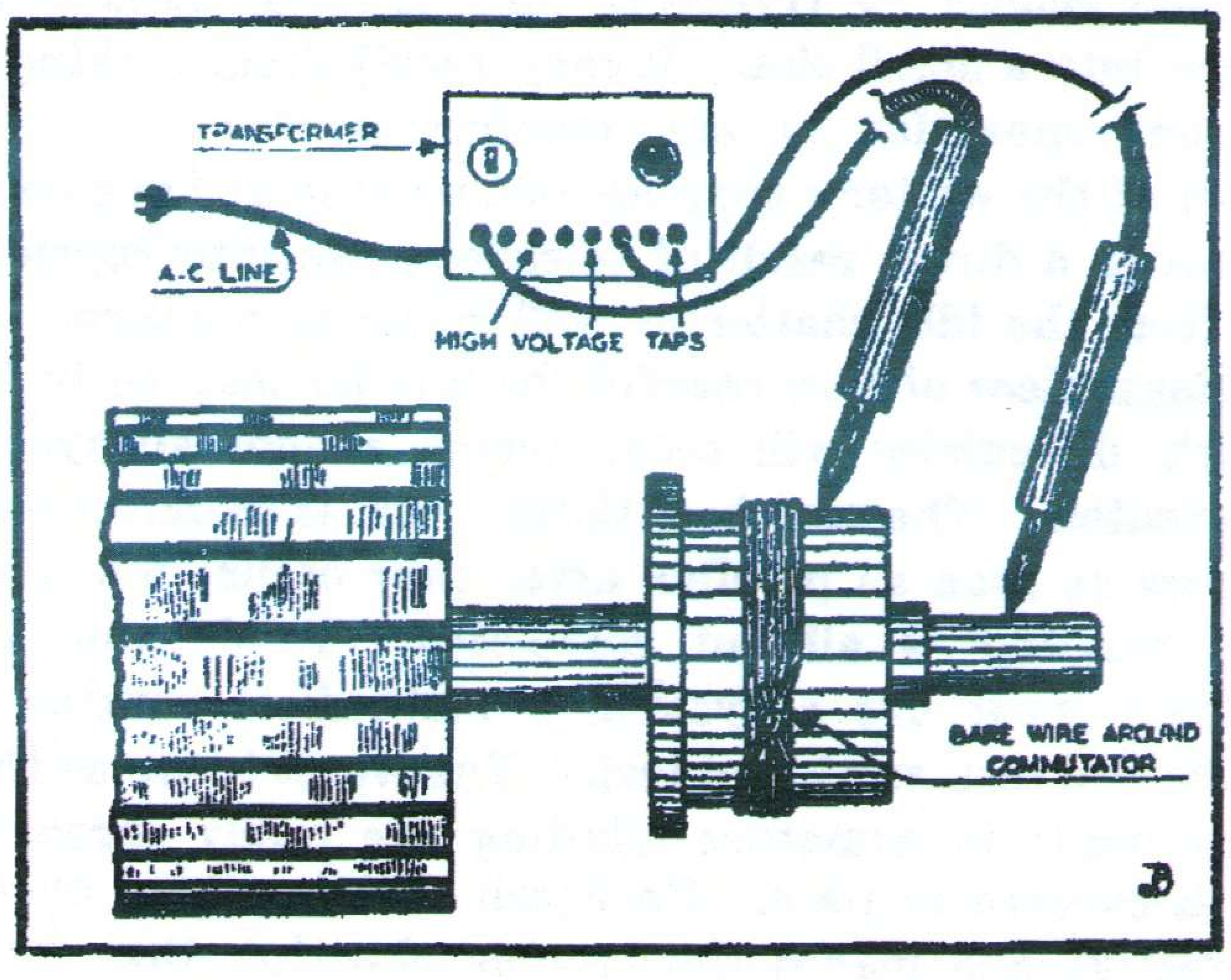


Fig. 1. A quick method of testing commutators for grounds is shown here. The wire connects all segments electrically so that only one test is required . . . .

