Romanian Journal of Civil Engineering, Volume 16 (2025), Number 3

Considerations regarding the operational reliability of equipment in the structure of water supply systems

Considerații privind fiabilitatea operațională a echipamentelor din structura sistemelor de alimentare cu apă

Gheorghe – Constantin Ionescu [1], George – Lucian Ionescu [2],

Dragoș-Vasile Ille[3]

[1] University of Oradea
4 Delavrancea Str., Oradea, Bihor, Romania
E-mail: gheionescu@gmail.com

[2] University of Oradea
4 Delavrancea Str., Oradea, Bihor, Romania
E-mail: lucian.ionescu1985@yahoo.com

[3] University of Oradea
4 Delavrancea Str., Oradea, Bihor, Romania
PhD student, Energy Engineering Field
E-mail: illedragos@yahoo.com

DOI: 10.37789/rjce.2025.16.3.5

Abstract. *Regardless of the precision or complexity of the reliability analysis method used, the quantitative assessment of the reliability of a system requires knowledge of the values of the reliability indicators of the component elements. Obtaining realistic results for the reliability of the system is conditioned by the credibility of the values of the reliability indicators of the elements. Information on the reliability of the elements is useful both for beneficiaries (for the purpose of optimizing maintenance) and for manufacturers (for the purpose of applying corrections in design and manufacturing).*

Key words: water supply, systems, operational reliability

1. Introduction

To estimate the reliability indicators of the elements, two analysis methods are used, namely: Experimental Reliability and Operational Reliability.

Operational reliability, corresponding to the situation in which the reliability indicators are determined based on observations made in real operating conditions of the equipment. As research has shown, there are a number of equipment for which

The article was received on 26.05.2025, accepted on 17.07.2025 and published on 18.08.2025

reliability tests in laboratory conditions are uneconomical and the only source of information on reliability remains monitoring in operation [5].

The evaluation variant of reliability indicators is clearly advantageous from an economic point of view, in relation to experimental reliability, requiring minimal expenses for recording and processing statistical data. The disadvantage of this analysis method is the long duration of observations and the difficulties encountered in ensuring a minimum required number of observed elements.

Studies of operational reliability of equipment in the structure of water supply systems are indispensable to obtain statistical data of adequate volume and credibility, on the basis of which to establish the values of reliability indicators and an optimal maintenance policy. Unfortunately, these studies in the field of water supplies are at a pioneering stage, which is why they must be based on incident sheets and event records existing at the level of water pumping stations (key point in a water supply installation) and on analyses performed on water samples taken from different treatment phases.

The studies in question mainly highlight the following aspects:

- the number of incidents at the pumping station level and their distribution across subsystems (pump drive motors, pumps themselves);
- the cost of corrective maintenance work carried out following incidents;
- the energy unavailable as a result of incidents and the distribution across subsystems;
- the causes of incidents and damaged elements

The observations that can be made regarding these studies are the following:

- they are not sufficiently detailed and in-depth, as they are limited to a part of the subsystems of a water supply installation;
- they prove useful, as they provide a first impression of the condition of the equipment, its operating behavior and its maintenance management;
- the data obtained are not processed in all aspects and, as a result, not all possible information is exploited;
- despite all efforts made towards the correct declaration of incidents and their parameters, there may still be errors.

Through this study, we aimed to overcome these issues, on the one hand by monitoring the equipment more closely and in more detail, and on the other hand, by processing the obtained data more extensively and at an adequate scientific level, in order to obtain more useful information in the operation of hydraulic installations within the water supply systems of urban centers [4], [5].

Based on the statistical data obtained from monitoring the operation of the equipment, three random variables can be studied, namely:

- the good operation time (TBF), representing the operation time between two successive failures;

- the corrective maintenance time (TMC), representing the failure time;
- the annual number of failures (NC).

The first two random variables are continuous, and the third is discrete.

