OPERATIONAL RELIABILITY ANALYSIS OF ASYNCHRONOUS MOTORS FROM “ZAHĂRUL„ ORADEA COMPANY

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Abstract: The paper presents the results of a operational reliability study, conducted on asynchronous motors of a power consumer, a company from city of Oradea S.C. “Zahărul”. The paper is structured in four parts. In the first part are presented some introductive elements regarding operational reliability. The second part presents, in fact, the actual phases of operational reliability study conducted. After a brief introduction of power consumer, the statistics from worksheets of the 586 asynchronous motors are the statistically processed. Here are calculated fundamental reliability indicators of asynchronous motors (ASM) and a causes of failure hierarchy of ASM is established, reported to its components. The results are presented graphically to make interpretation easy. In the last part of the paper are presented the conclusions of operational reliability study of ASM from considered power consumer.

Keywords: operational reliability, asynchronous motor, causes of failure, reliability indicators

1. INTRODUCTION

The knowledge of reliability indicators values of a system or system component is essential. Practically, all determination or analysis methods, of forecasted reliability starts from operational reliability values: average time for proper functioning and for maintenance (MTBF, MTM)„ failure rate (λ„), repairing rate (μ), of its component elements.

These values can be established or determined only by watching the considered system, in operation (or the components of considered system) or by conducting certain reliability tests, which are special laboratory tests with the purpose of establishing the above mentioned indicators values. Information thus obtained, regarding reliability of watched system or components of watched system are useful for both, beneficiaries, for maintenance optimization, and for manufacturers, in order to apply designing and manufacturing corrections. It is advisable that supplier, in order to obtain information, to select a number of important beneficiaries, on usage groups, operation conditions, maintenance type, etc. and to organize systematic and regular tracking of products behavior, gathering thus the recorder information.

There are two ways to obtain reliability indicators values [10]: through lab test (experimental reliability) or by tracking in operation (operational reliability).

Experimental reliability refers to experiments or lab tests, conducted in special conditions having the purpose to simulate the real operation conditions. Usually from these tests are obtained operation times of tested system or components of tested system.

Operational reliability (in operation) is determined in real operation conditions. Thus necessary data for reliability analysis (operation times, repairing times, number of defects) are taken directly from operation, tracking or maintenance sheets of tracked system. In case of some power equipments (power transformers, high power machines, medium and high voltage equipments, etc.) lab test are non-economic and tracking them in operation remains the only information source regarding reliability. Processing of data obtained by this way it’s done by the well known methodology [9], which actually it’s used on processing of data obtained from experimental reliability.

- The establishment of selection characteristics;
- Statistical estimation which can be done by one of the well known estimation methods, punctual or with confidence intervals [8, 11]. For ASM it can be applied, especially, punctual estimation methods: maximum plausibility method, method of moments, method of least squares, linearization method based on one of reliability variations laws exponential, Weibull and others;
- Statistical assumptions checking which can be done by one of the usually used tests: χ^2 test, Kolmogorov’s test, Wald’s test and others.

Asynchronous motors are major power consumers, having a important share within power consumers category, both by its number and by its power.

The study presented in this paper proposes the analysis of operational reliability of asynchronous motors and through this determination of its fundamental reliability indicators, completing so in a aught the know statistical data about asynchronous machines, respectively about its reliability. Data obtained in this study, respectively the calculated reliability indicators and other statistical data from other studies [1], can be used as a starting point for subsequent ASM forecasted reliability studies.

2. STATISTICAL ANALYSIS

For the conducted study it has been taken into consideration 586 ASM used to drive the main equipments, units and devices from consumers premises (table 1).

Studying the technological process which takes place in consumers premises, it have been established the following influences factors of own ASM operational reliability:

- the majority of ASM are locally manufactured;
- average operation durations are in a wide range, between (2÷10) years;
- solicitations are, mainly, specific to operation service of ASM: operation service S1(continuous operation a constant load), operation service S6 (continuous operation at intermittent load) and respectively operation service S7 (continuous operation with regular braking);
- ASM loading factor varies in a wide range $\beta = P/Pn = (0 \div 1)$;

Peculiarity of this power consumer is the fact that works temporary or seasonal, accordingly with year periods when there are available raw materials for sugar production, more precisely, October 1 ÷ December 31 (fall campaign) and respectively April 1 ÷ May 31 (spring campaign).

