Inter-Turn Stator Winding Fault Diagnosis in Three-Phase Induction Motors, by Park's Vector Approach

A. J. Marques Cardoso
Associate Member, IEEE

S. M. A. Cruz
Student Member, IEEE

D. S. B. Fonseca
Non-Member, IEEE

Universidade de Coimbra, Departamento de Engenharia Electrotécnica
Polo II - Pinhal de Marrocos
P-3030 Coimbra, Portugal

Abstract: The subject of on-line detection and location of inter-turn short circuits in the stator windings of three-phase induction motors is discussed, and a noninvasive approach, based on the computer-aided monitoring of the stator current Park's Vector, is introduced. Experimental results, obtained by using a special fault producing test rig, demonstrate the effectiveness of the proposed technique, for detecting inter-turn stator winding faults in operating three-phase induction machines. On-site tests conducted in a power generation plant, using the diagnostic instrumentation system developed, are also reported.

Keywords: Induction motors, fault diagnosis, stator winding faults, insulation failure.

I. INTRODUCTION

Previous research, concerning the use of Park's Vector Approach, has demonstrated the effectiveness of this noninvasive technique for diagnosing malfunctions, such as, single-phasing, open wound-rotor faults, airgap eccentricity and rotor cage faults, in operating three-phase induction motors [1]-[3].

Unfortunately, an induction motor can fail due to other fault mechanisms [4]. Stator winding failures, which can occur due to a combination of thermal, electrical, mechanical and environmental stresses that act on the stator [5], are found to be one of the major causes of motor failure [4].

The subject of on-line detection of inter-turn short circuits in the stator windings of three-phase induction motors has been addressed by some researchers. Techniques such as those based on the spectral analysis of the motor current [6], frame vibration [7], [8], or the axial leakage flux [7], [9], have been proposed. An on-line method to detect incipient failure of turn insulation in random-wound motors, based on an indicator termed the effective negative-sequence impedance which is computed from the voltage and current phasors at the motor terminals is also described in [10].

This paper introduces a new approach, based on the computer-aided monitoring of the motor current Park's Vector representation, for diagnosing inter-turn stator winding faults in operating three-phase induction machines.

II. PARK'S VECTOR APPROACH

As a function of mains phase-variables (i_A, i_B, i_C) the motor current Park's Vector components (i_D, i_Q) are

$$i_D = \left(\sqrt{2}/\sqrt{3}\right) i_A - \left(1/\sqrt{6}\right) i_B - \left(1/\sqrt{6}\right) i_C \qquad (1)$$

$$i_Q = \left(1/\sqrt{2}\right) i_B - \left(1/\sqrt{2}\right) i_C . \qquad (2)$$

Under ideal conditions, the three-phase currents lead to a Park's Vector with the following components:

$$i_D = \left(\sqrt{6}/2\right) i_M \sin(\omega t) \qquad (3)$$

$$i_Q = \left(\sqrt{6}/2\right) i_M \sin(\omega t - \pi/2) \qquad (4)$$

where

i_M maximum value of the supply phase current (A)
ω angular supply frequency (rad/s)
t time variable (s).

The corresponding representation is a circular locus centered at the origin of the coordinates.

Under abnormal conditions, (3) and (4) are no longer valid and consequently the observed picture differs from the reference pattern.

The operating philosophy of the Park's Vector Approach is thus based on identifying unique signature patterns in the figures obtained, corresponding to the motor current Park's Vector representation.

III. LABORATORY TESTS

A. Details of the Test Rig

The test motor used in the experimental investigation of the occurrence of inter-turn stator winding faults was a three-phase, 50 Hz, 4-pole, 15 kW, SEW-EURODRIVE® squirrel cage induction machine, type DV160L4, rated at 400 V, 29.5 A and 1450 rpm.