It is well known that performing operational reliability studies for a sample (lot) from a population of a product involves assuming a risk [4], [5]. When performing operational reliability studies, in order to ensure the premises of risk minimization, when the research results extend from the lot level to the population level, it is necessary to ensure compatible working hypotheses in the two cases. Given this objective, an operational reliability study with a certain degree of scientific rigor involves indicating the technical characteristics and factors that can influence reliability indicators, such as: the level of long-term demands, the level and frequency of overloads, environmental factors, maintenance conditions, etc. Without performing a complete characterization under the aforementioned aspects, I will specify, within the case study, most of the influencing factors.

The results obtained for the water supply system of Oradea municipality are presented synthetically in this chapter, the working methodology being valid for any other water supply system of urban centers.

2. Presentation of the water supply system of the Oradea Municipality

The drinking water supply of Oradea is provided by 5 pumping stations (SPO) located on both banks of the Crişul Repede River in the NE part of the city [6], [12].

For this purpose, both groundwater, captured from the groundwater table using drains, and surface water, captured from the Crişul Repede River, are used.

Table 1

Pumping station structure

Station	Group no. x pump type	Group characteristics			Normal operating configuration
		Q [mc/h]	H [m]	P_i [kW]	
SP 1	6 x KSB	435	55	145	4 + 2
SP 2	1 x SIGMA 2 x GAZ 3 x NDS	500 300 400	59 50 53	160 145 160	5 + 1 (NDS)
SP 3	3 x 8 NDS	350	80	110	2 + 1
SP 4	6 x 12 NDS 3 x 8 NDS	300 400	50 83	250 160	5 +1 2 + 1
SP 5	3 x BRATEŞ 2200 (TR. I) 3 x BRATEŞ 350 (TR. II) 5 X 12 NDS (TR. III)	1200 1400 900	12 11 60	90 75 200	2 + 1 2 + 1 4 + 1

On the right bank, surface water is captured using two Φ 1000 mm pipes. After passing through two horizontal decanters, the water enters the 13 basins with the role of enriching the underground phreatic layer, located parallel (8 +5) to the Criş riverbed. Between the two rows of basins and Criş, 2 drains are located for capturing groundwater, with the purpose of supplying the pump station 1 (S.P. 1). To the extent that this quantity of water does not satisfy the need for S.P. 1, surface water from the enrichment basins is also used, filtered using the 10 slow filters. The filters are fed directly from the raw water captured, through a Φ 600 mm2 pipe, when the turbidity is reduced in the Criş water and respectively from the last enrichment basin if the water in Criş has high turbidity.

Table 2

Global energy indicators of SPO (values in one year)

	SP 1	SP2	SP3	SP4	SP5	Total
Total pumped water	11.039.600	5.134.120	4.272.020	17.050.700	17.724.300	55.221.500
Surface water	10.847.800	5134.120	1.071.200	17.050.700	-	34.103.700
Groundwater	191.800	-	3.201.700	-	17.724.300	21.117.800
Installed power in pumping units (kW)	882	670	330	1850	1870	5602
Installed power in exploitation technology (kW)	950	680	330	2012	2340	6300
Electricity consumption (kWh)	4.243.830	1.690.770	1.022.220	4.647.620	4.106.460	17.470.020
Specific consumption kWh/m3	0,384	0,329	0,445	0,272	0,281	0,316

Pumping station no. 3 (SP 3), is also located on the right bank and pumps water into the compensation tanks (total capacity 22012 mc).

Pumping station no. 2 (S.P. 2) is located on the right bank and pumps groundwater into the network on the left bank. The groundwater supply to the drain is supplied through two enrichment basins.

On the left bank, the captured water reaches gravity through two pipes (Φ 1200 mm - Φ 1000 mm) in the 8 enrichment basins located perpendicular to the Criş riverbed. Among these basins are located the secondary drains that supply the main drain, located between the Criş riverbed and the 8 basins, ensuring the entire water needed for S.P. 4.

S.P. 5 exclusively uses surface water decanted with the two radial decanters and filtered through the 8 rapid filters within the plant.