Table 1 – Analyzed MAS from de la S.C. Zahărul Oradea S.A. company

No.	Rated power [kW]	Category symbol	No. of motors
1	Up to 2,2 kW	M-0	106
2	3 and 4 kW	M-1	119
3	5,5 and 7,5	M-2	81
4	10 ÷ 17 kW	M-3	89
5	18 ÷ 25 kW	M-4	71
6	30 ÷ 40 kW	M-5	40
7	45 ÷ 75 kW	M-6	46
8	90 ÷ 315 kW	M-7	34

2.1. Events statistics

Having at disposal the worksheets of ASM [2], we considered a analysis period of time by 3 years (2005, 2006 and 2008), respectively the periods 31.05.2005÷31.12.2006 and 01.01.2008 and 01.08.2008. These periods sum up 791 days or 18984 hours (2,167 years). Based on these worksheets it has been established the values of random variables proper functioning time (MTBF) and corrective maintenance time (MTMC) (expressed in hours) for each of above mentioned motor categories, values presented below.

For M-0 category:
TBF: 4176; 5640; 10752; 10800; 10824; 11112; 15072;
TMC: 3; 8; 8; 8; 72; 72; 72.

For M-1 category:
TBF: 2328; 3264; 3432; 3432; 3432; 3432; 3456; 3456; 4056; 4632; 4728; 4728; 5112; 5520; 5640; 6528.
TMC: 2; 3; 5; 8; 24; 24; 24; 48; 72; 72; 72; 72; 72; 72; 72; 72.

For M-2 category:
TBF: 4056; 6216; 6216; 6360; 6432; 10800; 11736; 12336; 14832; 14928
TMC: 8; 8; 8; 8; 8; 8; 8; 8; 72; 72.

For M-3 category:
TBF: 6216; 6240; 6264; 6384; 6408; 6480; 9000; 9744; 11136; 11448
TMC: 3; 8; 8; 8; 8; 8; 8; 72; 72; 72

For M-4 category:
TBF: 5040; 6192; 6264; 6408; 6432; 10320; 15000; 15312
TMC: 8; 8; 8; 8; 8; 72; 72; 72.

For M-5 category:
TBF: 3624; 3720; 5088; 5592; 6024; 6432; 10800; 14784; 15264
TMC: 8; 8; 8; 8; 8.25; 36; 72; 72; 72

For M-6 category:
TBF: 4680; 4920; 7224; 11016; 13320; 14448
TMC: 2; 2.25; 2.25; 2.25; 5; 5

For M-7 category:
TBF: 3768; 5976; 11544.
TMC: 8; 8; 48.

IT has been determined [2], for each motor category type, the following reliability indicators:

- average probable proper functioning time (figure 1):

$$MTBF^{*} = \frac{\sum_{i=1}^{N_{TBF}} TBF_i}{N_{TBF}} \quad (1)$$

- failure rate (table 2):

$$\lambda^{*} = \frac{1}{MTBF^{*}} \quad (2)$$

- average probable corrective maintenance time (figure 2):

$$MTM^{*} = \frac{\sum_{i=1}^{N_{TMC}} TMC_i}{N_{TMC}} \quad (3)$$

- repairing rate (table 2):

$$\mu^{*} = \frac{1}{MTM^{*}} \quad (4)$$

- average yearly fault time (figure 3):

$$M^{*}[\beta(T_A)] = \frac{\sum_{i=1}^{N_{TMC}} TMC_i}{T_A \cdot N_m} \quad (5)$$

- average yearly failures number (figure 4):

$$M^{*}[\nu(T_A)] = \frac{N_{TMC}}{T_A \cdot N_m} \quad (6)$$

where: T_A – analysis time interval, expressed in years (for analyzed case $T_A = 3$ years);
TBF_i, TMC_i – random variables values TBF and, respectively TMC, expressed in hours;

N_{TBF}, N_{TMC} – number of random variables values TBF, and TMC, between analysis time;
N_m – number of same type ASM tracked in the analysis time (table 1).

Because the analysis time interval is relatively short compared with average proper functioning times, without failure, of ASM (it has been identified even some motors without failure in the analyzed time), the resulted values for reliability indicators doesn't reflect, in some cases, the real situation, having more just a guidance character. In these conditions, the testing of how the empirical distributions are modeled by those theoretical, are not justified, but accepting the exponential distribution, we will calculate the failure and respectively repairing rates, for each motor category, using the relations (1 ÷ 6).