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The stator winding has been modified by addition of a number of tappings connected to the stator coils, for each of the three phases. The other end of these external wires is connected to an enlarged motor terminal box, allowing for the introduction of shorted turns at several locations in the stator winding. The motor has two parallel paths per phase and a total of 147 turns per path/phase. The stator winding arrangement is illustrated in Fig. 1 and the location of the tappings for one of the motor phases (phase A) is shown in Fig. 2.

The diagnostic instrumentation system used basically comprises a Macintosh II® microcomputer supporting a Data Translation data acquisition board, model DT 2228®, connected to three clip-on current probes, type Chauvin Arnoux PAC 500®, through a preconditioning module. Further details of this diagnostic instrumentation system can be found in [2].

B. Experimental Results

The motor was initially tested, in the absence of faults, in order to verify the current Park's Vector reference pattern. Subsequently, shorted turns were introduced in the stator winding and current Park's Vector examined as a function of the degree of severity of the fault and its location. The motor was delta connected and a shorting resistor was used, whose value was chosen so as to create an effect strong enough to be easily visualized, but simultaneously big enough to limit the short-circuit current and thus protecting the motor from complete failure when the short is introduced. To reduce the thermal problems, the laboratory tests were carried out at a reduced voltage of 220 V line.

Fig. 3 shows the typical stator current Park's Vector pattern corresponding to a healthy motor. This pattern differs slightly from the circular locus expected for ideal conditions because the supply voltage is not exactly sinusoidal [2].

The occurrence of inter-turn short circuits manifests itself in the deformation of the current Park's Vector pattern corresponding to a healthy condition, leading to an elliptic representation whose ellipticity increases with the severity of the fault (Figs. 3 - 6) and whose major axis orientation is associated to the faulty phase (Figs. 6 - 8).

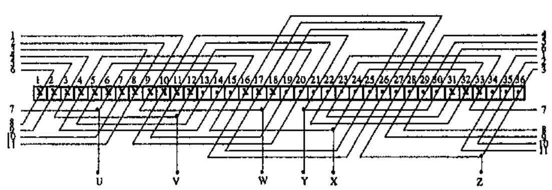

Fig. 1 — Stator winding arrangement.

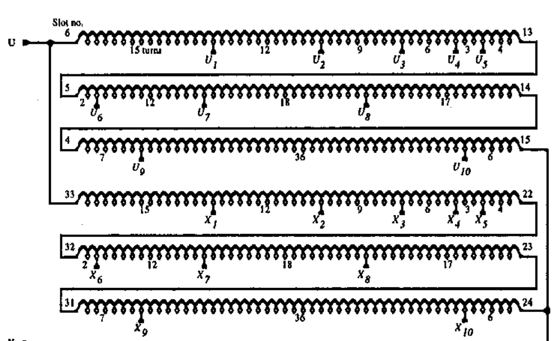

Fig. 2 — Location of the tappings for motor phase A.

Other experimental tests carried out with a Mawdsley Generalised Electrical Machine®, connected as a three-phase, 4-pole, induction motor, with a double-layer stator winding series arrangement and rated at 220/380 V, 1450 rpm, lead to similar results.

IV. ON-SITE TESTS

Field tests were conducted in a power generation plant in order to assess the suitability of the instrumentation system developed, when used in the industrial environment.

These tests were performed on several three-phase, 50 Hz, 4-pole, induction machines, whose rated power is in the range of 30 kW to 132 kW.

Although no stator winding faults were detected so far on the basis of the first test, the instrumentation system developed proved to be flexible and easy of use.

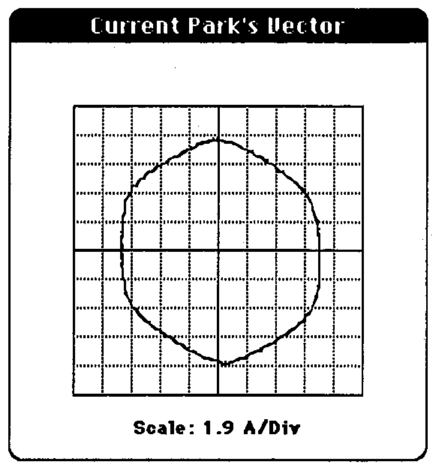

Fig. 3 — Experimental current Park's Vector pattern, corresponding to a healthy motor.