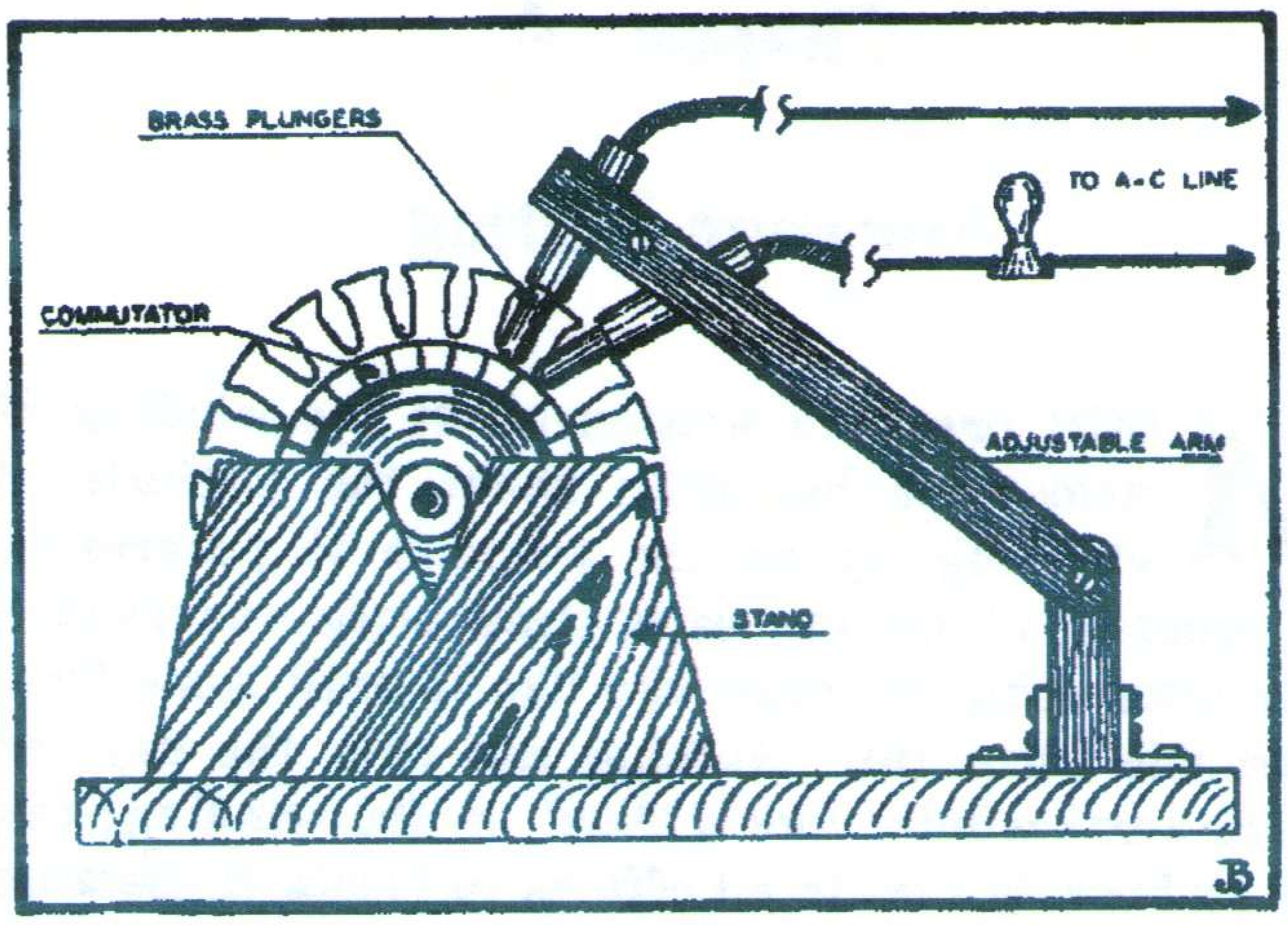


Fig. 2. This handy rack facilitates the testing of commutators for shorts between bars. Springs in the hollow plungers, insure good electrical contact with bars . . . . .

veloped a certain familiarity with the work. Ever so often, however, an odd job will turn up; one that so taxes the ability of the winder that an error may result from his confusion. The error may be a short or a ground caused by trying to pack a large number of turns into a small slot. It may result from making a wrong connection or any number of other reasons. Most of the writer's troubles in this respect have come about as a direct result of telephone call interruptions or from the idle chatter of well meaning visitors.