The S.P.O. structure was presented in table 4.1., and the values of significant indicators regarding the operation of the stations, in one year (2020), were mentioned in table 4.2.

3. Special features of pumping stations

In the exploitation activity, the following must be followed:

- periodic verification of the degree of clogging by reading the level difference between the raw water and the filtered water with a gauge;
- the captured flows must be constant (by draining);
- the operation of the decanters in parallel or in series, depending on the degree of turbidity, respectively on their clogging level;
- the correct operation of the Parshall flowmeter;
- the evacuation of deposits must be done periodically depending on the raw water load - once every 60 days;
- the inspection and maintenance of the maneuvering seals;
- washing the filter in order to form the biological membrane;
- emptying the decanter in order to wash the concrete foundation;
- maintaining a constant water level on the slow filters by adjusting the supply valve;
- emptying the clogged filter, respectively cleaning it by removing the 2-3 cm thick layer from the sand surface;
- disinfection of the sand with a solution of lime chloride in an amount of 0.5 kg/m^2;
- periodic reading of the flows on the two trapezoidal flowmeters.

The defense of pumping stations in different phases and defense hypotheses is carried out according to the defense plan, as follows:

a) upon reaching the attention level communicated by the County Flood Defense Commission, the observation-alarming and surveillance activity of the defense dikes will be organized, checking the existence of the materials necessary for the interventions in stock;

b) upon reaching the flood level communicated by the County Flood Defense Commission, the local defense of the basic objectives will be organized with the help of intervention teams and equipment, as follows:

- the dams at the raw water intakes will be closed and strengthened;
- the materials stored in the area of the basic objectives and the dangerous ones will be transported;
- the defense of the pumping stations and slow filters will be organized by executing local dams using our own materials and means;
- small infiltrations through the defense dikes will be eliminated;
- additional jute bags and sand stocks will be provided to raise the defense dikes and drains to the danger level;
- the County Flood Defense Commission will be requested to allocate additional forces, materials and equipment, the entire capable workforce and its own equipment will be mobilized and organized for interventions, in the event of reaching the danger level or the appearance of breaches in the defense dikes.

c) upon reaching the danger level or the appearance of large local erosions in the defense dike, with the support of additional forces and means allocated by the County Flood Defense Commission, the following will be done:

- evacuation of the coagulant stock;
- raising the dikes with sandbags and strengthening the eroded areas;
- announcement by the County Flood Defense Commission of the units that are located in the area.

If the intervention works cannot prevent flooding of the water plant territory, the pumping stations will be de-energized, the electric pumps and chlorine cylinders will be dismantled and evacuated until the temporary local dams fail [7], [9].

The operation of the pumping stations depending on the seasons of the year is as follows:

- During periods of average flow

They operate in normal mode: 4 groups at S.P. 1, 2 groups at S.P. 3, 2 groups at S.P. 2, 3 groups at S.P. 4, 1 or 2 groups at S.P. 5, depending on the pressure in the network. The intakes are opened depending on the water level in the enrichment basins.

- During periods of high water

The water in Crişul Repede being dirty (high turbidity) the intakes are closed to avoid clogging of the basins. At S.P. 5, where surface water is used, the dose of aluminum sulfate is increased to accelerate the decantation of solid suspensions from the water.

- During periods of freezing (ice rinks, ice floes, ice bridge)

Shifts of 2 people are formed, who will permanently supervise the intakes and will act with specific tools to avoid freezing in the intake area and clogging of the pipes.

- During periods of low water (drought)

The intakes will be permanently open. The flow rate of pumped water will be reduced depending on the water level in the caisson.

The functional schemes of pumping stations no. 1 and 3 are presented in fig.4.9. and 4.10.

Since the structure of the stations S.P. 1 and S.P. 3 is more homogeneous, the monitoring of the operating behavior of these S.P. is more rigorous. Since the specific electricity consumption is higher, the operational reliability study focused on these stations. The conclusions of the study are valid, for the most part, for the other SPs.

