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ANALYSIS OF VIBRATIONS IN CORELATION WITH FAULTS OF ELECTRICAL MACHINES USED IN HIBRIDID AND ELECTRICAL VECHICLES

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Abstract: *In the actual conditions of the energy and raw materials crisis, new efforts are made for increasing the performances of technical systems. In this framework, the reduction of the electrical motors vibrations used in hybrid and electrical vehicle is a way for increasing the lifetime and efficiency. The paper deals with an analysis of electrical machines faults in correlation with the vibration spectrum. Experimental tests on three types of induction motors with the speed of 1000 r.p.m., 1500 r.p.m. and 3000 r.p.m. with free suspension have been done. The vibration transducers of type accelerometers in combination with PULSE 12 platform have been used to measure the amplitudes of vibrations on the vertical, axial and perpendicular plan directions. Using the analysis in the frequency domain, the amplitudes of acceleration of the vibrations in the three directions in conformity with the regulation IEC 60034-14 have been established. The comparison with the literature data allowed identifying vibration sources, useful for the designers and manufacturers in diminishing the frequency of the induction machines defects.*

Keywords: *vibration measurement, FFT, vibrations diagnosis, induction motors, faults*

1. INTRODUCTION

The induction motors, built in a very large range of power (from units of W to tens MW), with supply of low voltage (up to 500V) or medium voltages (3 kV, 6 kV or 10 kV), and with the synchronism speed of 500, 600, 750, 1000, 1500 or 3000 rot/min, have a multitude of electrical drives of the industrial sector: machine tools, pumps, compressors, medical equipment, household equipment. Many actual researches on extending the applications of electrical machines in general and induction machines in hybrid and electrical vehicles have been done [1].

The condition diagnosis of the induction machines is focused on tracking and analyzing both the electric and the mechanical components. The mechanical components are the most important source for the development of the mechanical vibrations during the functioning [2].

The causes of vibrations in the induction machine are multiple, among them there can be mentioned: the precision of execution and assemblage of the different component elements, the magnetic forces developed during the functioning, the wear of the bearings, of the bushing [3].

An analysis of faults types and determinations of the level of the vibrations for a set of inductions machines with different rotative speeds are useful. The verification of the compliance with the product standards, the development of simple and efficient methods for the control of the level of vibrations, the localization of the faults and the analysis of the influence of the rotative speed upon the level of vibrations are useful for designers and manufactures of induction motor and extension of their applications.

2. FAULT ANALYSES

The induction motor is considered a robust and tolerant machine, being a good choosing for applications. However, the specific on-line monitoring of all variables of this type of machine is necessary. The causes of

induction motors faults and failures have the origin in design, tolerance of manufacturing, assembling, installing, functional environment, load nature, planning of maintenance.
Because the induction motor is stressed by electromagnetic and mechanical forces, two categories of motor faults should be distinguished [2], [3]. The motor faults can be internal (Figure 1) and external (Figure 2).