Regardless of how careful the winder may be in his work, difficulties will occur which cannot always be prevented. The next best thing, then, is to detect such errors as soon as possible after they occur; not after the winding is all but completed. To do this the winder must use a system, a methodical routine of work and test, work and test. The worst troubles that may occur in armature winding are easily corrected *if discovered in time*. Each coil that is wound over a defective one makes the trouble shooting that much more complicated and the remedy more difficult.

In armature winding, the most frequent causes of trouble can be traced to the following defects: short circuits, grounds, reversed connections, and open circuits.

nect the starting leads of each coil as it is wound to the commutator. The principle advantage of this method is that the winder has no trouble whatever in distinguishing his finishing leads as they are the only ones that remain unconnected when the winding is completed. A disadvantage of this method is the covering up of starting windings. If an error has been made, it will be difficult to correct without unwinding.

Some winders use a natural winding method that leaves the starting leads at the bottom of the coil and the finishing leads on top. There is little opportunity for error in this system but there is a greater chance of trouble developing later, such as shorts and grounds. It is much more difficult to insulate leads properly that are buried deep under the winding. Other winders manage to bring out both the starting and the finishing leads of the coils in the top of the slots, even though the coils to which they belong are wound in the bottom of the slots. This is done by leaving these ends outside of the slot to which they belong until the rest of the winding for that slot is in place. These leads, the starting end of one coil and the finishing end of another, are then laid in the top of the slot.

The winder may have difficulty in recognizing start leads from finishing leads unless some sure method of