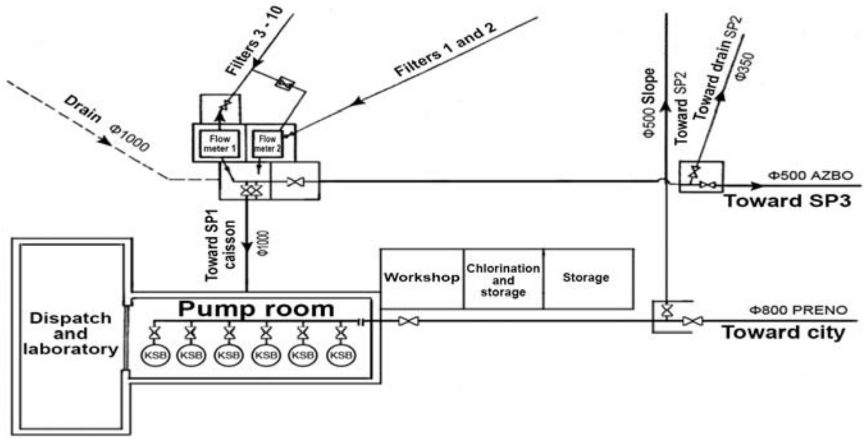

Fig. 3.1. – Functional diagram of Pumping Station no. 1 – ORADEA

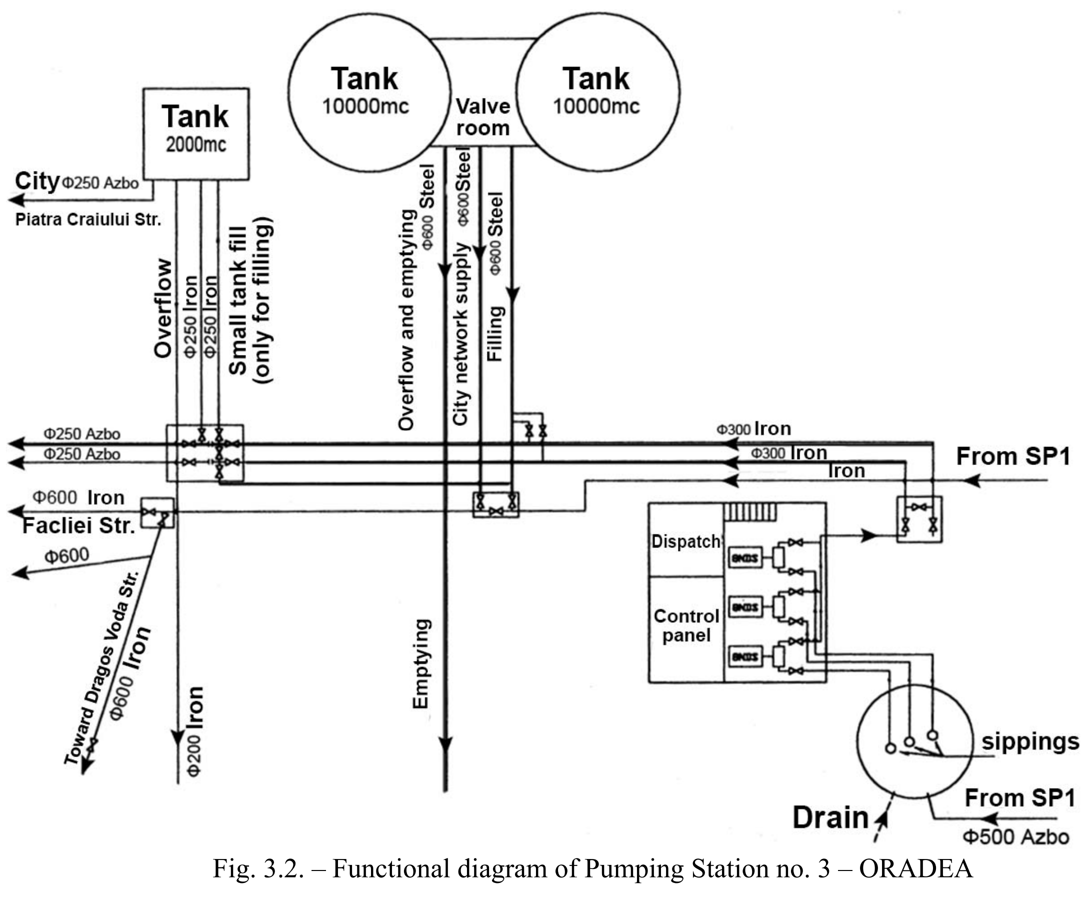

Fig. 3.2. – Functional diagram of Pumping Station no. 3 – ORADEA

