Vibrations Influence on the MS-1 N-8811 Permanent Magnet Synchronous Motors Reliability

Dan IUDEAN and Radu MUNTEANU jr.

Abstract - *This article has the purpose to estimate statistically the vibrations influence on the MS-1 N-8811 permanent magnet synchronous motors reliability and the working probability for a batch of ten permanent magnet synchronous motors of this type working properly and the faulted. The reliability calculation of ten permanent magnet synchronous motors was realized. To determine the vibrations and reliability parameters, the electric motors were tested in laboratory conditions.*

Index terms: Reliability; Reliability indicators; Vibrations, Electric motors

1. INTRODUCTION

The statistical estimation of the working probability [1] without fault is being realized starting from the background that the motors which break down are neither repaired nor replaced. This statistical estimation is given by the formula [2] [3]:

$$R(t) = \frac{N_0 - n(t)}{N_0} \tag{1}$$

where:

- N_0 represents the number of the motors at the beginning of the test;
- $n(t)$ represent the number of the deteriorated motors within time t.

The malfunction probability of the electric motor is given by the relation:

$$Q(t) = 1 - R(t) \tag{2}$$

The failure rate is marked with $\lambda(t)$ [4]. This represents the malfunction probability of an electric motor per unit time, after a predetermined time moment. The statistic estimation of the failure rate is given by the formula [1][6][10]:

$$\lambda(t) = \frac{n(t)}{\Delta t N_{med}} \tag{3}$$

where $n(t)$ represents the number of motors which broke down within a time period Δt, and N_{med} represents the average number of motors which are functioning within time period Δt.

The failure rate is equal to faults appearance probability related to the good functioning probability [1][10][14]:

$$\lambda(t) = \frac{dQ(t)/dt}{R(t)} \tag{4}$$

Thus, the failure rate for a normal functioning period of the motor could be considered constant, $\lambda = ct$. According to probability theory, the random faults are distributed exponentially. The intensity of these random faults is time-independent. In this case, the probability of functioning without fault is given by the formula [2][3]:

$$R(t) = e^{-\lambda t} \tag{5}$$

The average functioning time without fault is marked with t_{med}. The statistical estimation of this good functioning average time is given by the formula:

$$t_{med} = \frac{1}{N_0} \sum_{i=1}^{N_0} t_{ti} \tag{6}$$

where t_{ti} represents the time functioning without fault of a motor i (MTTF).

From a mathematical point of view, the good average functioning time represents the estimated functioning without a fault of a motor [7][10]:

$$t_{med} = \int_0^\infty R(t)dt \tag{7}$$

This defines an average period of time between the functioning start and the first fault. Considering $\lambda = ct.$ the average time of good functioning is equal to $t_{med} = \frac{1}{\lambda}$, this is also characterizing the good functioning average time between two faults (MTBF).

Manuscript received August 25, 2012.

2. REDUCING NOISES AND VIBRATIONS FOR PERMANENT MAGNET SYNCHRONOUS MOTORS IN ORDER TO IMPROVE RELIABILITY

Noises of mechanical and aerodynamic origin are louder than those that have an electromagnetic origin inside continuous current motors. Brushes are one of the major sources of noise.

Vibrations and noises of mechanical origin have a much higher level than those of electromagnetic origin in case of synchronous motors.

The noise of mechanical origin can be reduced realizing a prediction on natural functioning frequencies, on optimal selection of the constituent materials and on the proper assembly of the bearings and the engine mounting system from the designer point of view.

The aerodynamic noise can be reduced by an optimal selection of the number of cooling fan blades, the number of rotor notches and the channels ventilation form taking into consideration to minimize the siren effect.

The electromagnetic noise can be reduced by an adequate selection of the number of notches (reducing the parasitic radial forces and the torque pulsation), the electromagnetic loads, and the number of notches and maintain the same impedance winding phases.

The most reliable, rich in information and simple method is to monitor the input current, vibrations and the axial flow. Accelerometers and vibration pick-ups must be installed to monitor vibrations (considering their low cost).

Monitoring techniques are based on measurements in the time domain and frequency domain.

