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DIAGNOSIS OF FAULTS IN INDUCTION MACHINE MANUFACTURING

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Abstract: *Although there are now modern technologies of induction machine manufacturing, however, in production, a relatively large number of faults have been identified, which increase the share of manufacturing-related costs and the consumption of materials. In recent years, many methods for diagnosing the manufacturing faults and the defect flow from operations have been developed. However, the proposed methods are not completely settled and they do not provide an adequate prediction upon the occurrence of defects. The objective of this work is monitoring three-phase induction machine faults on the manufacturing line, in order to establish a strategy to reduce wastage in the process of manufacture. Tests were conducted on a sample of 20 types of induction motors, over a year. Internal and external faults were monitored on the manufacturing line: phase-earth breakdown faults, phase to phase breakdown faults, different resistances per phase, insulation faults and other manufacturing faults. A graphical analysis and a strategy to reduce the number of faults have been established.*

Keywords: *induction machine, manufacturing, monitoring, faults, graphical analysis, strategy*

1. INTRODUCTION

Induction machine protection and fault diagnosis have been subjects of research since the appearance of this category of equipment. First, producers of induction motors relied only on simple protections to ensure their safe operation. As the induction motor load and function were further complicated, fault-diagnosis methods have been designed and improved.

For operation, the first objective of the maintenance department is to keep the machine and electrical equipment in good operating condition to prevent failures and manufacturing losses [4]. Economic benefits are obtained when there are maintenance programs based on fault diagnosis and prognosis. Online information on the faults are an important aspect of system maintenance.

To obtain a high degree of safety and high performance in the operation of these technical systems, the researchers' attention is turned towards monitoring and evaluating the reliability of the design defects, manufacturing and operating. The literature presents a series of studies and researches related to the development of new analytical tools for quality and reliability predictions, so as to obtain a good working condition [2,7,10]. For manufacturing, the main objective is to reduce the flow of manufacturing waste. It can be reduced if the causes of faults are known. Rotating electrical machine malfunction causes are rooted in design, manufacturing tolerance, assembly, installation, operational environment and nature of the task of the carrying out maintenance program [3,6].

The induction motor, rotating electric machine like any other, is subject to both electromagnetic forces and mechanical forces, whose interaction is normal, resulting in stable operation with minimum noise and vibration, without damage. When failure occurs, the balance between these forces is lost, leading to a worsening of the fault.

In [8], the internal and external faults of the induction machine and the diagnostic methods for these defects are classified by the nature of the source of failure.

A proportion of 38% of the induction machine faults are due to the insulation system. Early detection of these faults results in saving the motor's total destruction.

Another significant proportion of the distribution of faults in electric motors is occupied by the bearings faults and broken rotor bars, about 50%. Screening methods and faults causes are analyzed and presented in [1,9,10]. Although they are more rigid and durable than those manufactured, cast rotors always show cracks or breaks, which represent 5-10% of the induction machine faults [2].

Recent research are aimed at establishing procedures as close as possible to the ideal diagnostic procedure: with a minimum of measurements, to be able to provide sufficient information with which to conduct analysis for diagnosis, to accurately and quickly indicate incipient failure modes. All studies related to the development of procedures and diagnostic tools are based on the classification of faults and failure sources [7,8]. Most of the induction machine diagnosis methods are based on the principle that the asynchronous machine is a symmetrical electromechanical system. Any fault that changes the symmetry properties can be identified by signals proceeding from sensors that measure mechanical and electrical quantities: current, voltage, magnetic flux, torque, speed.

Researchers' attention was focused on methods for induction machine faults detecting, in [4,7,9,10,11], and very few studies have been made towards the forecasting direction and upon fault loss reduction strategies.

This paper aims at monitoring the faults on the manufacturing line in order to establish a strategy to reduce the number of faults.

2. FAULT MONITORING ON THE MANUFACTURING LINE

Faults were monitored in a rotating electrical machinery manufacturing company production line, with powers from 0.09 to 1.5 kW, with speeds of 750 rpm, 1000 rpm, 1500 rpm and 3000 rpm and with 230/400 voltage.

On the line, there have been analyzed:

- stator execution;
- rotor;
- assembly.

In Table 1, 2, 3, 4 induction motor lots and their faults are eclasified and evaluated.

Table 1. Total verified motors in 2010

Months	1	2	3	4	5	6	7	8	9	10	11	12	Total
Induction machines tested in 2010	15064	18616	22957	20562	23942	25141	24360	18277	25556	23054	24511	18118	260158

3. FAULT DIAGNOSIS AND GRAPHICAL ANALYSIS

3.1 The stator faults and graphical analysis.

In the production line, the first step is the fault control before stator impregnation.