To illustrate the load level of the SP, figures 4.11 and 4.12 show the monthly load curves.

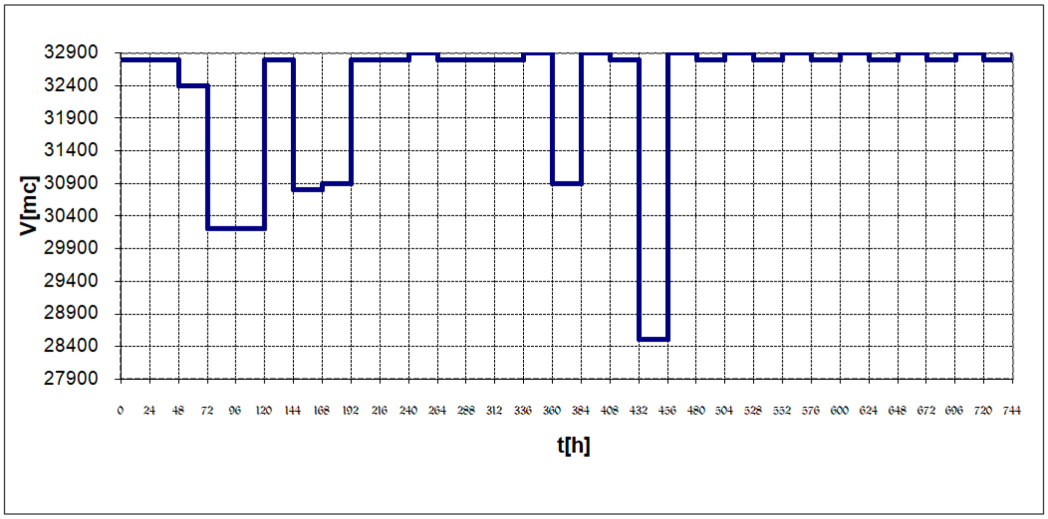

Fig. 3.3. - Monthly load curve of SP1 (January 2012)

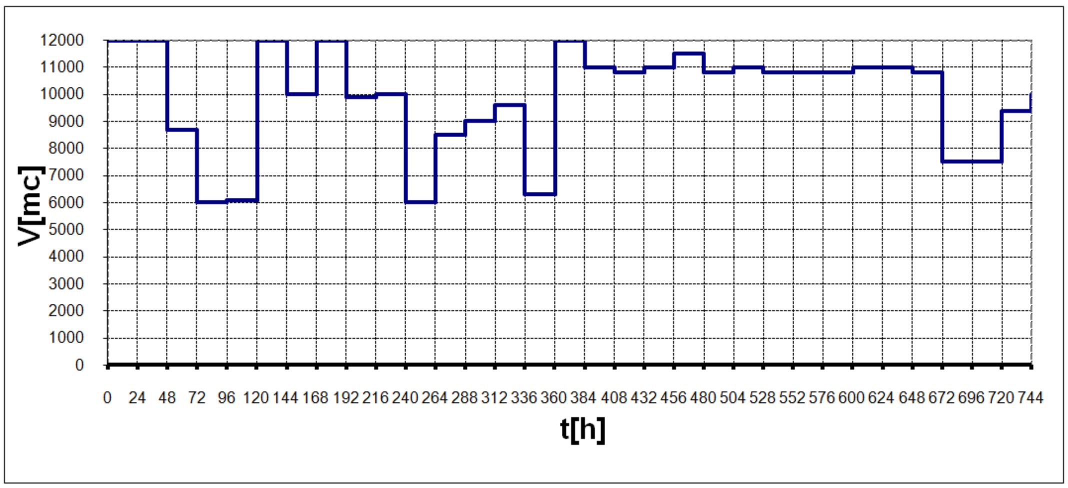

Fig. 3.4. - Monthly load curve of SP3 (January 2012)