The most frequently faults that can be seized by a vibration monitoring of the constant magnet electric motors are:

- The mechanical unbalance of the rotor or eccentricity characterized by a sinusoidal vibration having the frequency of one per rotation (number of rotations per second);
- Faults of the bearings having results in frequency depending on the type of fault
- Bearing lubrication problem characterized by a sinusoidal from 0.43 Hz up to 0.48 Hz of the number of revolutions per second;
- Frictions characterized by an equal vibration frequency or a multiple of the number of rotations per second;
- Thermal imbalance having as a result a change in vibrations amplitude as the motor warms.

TABLE I. Technical characteristics of the motor.

Frequency (Hz)	50
Rated voltage (V)	220
Maximum sink current (mA)	21
Coil resistance (Ω) ±5%	5000
Pull-out torque (Nm)	$5{,}88 \times 10^{-3}$
Breakaway torque (Nm)	$3{,}13 \times 10^{-3}$
Admitted peak torque (Nm)	$1{,}7 \times 10^{-3}$
Rated speed (rpm)	600
Apparent power (VA)	4,2
Real power (W)	3,7

TABLE II. Motor functioning conditions.

Functioning position	indifferent
Mode	continuous or intermittent
Operating mode	5 years
Normal period of operation	-10°C...+60°C
Relative humidity	max. 85% la +25°C
Over temperature	70°C
Without electric conductor powders and without active agents from a chemical point of view	

2.1. Tests to determine reliability indicators for ten motors

In order to determine reliability parameters of the motors, a number of ten motors were electrically tested. The test conditions were the following:

- Loading: no-load running;
- Electric supply at 220V, 50Hz, in continuous running;
- Normal climate (tests were realized in laboratory); temperature from 15°C to 30°C, relative humidity 40-80%
- Throughout the tests, the accurate operation of the motors was followed, measurements being made at every 300 hours of functioning.

The functional parameters of the motor on which measurements were made were the sink current and rotation speed. The following experimental data were achieved and are presented in table III.

TABLE III. The sink current and the rotation speed for the 1800 hours of functioning.

t (h)	0		300		600		900		1200		1500		1800	
	I (mA)	T (rpm)	I (mA)	T (rpm)	I (mA)	T (rpm)	I (mA)	T (rpm)	I (mA)	T (rpm)	I (mA)	T (rpm)	I (mA)	T (rpm)
Motorul 1	19	597	19,1	597	19	598	19	598	19,1	598	19	598	19	598
Motorul 2	18,8	597	18,8	598	18,8	597	18,8	598	18,5	597	18,8	598	18,7	598
Motorul 3	20,7	598	21	598	20,5	598	20,3	599	20,3	598	20,1	598	20	600
Motorul 4	18,7	597	19	597	18,3	597	18,7	597	18,5	597	18,3	597	18,5	597
Motorul 5	18,7	598	18,8	598	18,5	598	18,8	598	18,7	598	18,7	598	19	598
Motorul 6	19,7	597	19,5	597	19,5	597	19,3	596	19,5	596	19,5	595	19,7	595
Motorul 7	19,7	598	19,5	598	19,5	598	19,7	598	19,3	598	19,2	598	19,5	598
Motorul 8	17,7	598	17,7	598	17,7	598	18	598	17,8	597	17,7	597	17,7	597
Motorul 9	17,8	597	18	598	18,3	597	18	597	18,3	597	18,3	597	18,2	597
Motorul 10	18,8	598	19	598	19,3	598	19	598	19,5	598	19,3	597	19,5	598

The reliability indicators were determined in these conditions:

- The number of elements in testing: $n = 10$ motors;
- The number of malfunctions reported: $c = 1$
- Total test time: $t = 1800$ hours
- The confidence level of determination: $p^* = 0{,}9$.

The exponential partition law and Weibull distribution law were used to analyze and to statistically process the results.

The attestation of the reliability indicators is subject to the following malfunction criteria:

- Total malfunctions: burning coil, blockings, part damages, etc.
- Functional parameters modification: failure due to the torque value given by the technical specifications.

After 1800 hours of operation, it was ascertained that the tested motors present a good functioning stability by keeping the revolution per minute and the current in acceptable limits, presenting revolution per minute variations $-0,3\%..-0,5\%$ and maximum sink current -4mA. During the 1800 hours of operation, a single fault has been reported on the ten samples tested at the last measurement referred to 1800 hours of functioning and it consisted in a perceptible weak noise in the motor reduction.