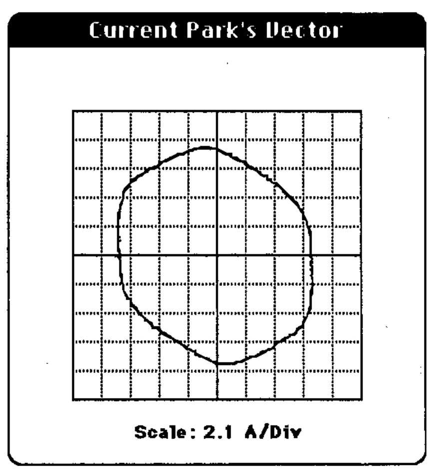

Fig. 4 — Experimental current Park's Vector pattern, for the case of three shorted turns in phase A (U_4-U_5).

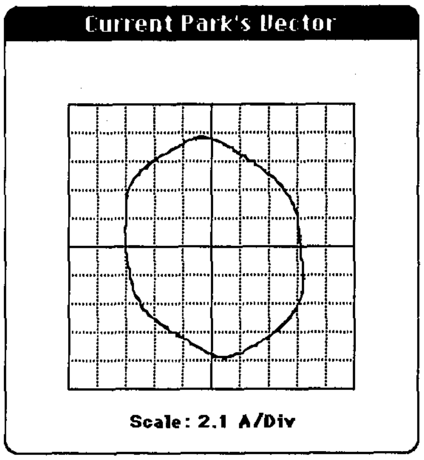

Fig. 5 — Experimental current Park's Vector pattern, for the case of six shorted turns in phase *A* (U_3-U_4).

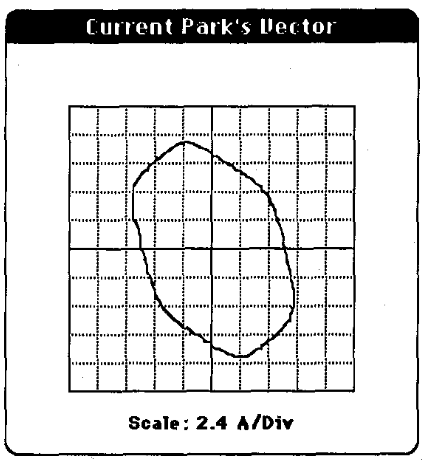

Fig. 6 — Experimental current Park's Vector pattern, for the case of eighteen shorted turns in phase *A* (U_7-U_8).

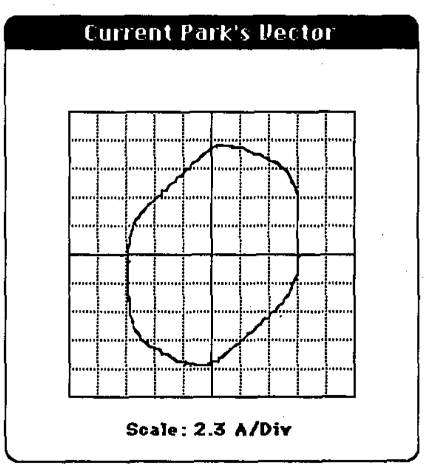

Fig. 7 — Experimental current Park's Vector pattern, for the case of eighteen shorted turns in phase *B* (V_7-V_8).