For each type of motor category it has been calculated fundamental reliability indicators, presented in the following table.

Table 2 – Failure and repairing rates values for ASM from S.C. Zahărul S.A.

Motor categ.	MTBF	$\lambda\ [10^{-4}\cdot h^{-1}]$	MTR	NTMC	$\mu\ [10^{-4}\cdot h^{-1}]$	N_m	$M^*[\beta(TA)]$	$M^*[\nu(TA)]$
M-0	9768	1.024	34.71429	7	288.066	106	1.0579	0.030
M-1	4198.5	2.382	44.625	16	224.090	119	2.769	0.062
M-2	9391.2	1.065	20.8	10	480.769	81	1.180	0.056
M-3	7932	1.261	26.7	10	374.532	89	1.384	0.052
M-4	8871	1.127	32	8	312.500	71	1.664	0.052
M-5	7925.333	1.262	32.47222	9	307.956	40	3.372	0.104
M-6	9268	1.079	3.125	6	3200.000	46	0.188	0.060
M-7	7096	1.409	21.33333	3	468.750	34	0.869	0.041

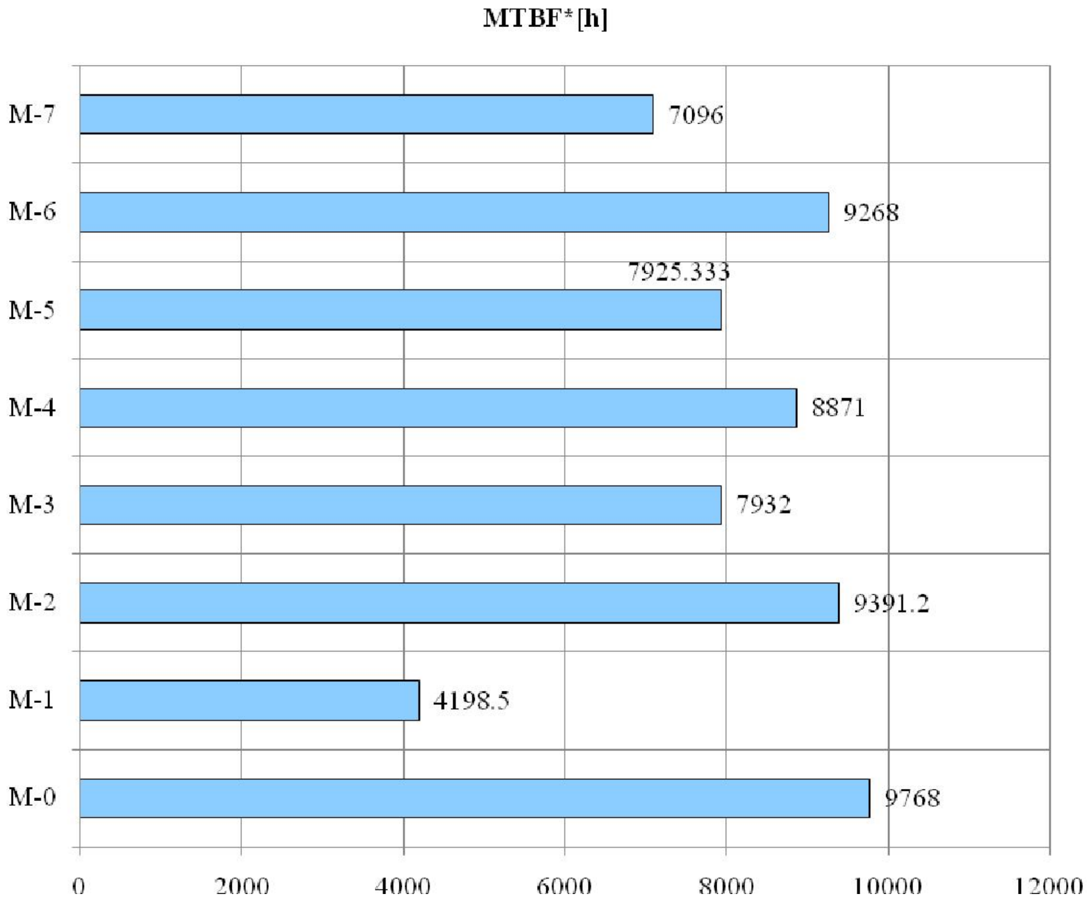

Fig. 1 – Average proper function times for MAS from S.C. Zahărul Oradea S.A.