Table 2. Stator fault types

Critical faults	Main faults	Secondary faults
phase-earth breakdown	incorrect sizes	improper wire connection
phase to phase breakdown	turns out of the head coil	
wrong links	incorrect insulation	
different resistance per phase	improper welding	

Table 3. Total tested stators

Months	1	2	3	4	5	6	7	8	9	10	11	12	Total
Stators tested in 2010	16617	20109	24428	20817	25414	25681	24234	19827	27012	22843	25916	16487	269385

Table 4. Total stator faults in 2010

Faults \ Months	1	2	3	4	5	6	7	8	9	10	11	12
phase-earth breakdown	133	160	199	214	318	418	379	226	376	289	342	191
phase to phase breakdown	76	95	122	204	272	410	319	271	354	279	292	234
wrong links	2	10	20	12	17	21	15	3	16	7	10	3
different resistance per phase	30	11	24	38	18	20	35	17	24	10	25	16
incorrect sizes	46	79	104	104	163	184	159	112	246	145	254	90
turns out of the head coil	24	32	62	63	110	88	63	41	96	72	111	33
incorrect insulation	119	137	173	178	392	366	316	248	362	286	369	198
improper welding	47	55	86	86	115	162	178	94	136	182	95	80
improper wire connection	36	26	68	62	65	43	62	51	71	81	57	48
Total stator faults	513	605	858	961	1470	1712	1526	1063	1681	1351	1555	893

a) Critical faults (Fig.1, Fig.2)

1) Phase-earth breakdown: destruction of electrical insulation, which leads to direct contact between one phase stator winding and stator package (consisting of electrical sheets).

The fault appears in the following:
- coil head formation process, when insulation is subjected to shear stator teeth with the outermost stator laminations;
- nonlinearity stator lamination of the package;
- core insulation damage during winding.

2) Phase to phase breakdown: wrong layout (winder inattention) of the coil head insulation of stator winding phases.

The fault appears in the following:
- coil head formation process when the insulation between phases can be moved quite easily;
- core insulation damage during winding.

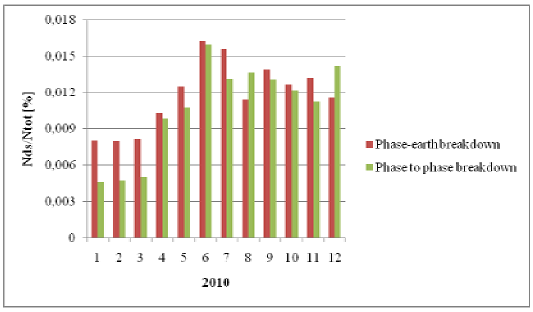

Fig.1. Phase-earth breakdown and phase to phase breakdown

N_{ds}/N_{tot} represents the percentage ratio between the number of stator faults and the total number of stators monitored each month.

Fault increase in June and July may be due to low power stator production; the head of the coil being formed with difficulty, leading to insulation shearing. Other reasons are the small size of the insulation between phases or the hitting of the conductors during the head coil forming.

3) Wrong links:

This fault appears in the following:
- lack of the employee's information upon the change of the winding scheme;
- careless welding process for series-connected coils per phase;
- careless seales in the connection conductors (colour code compliance).

4) Different resistance per phase

The fault appears in the following:
- failure to record the number of turns required on the windings;
- wrong links.

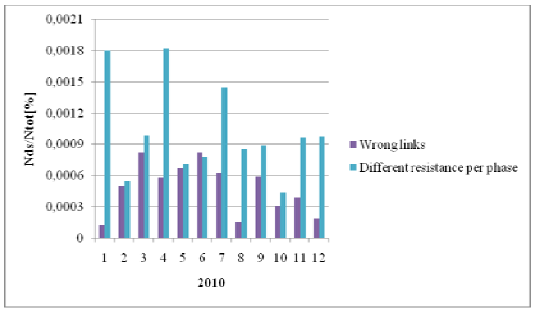

Fig.2. Wrong links and different resistance per phase

Varied types of stator fabrication and their quantity may be a cause of fault growth for wrong links. Introducing, on the manufacturing line, certain types of stators whose characteristics (voltage, resistance, number of turns) change, may influence the growth of a different resistance per phase fault type.

b) Main faults (Fig.3)

1) Incorrect sizes

This fault appears in the following:
- manufacture or misuse of templates specific to each phase coil;
- poor adjustment of the head coil device forming.

2) Turns out of the head coil

This fault appears in the following:
- stator winding;
- isolation between phases;
- head coil binding;

- head coil forming.