We've found a pronounced wear of the bearings after the motor trip. The wearing degree isn't uniform on all six bearings. This increases progressively till the bearing on the arbor. Here, the defect is maximum, catastrophic.

After the other motors tests, we find a weak wear of the bearings which is due to the wearing after 1800 hours of functioning in the stationary regime duty operating mode.

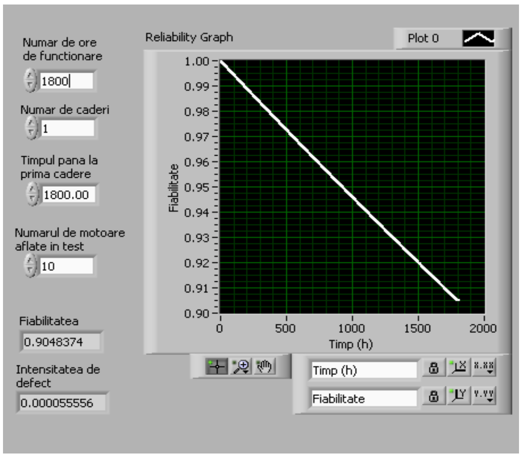
In terms of the fault discovered after 1800 hours of functioning, it is considered to be an accidental fault.

The fractional-power motors showed no electrical or mechanical faults after 1800 hours of functioning.

2.2. Ten motors reliability calculation

To calculate the reliability, the lot of ten motors was stressed in idle mode.

Measurements were made at every 300 hours of functioning. The exponential distribution law was used to analyze and statistically process the obtained results. During 1800 hours of functioning, on the ten tested samples, a single fault detected at the last measurement was signaled. Thus, a virtual Lab View instrument was realized to calculate the reliability and the fault rate of the ten motors lot taking into account the results obtained in practice.



Numar de ore de functionare: 1800

Numar de caderi: 1

Timpul pana la prima cadere: 1800.00

Numarul de motoare aflate in test: 10

Fiabilitatea: 0.9048374

Intensitatea de defect: 0.000055556

Fig. 1. Reliability calculus of the ten motors batch.

As it can be seen, going from the experimental data obtained, the reliability obtained for the whole lot of ten motors is very close to the analytically calculated reliability for a single motor. Thus, considering the construction data given by the manufacturer, the analytical calculation method of the motor's reliability is validated.

TABLE IV. A single motor reliability, calculated from the practical data obtained and the reliability of a motor, analytical calculated.

Reliability calculus mode	Analytical – using data given by the manufacturer	Practical – using data obtained from the ten motors lot
Reliability	0,9199631	0,9048374

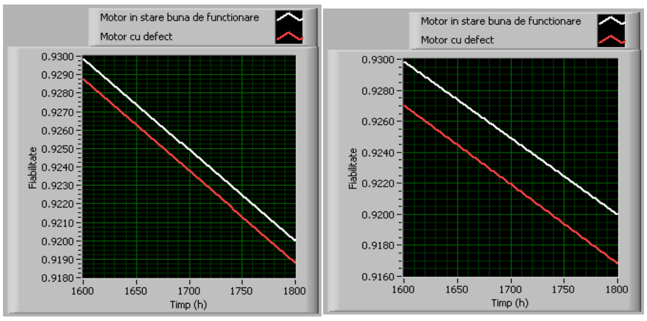
2.3. The vibration influence over the motor's reliability

To calculate the influence of vibrations over the motor's reliability, the practical results obtained from the tested motors are taken into consideration [12][14]. Thus, we can follow the evolution of forces that produce these vibrations. Comparing the motor in fault state, the reliability of the motor in good functioning state is calculated, replacing this coefficient with its new value that depends on vibrations.

The faults taken into consideration are:

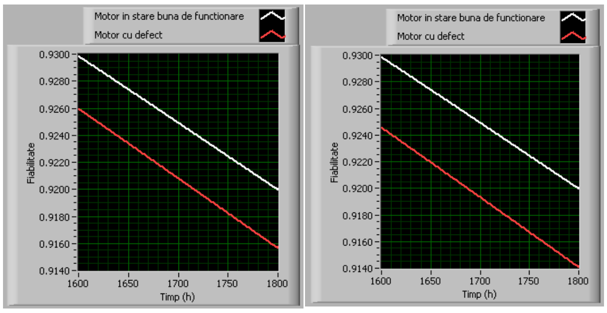
- cracks in stator, rotor and motor teeth;
- material faults in stator, rotor and motor teeth;
- eccentricity.