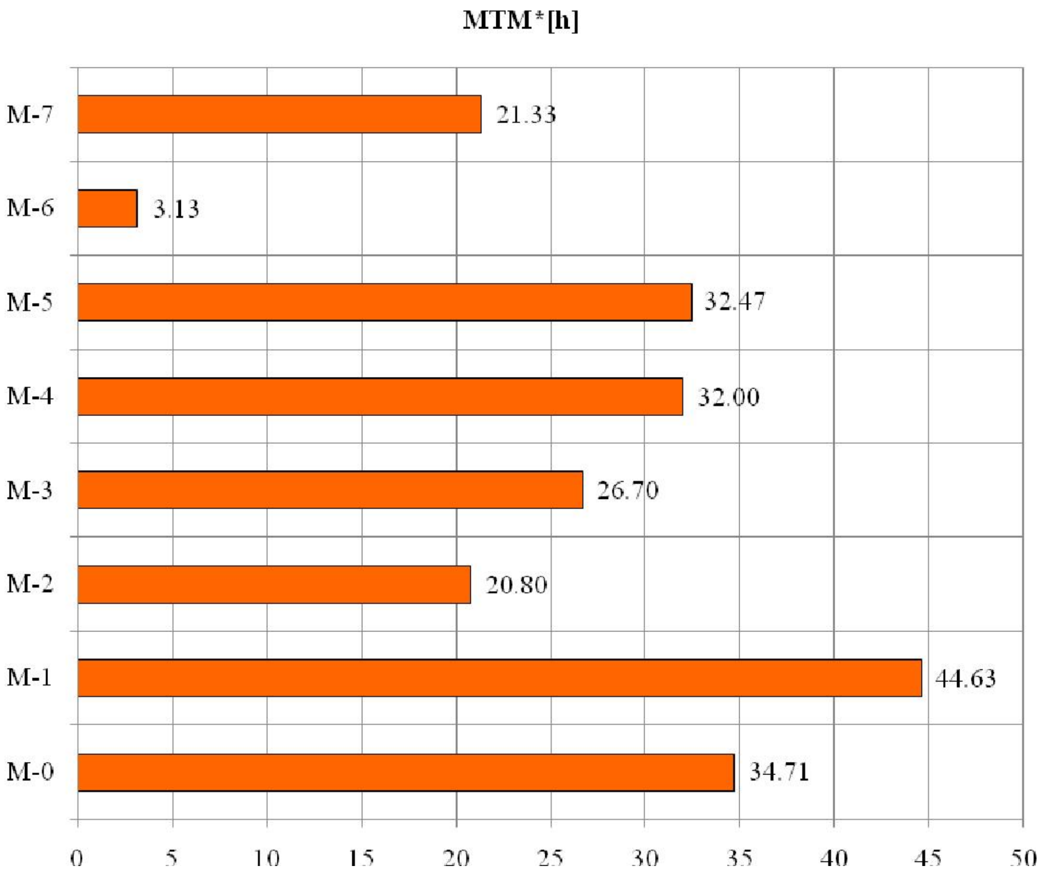

Fig. 2 – Average corrective maintenance times for ASM from S.C. Zahărul Oradea S.A.