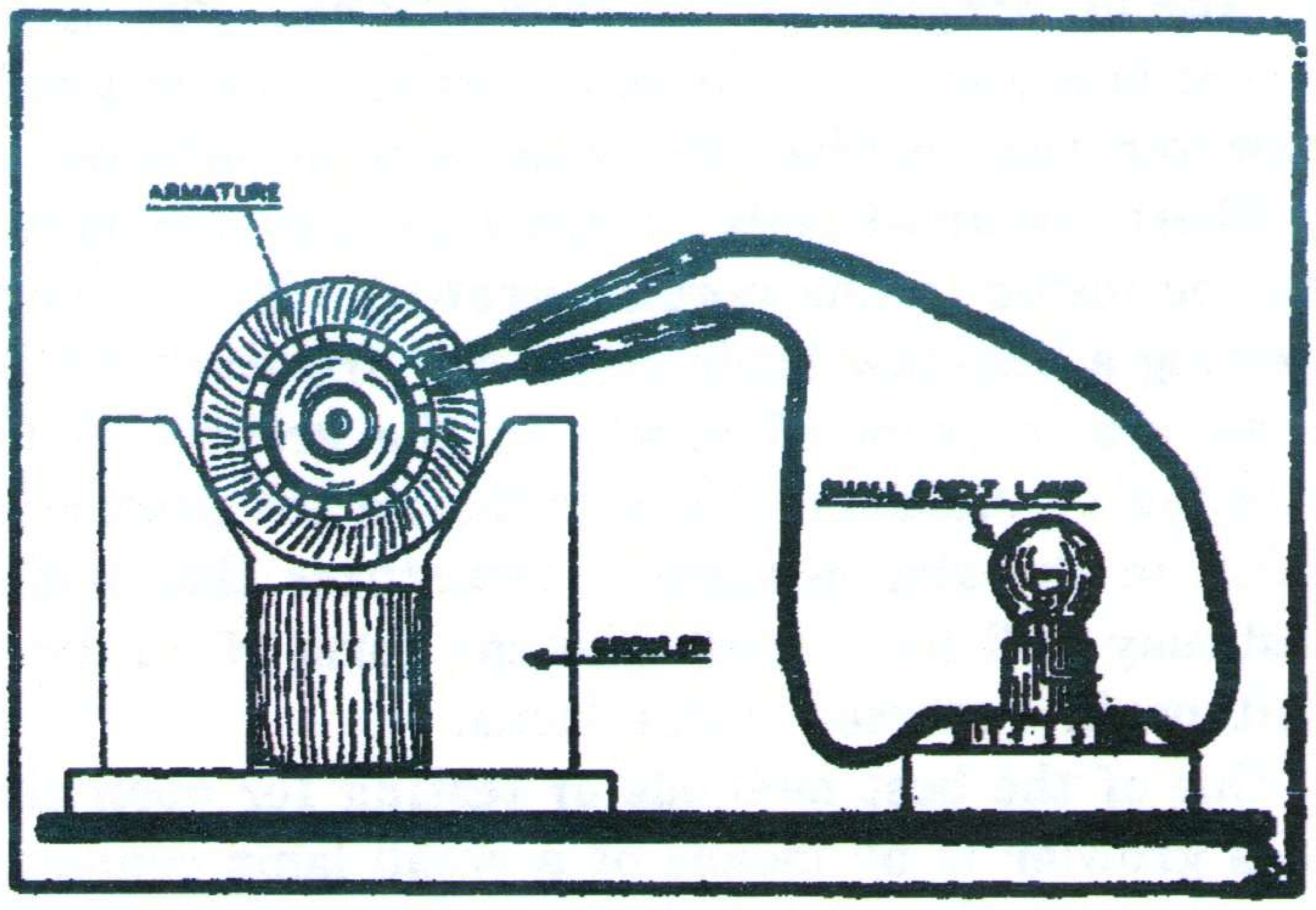


Fig. 5. A test lamp such as the one shown here provides an excellent means of locating shorts, grounds, and open circuits. Induced voltage from the growler lights the lamp . .

G158(90)

identification is employed. One of the best systems of identification requires that the start and finishing leads be of unequal length. If the starting ends are clipped just long enough to reach the right commutator bars, and if the finishing leads are left at least two inches longer, mistakes are not likely to occur. When the winding consists of more than one wire in hand, which is usually the case with this type of winding, colored tracer wire will simplify connecting and will save the time of testing each circuit.

Make Coil Tests Before Soldering

Tests for shorts, grounds, and reversed connections should be made as soon as the leads are staken in the commutator slot, and before the leads are soldered. Unsoldered leads can be changed easily if a wrong connection is discovered. They can be raised if special tests should be required. All armatures can not be tested in the same way or with the same equipment. They can be given a final test for grounds, however, by applying the proper test voltage to commutator and shaft.

Armatures can be tested for short circuits in a number of ways. Direct current armatures and some a-c armatures can be tested quickly and accurately in an armature growler. Some of the a-c armatures of the repulsion-start, induction-run type have cross connections between opposite commutator bars, and can not be tested properly in a conventional type growler. There is a special form of external growler available, however, that can be used with these armatures.

Short circuited coils in armatures of the type that can be tested in the regular growler may be found by passing a hacksaw blade above the armature, while the armature is revolved slowly in the growler field. A sticking or vibrating blade indicates the presence of a short in the slot beneath. Armatures that pass this test may still have trouble in the form of an open circuit or in reversed connections.

One of the best methods of testing for open circuits in a growler is by means of a small lamp connected to two test prods. A good lamp for this purpose is a Mazda No. 63, such as is commonly used in automobile dash and tail lights. As the armature is slowly revolved in the growler, the two leads to the lamp are

9158(91)