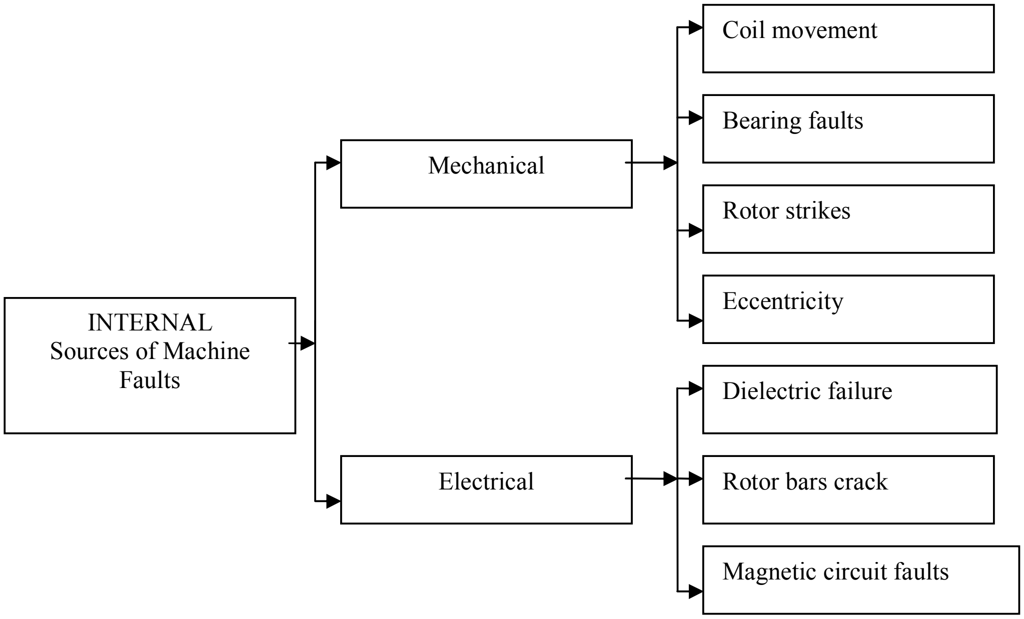

Figure 1: Induction motor internal fault sources

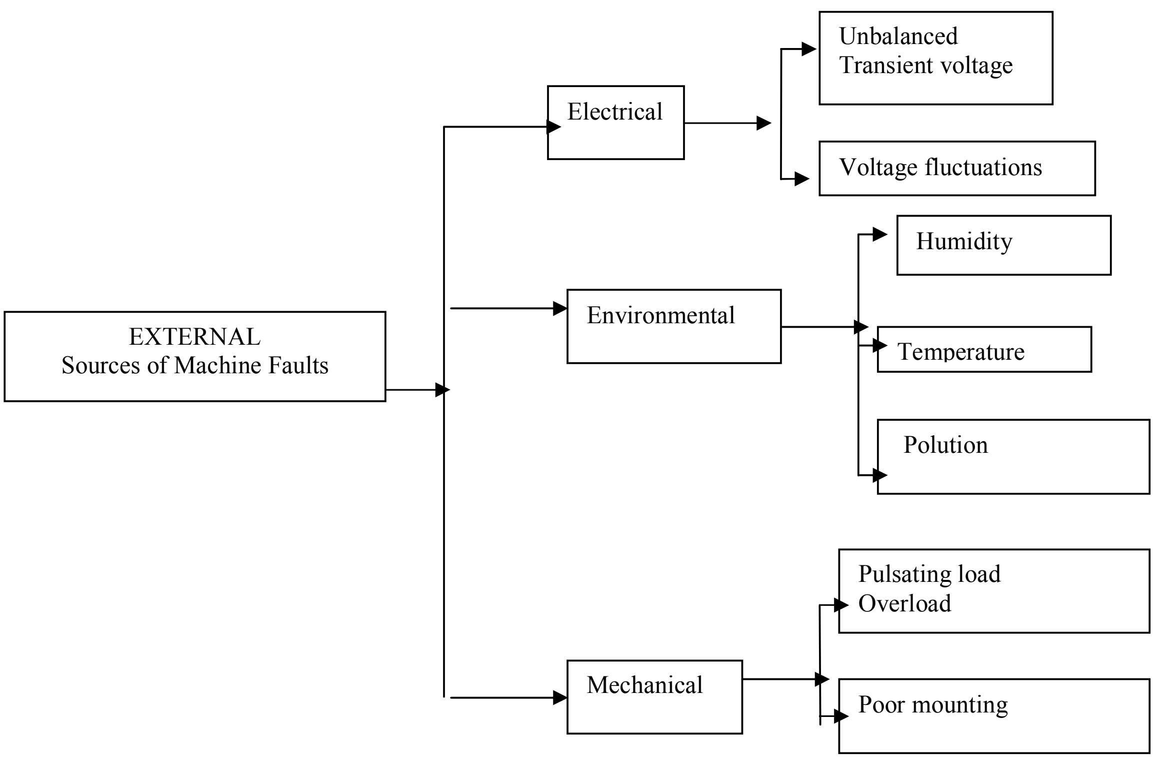

Figure 2: Induction motor external fault sources

The internal faults should be classified referring to their origin, in electrical and mechanical, in function of their location, in stator or rotor. Usually, other types of failures – faults of bearing and cooling system are considered to be included in the category of rotor faults belonging to the mobile part of motor.
Figure 3 and Figure 4 show the tree of motor faults, classify with the criterion of location: stator and rotor.