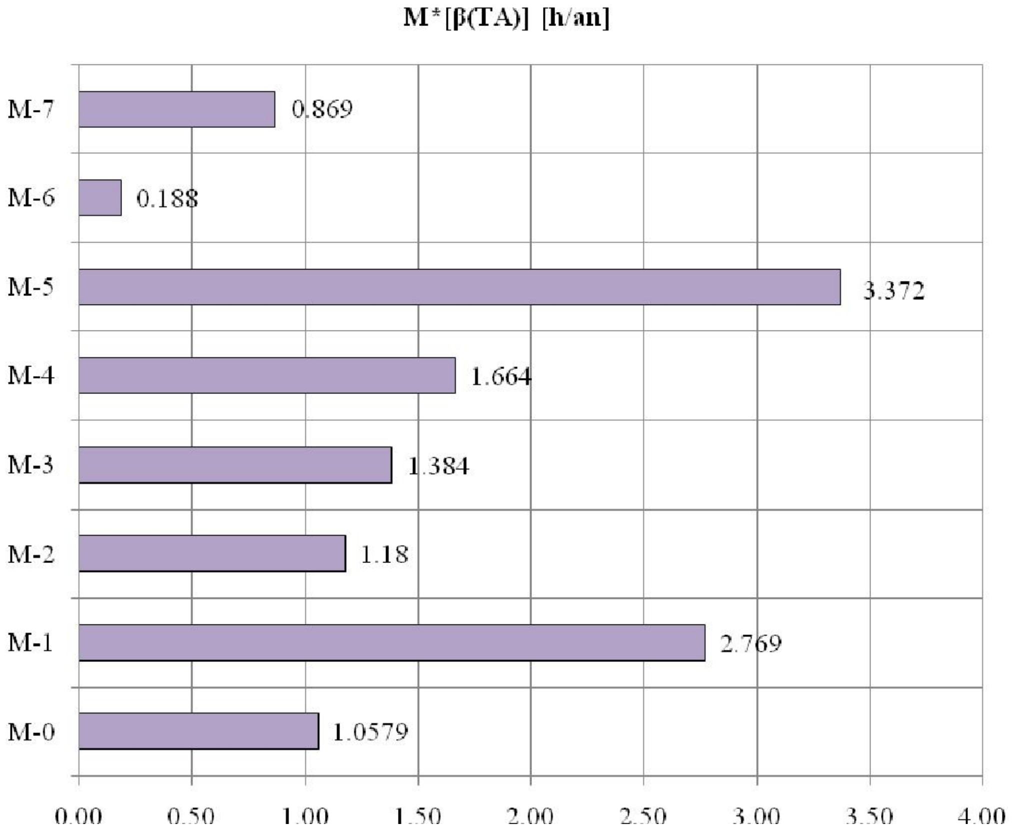

Fig. 3 – Average yearly failure time durations for ASM from S.C. Zahărul Oradea S.A.