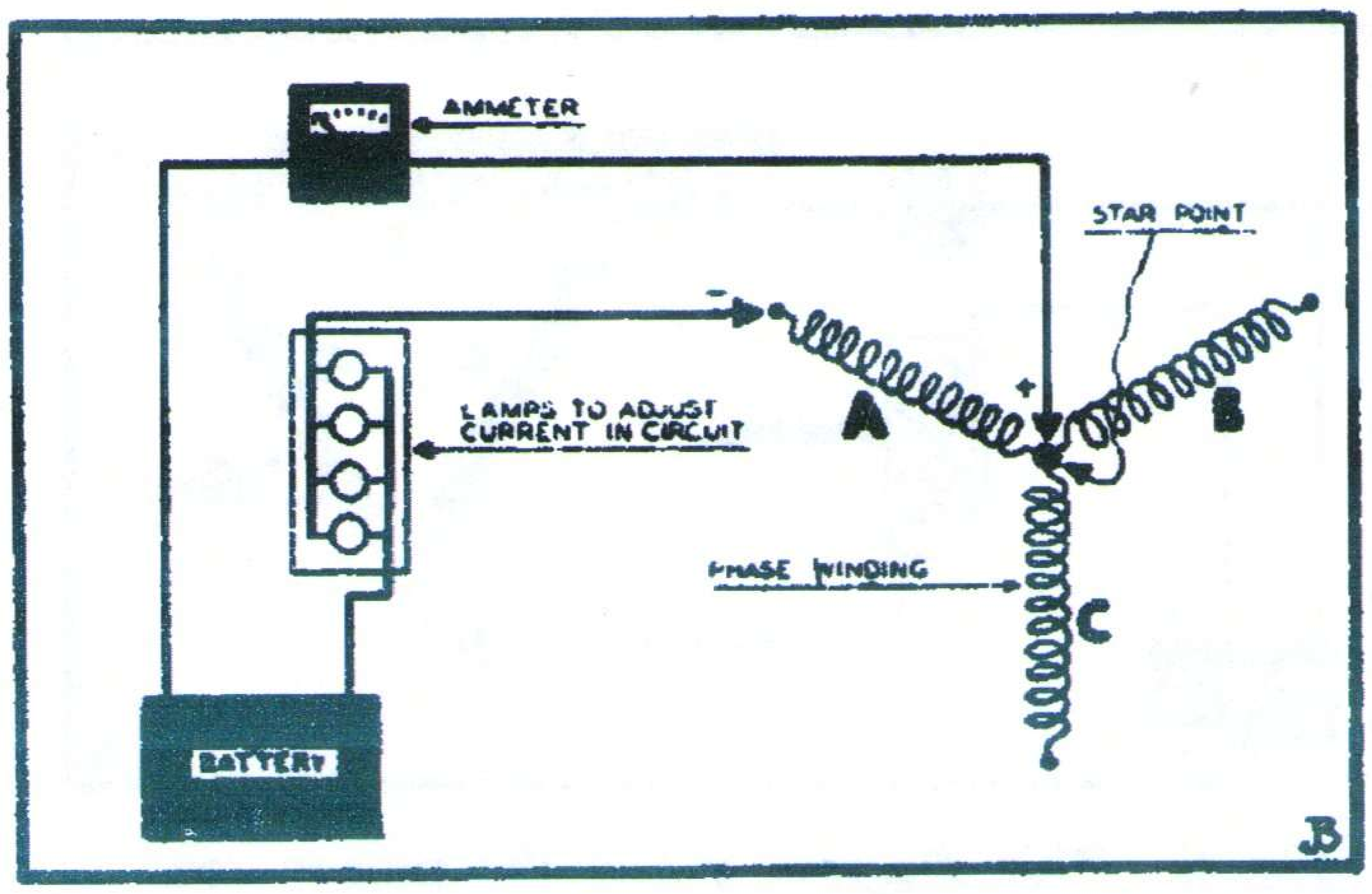


Fig. 5. In testing a three-phase star winding for polarity, one of the d-c test lines must be connected at the junction of all three phases and the other to the phase under test. . .

primary winding to an a-c supply source, leaving the secondary terminals unconnected, we will find that the flow of current through the primary is almost negligible. In this case the core becomes saturated magnetically which tends to retard the flow of current in the primary winding except such as required to establish the magnetic field. However, if we connect the secondary winding terminals to some form of load we find that there is an immediate increase in the current drawn by the primary. The current in the primary winding will depend upon the current supplied from the secondary. When the section of the stator winding under the growler contains a short circuited coil, the primary current reaches a maximum value. On the other hand, when the internal growler is held over stator coils that are free of shorts, there is no circuit in the secondary, and the current in the growler primary is a minimum. These facts are used to good advantage when testing for shorts.

Figure 2 gives the details for constructing an internal growler suitable for stator testing on a wide variety of motor sizes. The preparation of the laminated core is the only difficult part of the job and this will be simplified if the core from an old transformer of the right kind is available. The core should be H shaped, with the coil wound in the center. The bot-