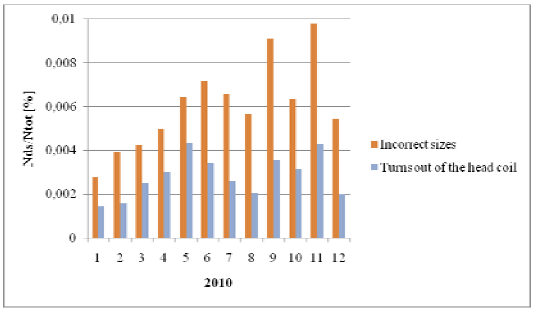

Fig.3. Incorrect sizes and turns out of the head coil

3) Incorrect insulation

This fault appears in the following:

- inadequate insulation settlement of the stator phases in the head coil;
- inadequate insulation settlement between coil phases;
- nonlinearity insulation feathers;
- bending under the insulation failure;
- uneven tightening of the head coil.

4) Improper welding

This fault appears in the following:

- welding for series-connected coils per phase;
- welding wire connection.

c) Secondary faults (Fig.4)

1) Improper wire connection

This fault appears in the following:

- welding wrong connection conductors;
- failure of connection wire colour code.

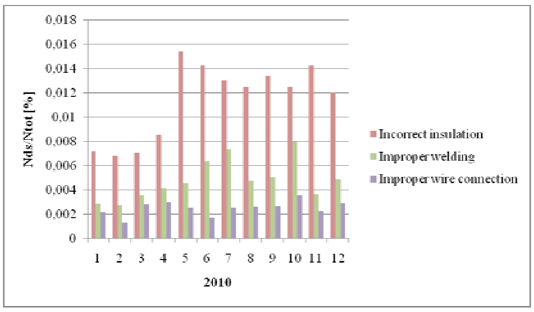

Fig. 4. Incorrect insulation, improper welding and improper wire connection

3.2 Motor faults and graphical analysis. Next, stator control on the production line takes place after motor mounting.

Table 5. Fault types after motor testing

Critical faults	Main faults	Secondary faults
breakdowns	Io; Po; Ik; Pk; DPC	axial clearance
interrupted phase	vibration	manufacturing poor quality
blocked bearing	friction	
wrong links	bearing noise	
starting torque	electromagnetic noise	
winding smoke	clockwise rotation	

Table 6. Total motor faults in 2010

Faults \ Months	1	2	3	4	5	6	7	8	9	10	11	12
breakdown	235	223	313	225	262	319	309	236	321	297	356	226
interrupted phase	71	74	64	84	49	92	74	70	133	135	114	111
Io; Po; Ik; Pk; DPC	62	75	75	39	88	125	137	60	127	165	96	110
eccencentry	286	300	376	344	371	377	373	278	378	377	465	331
bearing noise	79	103	92	59	76	87	114	70	126	97	96	23
electromagnetic noise	37	44	20	12	6	46	43	39	43	31	27	26
manufacturing	0	23	22	37	20	19	30	20	0	71	58	28
Total faults	770	842	962	800	872	1065	1080	773	1128	1173	1212	855

a) Critical faults (Fig.5)

1) Breakdowns (phase-earth, phase to phase): destruction of electrical insulation and wrong layout (winder inattention) of the coil head insulation of stator winding phases.

2) Interrupted phase: the electromagnetic circuit is broken.

3) Blocked bearing: incorrect installation, unbalanced voltage supply, overheating, impure oil lubrication.

4) Wrong links: impurities, excessive vibration.

5) Starting torque: broken rotor bar or defective bearings.

6) Winding smoke: conductor insulation damage (email terephthalic in single or double layer).

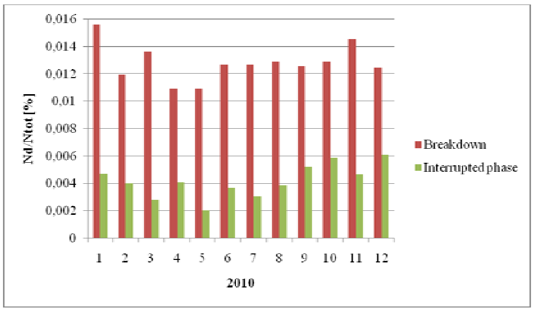

Fig. 5. Breakdown and interrupted phase

N_d/N_{tot} represents the percentage ratio between the number of motor faults and the total number of motors monitored each month.

Faults due to the insulation breakdown, even after impregnating the stator, are in a quite high percentage. These faults are due to the collision of the stator insulation during transportation or in frame pressing.

b) Main faults (Fig.6, Fig.7)

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1) Io; Po; Ik; Pk; DPC (different phase current): failure to comply with the limits imposed by the laboratory diagram.
2) Vibration: bearing game, unbalanced voltage, overload, wrong installation, rotor fault.
3) Friction: eccentricity, rotor insulation touches.