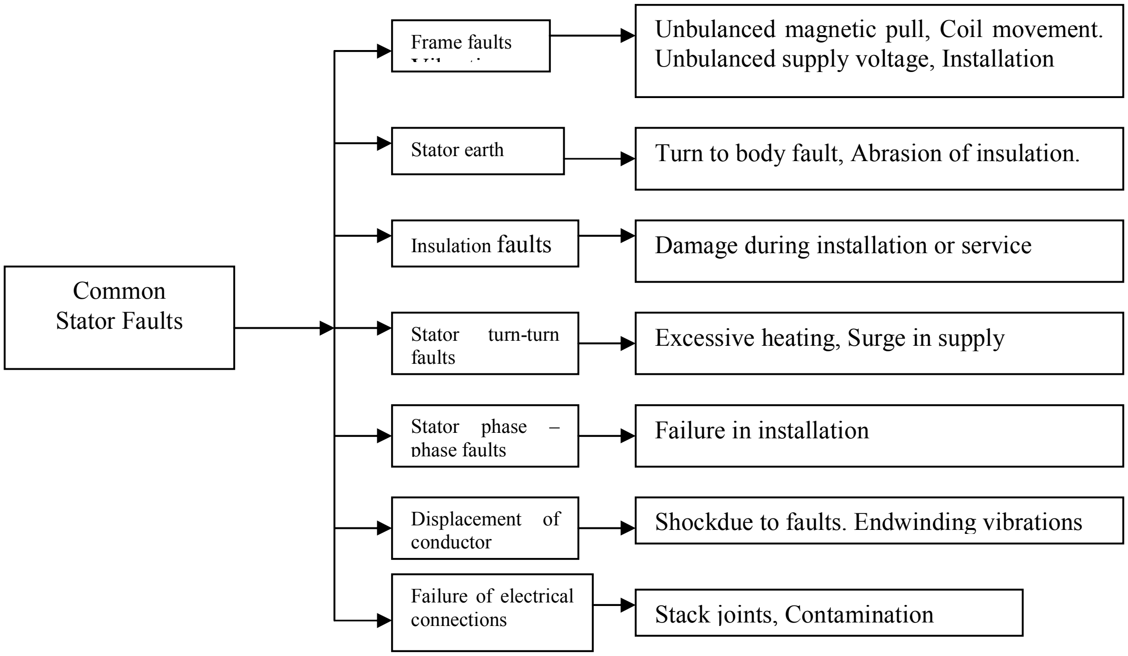

Figure 3: Internal mechanical faults in induction motor

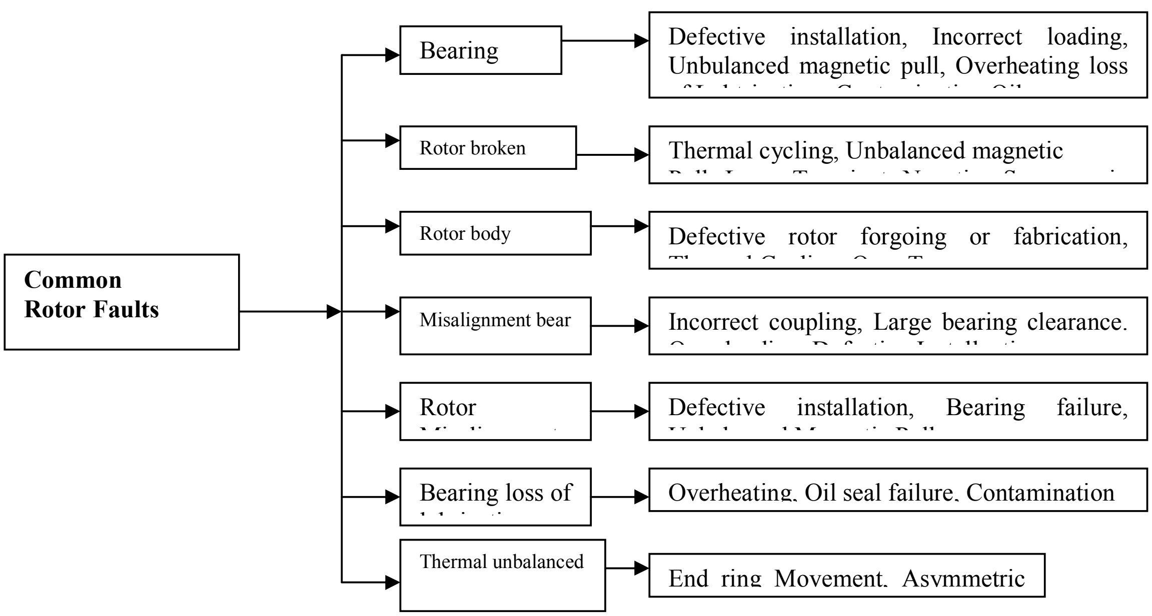

Figure 4: External electrical faults in induction motor

The electrical and mechanical faults are the most important sources for the development of the mechanical vibrations in induction motor. Specific experimental measurement of induction motor vibrations should identify the possible types of faults.