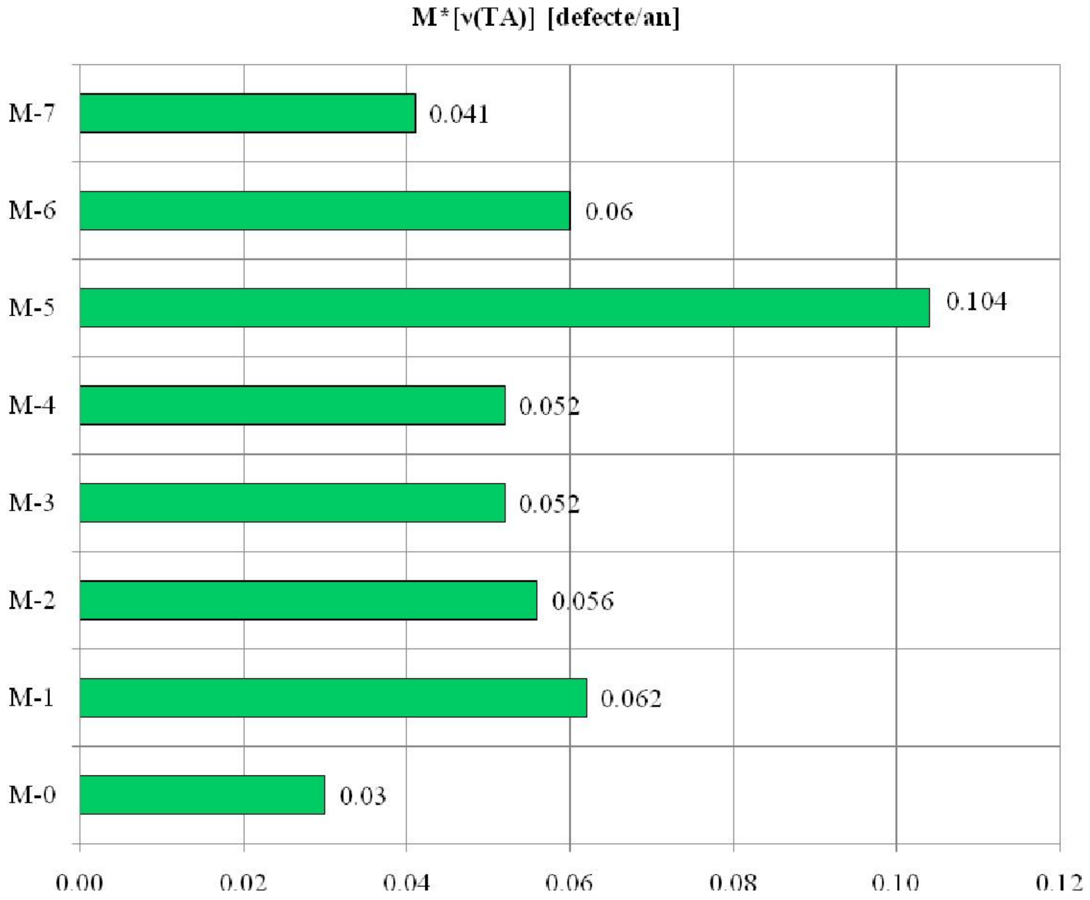

Fig. 4 – Average numbers of yearly failures for ASM from S.C. Zahărul Oradea S.A.

Table 3 – Expressions of frequency function for "NC" random variable of ASM from S.C. Zahărul S.A.

Motor	f(x)	Motor	f(x)	Motor	f(x)
M-0	$\frac{(0{,}03)^x}{x!} \cdot e^{-0{,}03}$	M-1	$\frac{(0.062)^x}{x!} \cdot e^{-0.062}$	M-2	$\frac{(0{,}056)^x}{x!} \cdot e^{-0{,}056}$
M-3	$\frac{(0{,}052)^x}{x!} \cdot e^{-0{,}052}$	M-4	$\frac{(0{,}052)^x}{x!} \cdot e^{-0{,}052}$	M-5	$\frac{(0{,}104)^x}{x!} \cdot e^{-0{,}104}$
M-6	$\frac{(0{,}06)^x}{x!} \cdot e^{-0{,}06}$	M-7	$\frac{(0{,}041)^x}{x!} \cdot e^{-0{,}041}$	-	-

Table 4– Frequency functions expressions for 8 ASM category types for x = {1, 2, 3, 4}, where x is "NC" - variable yearly number of failures

x	f(x)M-0	f(x)M-1	f(x)M-2	f(x)M-3	f(x)M-4	f(x)M-5	f(x)M-6	f(x)M-7
1	2,911·10-2	5,827·10-2	5,295·10-2	4,936·10-2	4,936·10-2	9,373·10-2	5,651·10-2	3,935·10-2
2	4,367·10-4	1,806·10-3	1,483·10-3	1,283·10-3	1,283·10-3	4,874·10-3	1,695·10-3	8,067·10-4
3	4,367·10-6	3,733·10-5	2,768·10-5	2,225·10-5	2,22·10-5	1,670·10-4	3,390·10-5	1,102·10-5
4	3,275·10-8	5,787·10-7	3,874·10-7	2,892·10-7	2,89·10-7	4,393·10-6	5,086·10-7	1,13010-7

In case of ASM from considered consumer it may present interest the discrete random variable "yearly number of failures" (NC).

To describe the trend of discrete random variable "NC" we can accept Poisson distribution, because yearly number of failures is relatively small (much smaller than number of motors). Frequency function (density) for Poisson distribution is expressed [3, 4, 5, 6, 7] as follows:

$$f(x) = \frac{a^x}{x!} \cdot e^{-a} \qquad (7)$$

where "a" is average yearly number of failures for a analyzed ASM category(or type).

The results obtained for ASM from S.C. Zahărul Oradea S.A, in terms of random variable "NC", are synthetically presented in table 3. In table 4 are given the results of frequency function for variable “NC”= {1, 2, 3, 4, 5} in the case of applying the 8 types of functions.

2.2. Causes of failure hierarchy

To establish the units or components most important from reliability perspective, which have a greater impact on ASM reliability, a hierarchy of causes which led to failure of ASM has been done.

Analyzing statistical data from a analysis period of time T_A = 791 days = 18984 hours = 2,167 years, were found a number of 71 ASM failures, from a total asynchronous motors number of 586, from the considered power consumer. In figure 4 are presented the causes of these failures.