4. Conclusions

The operational reliability (FO) study of SP1 and SP3 is extended over a period T = 10.5 years, comprising data collected in the interval [01.01.2011 ÷ 30.06.2021]. Some elements that characterize the level of demand of the equipment in the structure of S.P. 1 and S.P. 2 are:

SP1:

• average annual operating duration of a group: 5840 hours / year;

• average load degree: 78% of the nominal value;

• number of maneuvers: 40 maneuvers / year;

• characterization of the working environment: average temperature 220C; quality of pumped water: potable; humid environment.

SP3:

• average annual operating duration of a group: 5840 hours / year;

• average load degree: 60% of the nominal value;

• number of maneuvers: 20 maneuvers / year;

• characterization of the working environment: average temperature 220C, quality of pumped water: potable; humid environment.

Since the equipment in the structure of the two SPs has different characteristics, the FO study was carried out separately for each station. The tracking of the equipment in the SPO structure was carried out based on the operation and intervention registers, which can be equated with a FO study typical for "truncated tests with replacement" [12].

The random variables (VA) of interest for the FO study of the S.P. are: "good operating time" (TBF) and "corrective maintenance time" (TMC). The statistical data taken from the registers allowed us to establish – with reference to the groups – the series of values for the two VAs and highlight the failure modes and the share of component failures in the failure of the groups. Detailed statistical data are presented in [152], where the variational series of the values of the two VAs is also presented. The volume of the selection (r = 437 → S.P. 1 and r = 216 → S.P. 3) is large enough to admit that the results obtained from the study have sufficient credibility. Based on the models, algorithm and FRVA program, commonly applied to the processing of statistical data [7], [9], these data were processed, testing three theoretical distributions (exponential, Weibull and normal) to establish the best estimate of the empirical distribution.

The results are presented in table 4.1.

Table 4.1

Pumping station structure

Station	Distribution function	TBF (F)		TMC (M)	
		Parameter values	D_{max}	Parameter values	D_{max}
S.P. 1 r = 437	Exponential	$\lambda = 3{,}33 \cdot 10^{-5}\ h^{-1}$	0,083	$\mu = 0{,}738$	0,522
	Weibull	$\eta = 3{,}29 \cdot 10^{4}$ h $\beta = 0{,}83$	0,08	$\eta_M = 1{,}74$ h $\beta_M = 1{,}42$	0,508
	Normal	$m = 3{,}17 \cdot 10^{4}$ h $\sigma = 2{,}76 \cdot 10^{4}$ h	0,142	$m_M = 1{,}34$ h $\sigma = 1{,}87$ h	0,443
S.P. 3 r = 216	Exponential	$\lambda = 3{,}48 \cdot 10^{-5}\ h^{-1}$	0,095	$\mu = 0{,}69$	0,326
	Weibull	$\eta = 3{,}08 \cdot 10^{4}$ h $\beta = 0{,}83$	0,097	$\eta_M = 1{,}48$ h $\beta_M = 1{,}54$	0,407
	Normal	$m = 3{,}01 \cdot 10^{4}$ h $\sigma = 2{,}79 \cdot 10^{4}$ h	0,127	$m_M = 1{,}34$ h $\sigma = 1{,}85$ h	0,4

The FD expressions and the meaning of the parameters are as indicated in [12].