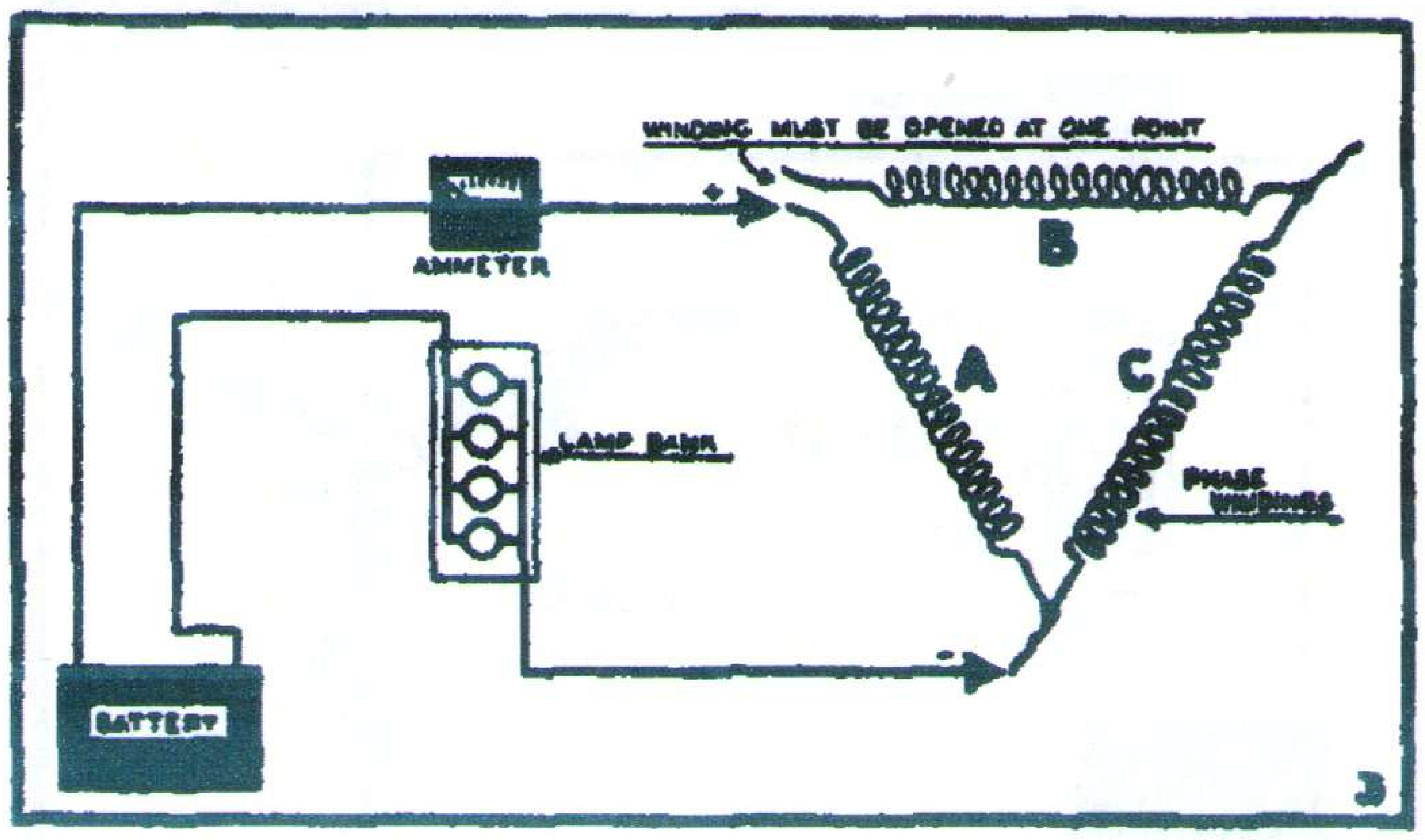


Fig. 6. This diagram shows the proper connections for making a polarity test on a three-phase delta connected stator. The windin; must be disconnected at one point as shown.

tom legs of the core should be rounded so as to fit the inside bore of the stators. Laminations of a larger size can be trimmed down to fit with a pair of tin shears. The core should be firmly bolted or riveted together with provision for some form of a handle. A thumb switch on the handle will greatly facilitate the use of an internal growler.

With the aid of this growler, shorts can be detected in several ways. One method is to use a hacksaw blade to "feel out" the winding one coil pitch in advance of the growler's position. If the blade tends to stick or vibrate, the short will be located under the surface at that point. Another method that gives very good results is to cut an a-c ammeter into the primary circuit of the growler. In a clear winding there will be but little current flowing in the primary and the ammeter will give a low reading. However, as soon as the growler is located over a coil containing a short circuit, the current flow in the primary will increase. The current indicated by the ammeter will depend upon the resistance of the short circuit. Figure 8 shows a circuit diagram of a short circuit testing device of this kind.

The internal growler has still another use: it can also be used for locating grounds. The growler is moved about inside the stator and at each position one lead from each of the stator circuits is flashed