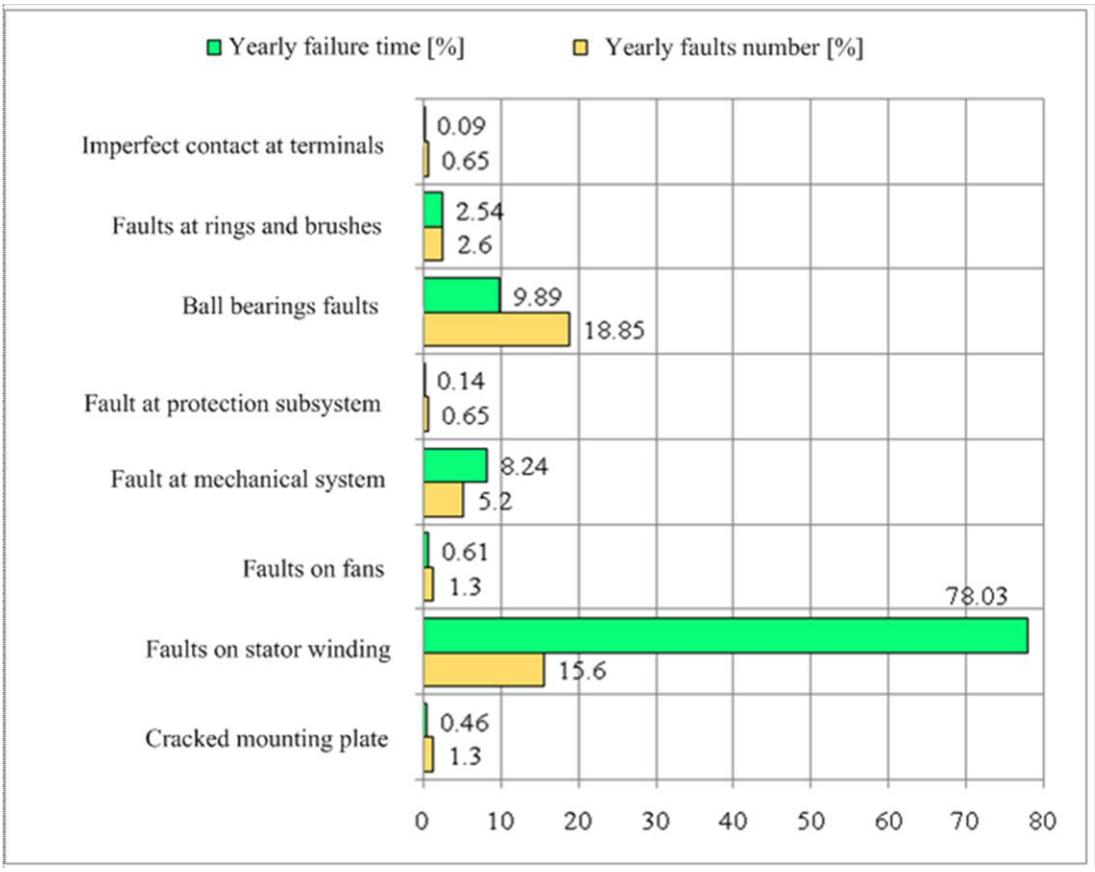

Fig. 5 – Causes of failure hierarchy for ASM from S.C. Zahărul Oradea S.A.

3. CONCLUSIONS

From the conducted analysis through this study the followings conclusions can be draw:

in the case of high power ASM lab tests are uneconomical and the tracking in operations remains the only information source regarding reliability, so the study of its reliability it’s done mainly on statistical data basis, gathered from ASM operation.

Depending on availability of statistical data, reliability studies have been conducted on a relatively short time. Because analysis time interval is short compared with ASM average operation time without fault the obtained values for reliability indicators presents a guidance character and doesn’t reflect entirely the reality. Because of this, the testing of mode in which empirical distribution are modeled by the theoretical ones it’s not justified. Instead, accepting exponential distribution failure and maintenance rates for every ASM category have been calculated.

With regarding to operational reliability of ASM from S.C. “Zahărul Oradea” S.A. company, we can conclude the followings:

- ❖ Yearly average failure times have values between [0,88÷3,37] hours/year. The most less reliable ASM are from M5 category, with powers between 30 and 40 kW, and the most reliable ASM are those from M6 category with powers between 45 and 70 kW.
- ❖ Average corrective maintenance time is between range [0,125÷44,5] hours, the highest values being at M1 category with powers between 3 and 4 kW.
- ❖ Based on the analysis, results the following failure hierarchy of ASM components (taken after yearly number of fault share)
  - ➢ Ball bearings faults 18,85%
  - ➢ Statoric winding faults (at insulation) 15,6%
  - ➢ Faults at mechanical system 5,2%
  - Faults at rings and brushes 2,6%
  - Cracked mounting plate 1,3%
  - Faults on fans 1,3%

Failure rate (λ) and repairing rate values, for analyzed ASM, are, generally, higher than those given in PE013regulation.

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