The results are shown in the next figures:



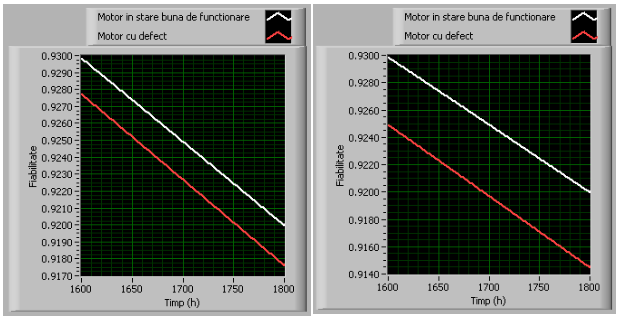
a)

Fig. 2. Good functioning state reliability motor compared with the reliability of the motor that has cracks in stator: **a)** calculated reliability for minimum level of vibrations obtained in this case; **b)** calculated reliability for maximum level of vibrations obtained in this case.



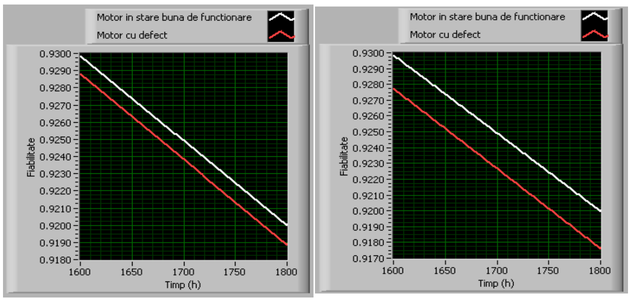
a)

Fig. 3. Good functioning state reliability motor compared with the reliability of the motor that has cracks in rotor: **a)** calculated reliability for minimum level of vibrations obtained in this case; **b)** calculated reliability for maximum level of vibrations obtained in this case.



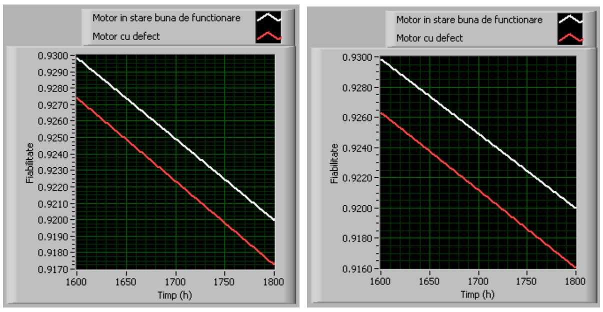
a)

Fig. 4. Good functioning state reliability motor compared with the reliability of the motor that has cracks in teeth: **a)** calculated reliability for minimum level of vibrations obtained in this case; **b)** calculated reliability for maximum level of vibrations obtained in this case.



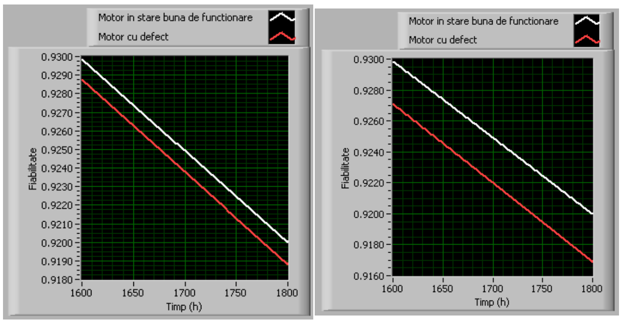
a)

Fig. 5. Good functioning state reliability motor compared with the reliability of the motor that has material faults in stator: **a)** calculated reliability for minimum level of vibrations obtained in this case; **b)** calculated reliability for maximum level of vibrations obtained in this case.