3. EXPERIMENTAL DETERMINATIONS

The experimental determinations of the vibration levels have been done on three types of induction motors of 1.5 kW, and speed of 1000, 1500, 3000 r.p.m. The motors, with free suspension, were supplied at 3x400 V without loading. The vibration measurement method was in conformity with ISO 2945, ISO/DIN 10817-1 regulations and Romanian standards [4]-[6].

The measurement set-up contains the vibration transducers, PULSE 12 platform connected through LAN to a PC (Figure 5). The transducers are assembled in the measuring areas in compliance with the manufacturer's specifications, the assemblage being done so as not to perturb the vibration conditions of the tested equipment (Figure 6).

Figure 5: Set-up for vibration measurement

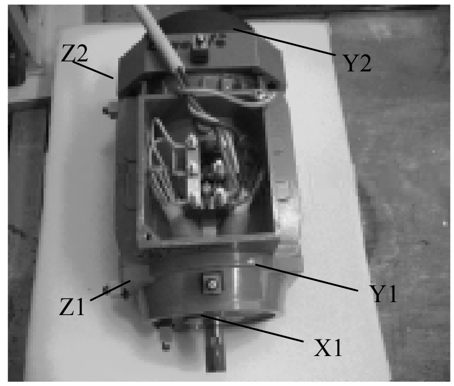

Figure 6: Transducers mounted on induction motor

The processing and the analysis of the recorded signals were carried out with a series of software, production Brüel&Kjaer: soft analysis FFT type 7770-6, soft data acquisition type 7705 and soft data processing type 7709 [7]. The data acquisition was achieved through the software LabShop v.12.0 associated to PULSE 12 platform. The main phases unfolded during the measurement preparation and unfolding were: defining the acceleration transducers, allotting to these transducers the indicatives X1, Y1, Z1, Y2 and Z2 (the Fig.6), grouping the accelerometers in three groups of signals, choosing the type of signal analysis in the field time and in the field frequency - and defining the visualization functions of the recorded signals. In view of obtaining a sufficiently high precision, the same sampling rate 400 ms for all three types of motors has been chosen, there being considered the maximum level of the measured frequencies of 1600 Hz.

4. RECORDED RESULTS

The analysis in the frequency domain was achieved, in parallel with the analysis in the time domain. Some results obtained for induction motor with speed of 1000 r.p.m., free suspension, non-loaded are shown in Figures 7 and 8.

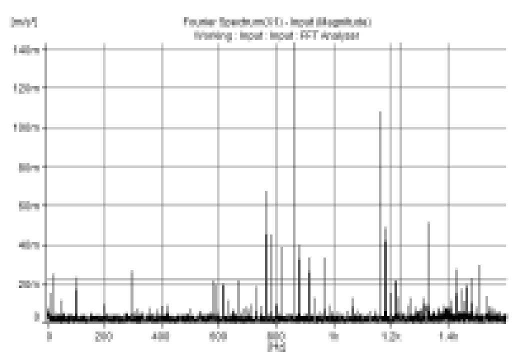

Figure 7: Analysis in the frequency domain of the signal X1

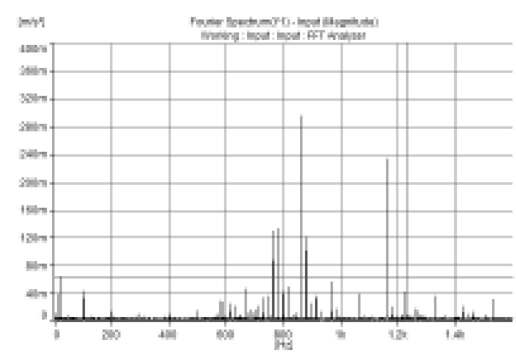

Figure 8: Analysis in the frequency domain of the signal Y1

The analysis of registered signals in time domain and frequency domain sows that in front part of motor on horizontal direction (X1) the highest amplitude of vibrations is produced in comparison with vibrations on the other directions.
The results of measurements for the induction motors with speed of 1500 r.p.m and 3000 r.p.m. shows that in front part of motor on (Z1) direction the highest amplitude of vibrations is produced in comparison with vibrations on the other directions.
The vibration acceleration amplitudes in the five measured points of 1000 r.p.m. inducton motor sample are presented in Table 1.