Therefore, the recommended distribution function expressions for the groups of the two pumping stations, with reference to the two random variables, are:

- Pumping station 1 (SP 1)

- TBF random variable:

$$R(t)=e^{-3{,}33\cdot 10^{-5}\,t} \quad (1)$$

- TMC random variable:

$$M(t)=1-e^{-\left(\frac{t}{1{,}74}\right)^{1{,}42}} \quad (2)$$

- Pumping station 2 (SP 2)

- Random variable TBF:

$$R(t)=e^{-3{,}48\cdot 10^{-5}\,t} \quad (3)$$

- TMC random variable:

$$M(t)=1-e^{-0{,}69t} \quad (4)$$

Statistical data on events occurring at pumping stations 1 and 3 are presented in Annex 1. Based on these tables, failure rates for groups, respectively pumps, were calculated and represented. The absolute and percentage values of the variable v(T), for groups and their components are given in table 4.2., and table 4.3. presents the contribution of the components in the structure of the electric motors driving the pumps, to their failure.

Table 4.2

Absolute and percentage values of the variable v(T), with reference to the analyzed SP

SP1	Trimmings		Motor		Valve		Flap	
	No. of defetcts	%	No. of defetcts	%	No. of defetcts	%	No. of defetcts	%
GR I	64	72,72	20	22,72	2	2,27	2	2,27
GR II	54	69,23	21	26,92	1	1,28	2	2,56
GR III	50	68,49	20	27,39	1	1,36	2	2,73
GR IV	43	69,35	16	25,80	2	3,22	1	1,61
GR V	58	76,31	16	21,05	1	1,31	1	1,31
GR VI	54	72	17	22,66	3	4	1	1,33
S.P. 1	323	71,46	110	24,33	10	2,21	9	1,99

SP3	Trimmings		Motor		Valve		Flap		Pump grease	
	No. of defetcts	%	No. of defetcts	%	No. of defetcts	%	No. of defetcts	%	No. of defetcts	%
GR I	35	54,68	10	18,75	2	1,56	1	1,56	15	23,43
GR II	47	59,49	10	15,19	2	1,26	1	1,26	18	22,78
GR III	40	55,55	7	15,27	4	1,38	1	1,38	19	26,38
S.P. 3	122	56,74	35	16,27	3	1,39	3	1,39	52	24,18

Table 4.3

Absolute and weighted values of the variable v(T),
with reference to the engines in the SP structure analyzed

Motor S.P. 1

	Bushings		Bearings		Shaft		Rotor		Stator		Coil Breakdown		Oil change	
	No. def.	%	No. def.	%	No. def.	%	No. def.	%	No. def.	%	No. def.	%	No. def.	%
GR I	1	5	2	10	1	5	2	10	2	10	1	5	11	55
GR II	3	14,28	2	9,52	2	9,52	1	4,76	1	4,76	1	4,76	11	52,38
GR III	1	5	2	10	1	5	2	10	2	10	1	5	11	55
GR IV	-	-	2	13	1	6,25	1	6,25	1	6,25	1	6,25	10	62,5
GR V	-	-	2	13	1	6,25	1	6,25	1	6,25	1	6,25	10	62,5
GR VI	-	-	2	11,76	1	5,88	1	5,88	1	5,88	1	5,88	11	64,7
S.P. 1	5	4,54	12	10,90	7	6,36	8	7.27	8	7,27	6	5,45	64	58,18

Motor S.P. 3

	Bushings		Bearings		Shaft		Rotor		Stator		Coil Breakdown		Coupling replacement	
	No. def.	%	No. def.	%	No. def.	%	No. def.	%	No. def.	%	No. def.	%	No. def.	%
GR I	1	8,33	2	16,66	4	33,33	2	16,66	2	16,6	1	8,33	-	-
GR II	2	16,66	2	16,66	2	16,66	2	16,66	1	8,33	2	16,66	1	8,33
GR III	1	9,09	4	36,36	2	18,18	1	9,09	1	9,09	2	18,18	-	-
S.P. 3	4	11,42	8	22,85	8	22,85	5	14,28	4	11,42	5	14,28	1	2,85

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