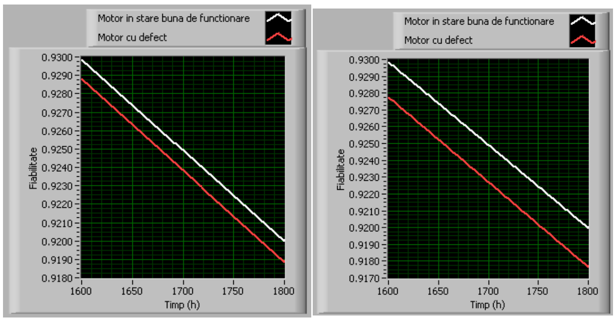
a)

Fig. 6. Good functioning state reliability motor compared with the reliability of the motor that has material faults in rotor: **a)** calculated reliability for minimum level of vibrations obtained in this case; **b)** calculated reliability for maximum level of vibrations obtained in this case.



a)

Fig. 7. Good functioning state reliability motor compared with the reliability of the motor that has material faults in teeth: **a)** calculated reliability for minimum level of vibrations obtained in this case; **b)** calculated reliability for maximum level of vibrations obtained in this case.



a)

Fig. 8. Good functioning state reliability motor compared with the reliability of the motor that has eccentric rotor: **a)** calculated reliability for minimum level of vibrations obtained in this case; **b)** calculated reliability for maximum level of vibrations obtained in this case.

3. CONCLUSIONS

The present study shows that the reliability decreases with the vibrations increasing.

Having considered that reliability is calculated with exponential distribution method, we could estimate a difference that rises exponentially between motor's reliability in good functioning state and faulty motor. By the time passing, this difference rises and the two reliabilities have different features.

REFERENCES

1. GIERAS, J.F., Wing, M. – "Permanent Magnet Motor Technology", University of Cape Town, South Africa, 1997.
2. Birolini, A., "Quality and Reliability of Technical Systems", Springer-Verlag Berlin Heidelberg, 2nd edition, 1997.
3. D. IUDEAN, R. Munteanu jr., R. Dragomirescu and M. Buzdugan „MS-1 N-8811 Permanent Magnet Synchronous Motor Reliability Calculation", 4th International Conference on Modern Power Systems MPS 2011, 17-20 Mai 2011, Cluj-Napoca, Romania, pg. 233-236.
4. M.D. Iudean, "Reliability and Availability of Repairable Systems", D.A.A.D. Academy Ohrid, 2000.
5. LabVIEW Tutorial Manual, National Instruments, LabVIEW User Manual, vol 1&2, National Instruments.
6. MAGUREANU, R., Vasile, N. – "Motoare sincrone cu magneti permanenti si reluctanta variabila", Editura Tehnica, Bucuresti, 1982.
7. MOREL, J. – "Surveillance vibratoire et maintenance prédictive", par Ingénieur de l'École nationale supérieure de mécanique (ENSM), Ancien chef adjoint du Département surveillance diagnostic maintenance à EDF, Division recherches et développement.
8. HARRIS, M. C., Crede, C. E. – "Shock an Vibration Handbook – in three volumes", McGraw-Hill Book Company, New-York, 1961.
9. MUNTEANU, R., "Statistical Control and Reliability", Editura Didactica si Pedagogica, Bucuresti, 1982.
10. MUNTEANU, R., Rusu, T. – "Introducere in ingineria calitatii", Editura Mediamira, Cluj-Napoca, 2002.
11. NEELY, J. D. – "Fault Types and Reliability Estimates in Permanent Magnet AC Motors", Michigan State University, USA, 2005.
12. Iudean, M.D., Djerdir, A., Miraoui, A., "Induced Vibrations of an Eccentric Rotor for a Permanent Magnet Synchronous Machine", ELECTROMOTION, vol. XI, nr.4, 2004, pg.198-204
13. ROIVAINEN, J. "Determination of noise sources in an induction machine", ICEM 2000, Espoo Finland, pp. 1810-1814.
14. Traian Crețu, Dan IUDEAN**,** Lorand Szabo, Radu A. Munteanu – „Study on the Influences of Degraded Stator and Rotor Materials on PMSM Vibrations", The XXIV, microCAD

International Scientific Conference, 18-20 March 2010, Miskolc, Hungary, pg. 133-138.

Dan IUDEAN
Radu MUNTEANU jr.

Department of Electrical Engineering and Measurements
Faculty of Electrical Engineering
Technical University of Cluj-Napoca
25-26, Bariţiu st., Cluj-Napoca, Romania
E-mail: Dan.Iudean@ethm.utcluj.ro;
Radu.A.Munteanu@ethm.utcluj.ro