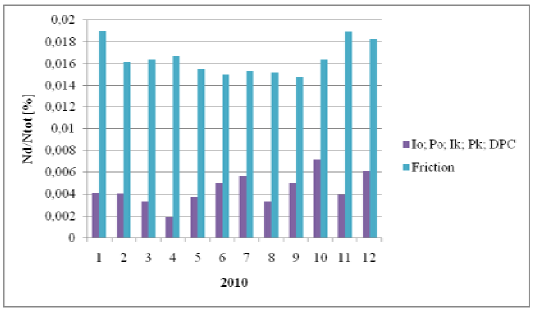

Fig. 6. Io, Po, Ik, Pk, DPC and friction

4) Bearing noise: wrong installation, lack of lubrication, impure oil, overload.
5) Electromagnetic noise: rotor bar inclination angle, uneven winding scheme (higher harmonics).
6) Clockwise rotation: wrong connection links.
c) Secondary faults
1) Axial clearance: wrong installation.
2) Manufacturing: broken ribs, inappropriate paint.

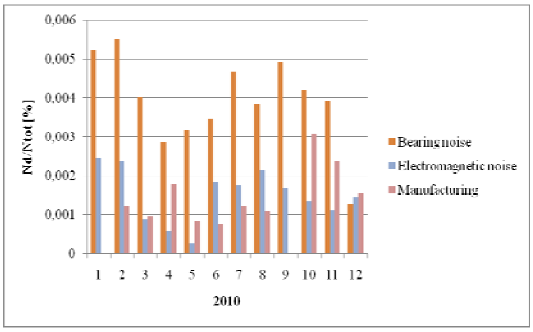

Fig. 7. Bearing noise, electromagnetic noise and manufacturing

The listed faults have the following symptoms:
- voltages and currents of air-gap line are unbalanced;
- increased torque pulsations;
- induction machine torque decreased;
- increased losses and reduced efficiency;
- excessive heat;
- excessive vibration;
- noise.

Through failure analysis on the production line, an action plan has been established for reducing the number of faults:
- investigation of the possibility of using new insulating materials, more resistant to the action of technological factors. A solution to reduce faults due to the insulation system is to improve the quality of the insulating materials and treatment processes;
- development of new testing methods;
- implementation of monitoring procedures, which are placed in new positions for verification.

In Fig. 8 the process for fabricating improved induction machines is illustrated.

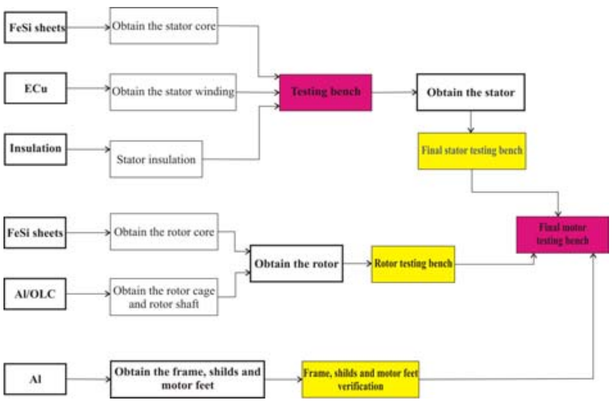

Fig.8. Improved manufacturing line of induction machine

For the execution of induction motor control, only two banks existed (indicated in red) despite which, as presented in graphical analysis, regardless of motor speed and power, there manifest a lot of defects without being able to find their early appearance.

Through the introduction of three control benches (indicated in yellow) on the technological line, manufacturing faults are reduced. In the first control bench, before stator impregnation, a device was introduced for checking the direction of magnetic field rotation.

At the final testing of the stator, insulation faults can be detected. Rotor verification after manufacturing reduces the types of defects and the electromagnetic noise due to the angle bar inclination. Paint defects, broken ribs can be prevented by the introduction of the third control bench, after frame, shields, and feet production.

4. CONCLUSIONS

Insulation systems used in the construction of induction machines are still the main factor in the breakdown of the manufacture process. They must fall into the class of insulation for which the motor is manufactured, so as to be the best in terms of quality and to withstand electro-mechanical actions.

If the human intervention in the manufacturing process is reduced, the percentage of failures occurring in the induction machine is lower. This implies the mechanization and automation of all stages of the manufacturing technology process and the introduction of new methods and new control benches for monitoring the induction machines faults. Knowing the faults since the design stage and monitoring the manufacturing technology process can reduce the induction machine damage, with obvious effects on the maintenance costs.

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