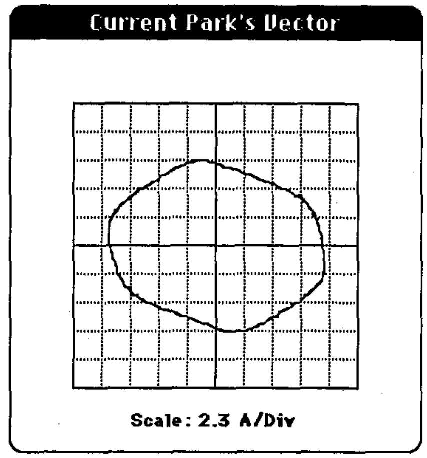

Fig. 8 — Experimental current Park's Vector pattern, for the case of eighteen shorted turns in phase *C* (W_7-W_8).

Further evaluation tests have to be done in the industrial environment, in order to assess the effectiveness of the diagnostic technique developed in the laboratory, when applied to large three-phase induction motors.

V. CONCLUSION

This paper introduces a new approach, based on the computer-aided monitoring of the motor current Park's Vector, for diagnosing the occurrence of inter-turn short circuits in the stator windings of operating three-phase induction machines.

The on-line diagnosis is based on identifying the appearance of an elliptic pattern, corresponding to the motor current Park's Vector representation, whose ellipticity increases with the severity of the fault and whose major axis orientation is associated to the faulty phase.

Further work is currently in progress concerning the use of this approach for diagnosing also stator winding faults in three-phase synchronous machines.

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VIII. BIOGRAPHIES

A. J. Marques Cardoso (S'89, A'95) was born in Coimbra, Portugal, on August 21, 1962. He received the E. E. Diploma and the Dr. Eng. degree from the University of Coimbra in 1985 and 1995, respectively.

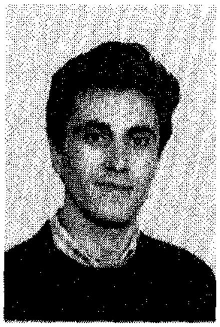
He has been with the University of Coimbra since 1985, where he is currently an Assistant Professor in the Department of Electrical Engineering and Director of the Electrical Machines Laboratory. His teaching interests cover electrical machines and power electronics and his research interests are focused on condition monitoring and diagnostics of electrical machines and drives. He has published a book entitled *Fault Diagnosis in Three-Phase Induction Motors* (in Portuguese) and more than 30 papers in technical journals and conference procedings.

Dr. Marques Cardoso is actively involved, as an expert, in the field of standardisation on condition monitoring and diagnostics, both at a national and international level, where he has been acting as a convenor of ISO/TC 108/SC 5 Advisory Group C *(Condition monitoring of electrical motors and generators, for the purposes of diagnostics)* and member of several Working Groups of ISO, IEC and CEN.

He was appointed member of the Overseas Advisory Panel of *Condition Monitoring and Diagnostic Technology*, a former journal published by the British Institute of Non-Destructive Testing, now incorporated into *Insight* and he was also a founder member of the European Consortium for Research on Condition Monitoring of Electrical Systems and Drives.

Dr. Marques Cardoso is a member of the New York Academy of Sciences, the European Power Electronics and Drives Association (EPE), the Electrical Machines and the Industrial Drives Committees of the IEEE/IAS, the Portuguese Federation of Industrial Maintenance (APMI) and a senior member of the Portuguese Engineers Association (ODE).

He has been listed in Who's Who in the World, BEST Europe, among others.



Sérgio M. A. Cruz (S'96) was born in Coimbra, Portugal, on June 19, 1971. He received the E. E. Diploma, in 1994, from the University of Coimbra, where he is currently a M.Sc. student and Teaching Assistant in the Department of Electrical Engineering.

His current research interests are on fault diagnosis in electrical machines. He has published 5 papers on this subject.

Mr. Cruz is member of the Portuguese Federation of Industrial Maintenance (APMI) and of the Portuguese Engineers Association (ODE).

Davide S. B. Fonseca was born in Castelo Branco, Portugal, on December 23, 1972.

He received the E. E. Diploma from the University of Coimbra, Coimbra, Portugal, in 1996.

He is currently with Delphi Packard Electric Systems, Castelo Branco, Portugal.