Table 1: A synthesis of the amplitude of measured vibration accelerations for the 1000 r.p.m. induction machine in measured five points

Frequency [Hz]	Amplitude of measured vibration accelerations [mm/s^2]				
	X1	Y1	Z1	Y2	Z2
16,75	24,80	57,00	17,00	52,40	40,70
580,50	15,70	22,20	20,70	29,40	27,50
664,00	21,20	46,80	9,17	45,70	2,31
730,10	18,10	32,90	16,40	48,30	17,60
764,00	66,90	129,00	41,50	108,00	99,70
780,50	45,00	133,00	51,60	163,00	99,20
813,70	38,00	49,20	36,50	88,20	45,90
864,00	143,00	295,00	256,00	106,00	32,80
880,50	39,00	120,00	127,00	190,00	205,00
913,70	33,00	35,70	24,50	37,40	28,40
964,00	32,90	56,00	55,40	18,30	14,40
1064,00	12,5	38,50	20,80	1,38	2,09
1164,00	108,00	233,00	225,00	37,40	24,20

Table 1 shows the folowing aspects: for the frequencies of 764,0 Hz, 864,0 Hz, 880,5 Hz, 1164,0 Hz, the highist amplitude of vibration accelerations are produced; for the frequency of 1164 Hz the high values of vibration acceleration amplitudes on X1, Y1 and Z1 are also produced; over 1 kHz the higher values are obtained for axiale vibrations (X1 direction) but of low values.
The vibration acceleration amplitudes in the measured five points of the 1500 r.p.m. inducton motor sample are presented in Table 2.

Table 2: A synthesis of the amplitude of measured vibration accelerations for the 1500 r.p.m. induction machine in measured five points

Frequency [Hz]	Amplitude of measured vibration accelerations [mm/s^2]				
	X1		X1		X1
25,00	28,40	48,70	65,40	71,90	25,30
100,00	4,72	29,80	8,37	14,60	29,10
573,50	57,1	45,00	34,6	29,60	39,80
598,20	29,50	23,60	10,20	16,50	22,70
623,20	46,80	40,1	29,40	22,40	43,90
647,50	145,00	109,00	127,00	84,00	128,00
747,50	44,50	31,90	43,80	34,80	18,60
847,50	98,00	7,23	149,00	141,00	59,90
872,50	184,00	153,00	214,00	186,00	130,00
947,50	50,70	52,60	58,60	49,80	25,00
1172,00	131,00	64,70	63,40	64,20	71,10

Table 2 shows the folowing aspects: on Z1 direction a strong vibrational movement is founded; for the frequencies of 647,50 Hz, 847,50 Hz, and 872,50 Hz; the highist values of vibration accelerations are produced; over 1172 Hz the higher values are obtained for X1 direction but of low values; the highist values of vibrations are produced at 872,50 Hz through all directions.

The vibration acceleration amplitudes in the measured five points of the 3000 r.p.m. inducton motor sample are presented in Table 3.

Table 3: A synthesis of the amplitude of measured vibration accelerations for the 3000 r.p.m. induction machine in measured five points

Frequency [Hz]	Amplitude of measured vibration accelerations [mm/s^2]				
	X1		X1		X1
50,00	225,00	921,00	886,00	314,00	293,00
100,00	29,40	35,90	15,80	62,6	68,80
491,50	315,00	16,8	302,00	28,80	51,10
847,20	204,00	75,90	70,40	34,30	34,90
897,00	224,00	75,40	201,00	72,80	107,00
933,20	194,00	70,60	28,00	29,70	15,90
947,00	1840,00	618,00	577,00	286,00	308,00
973,20	132,00	41,70	58,40	16,60	25,10
997,50	765,00	193,00	141,00	213,00	137,00

Table 3 shows the folowing aspects: through all directions the highist values for amplitude of vibrational movement is founded for the frequencies of 50 Hz (corespunding to the synchronous speed of motor), 947,00 Hz and 997,50 Hz; over 1 kHz the axial vibrations are highist but at low levels.

5. CONCLUSIONS

In designing and implementation of new drives for hybrid and electric vehicles the induction motors have an important role. Even if the induction motor is considered robust the vibration motion monitoring is useful.
The main sources of vibrations are different types of faults determined by the imprecision of execution and assemblage of the different component elements, by the magnetic forces developed during the functioning, the wear of the bearings, by overheating etc.
The experimental tests on three types of induction motors with the speed of 1000 r.p.m., 1500 r.p.m. and 3000 r.p.m. with free suspension have been proposed to measure the amplitudes of vibrations on the vertical, axial and perpendicular plan directions. The analysis in the frequency domain shows the high values of vibration movement acceleration which are in connection with possible faults and electromagnetic and mechanical force actions.

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