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Computation of the Reliability in Operation for Automatic Telephone Exchanges Manufactured in the Socialist Republic of Romania

In this paper the authors present the methodology for computing the reliability in operation of automatic exchanges using electro-magnetic switching elements. The respective methodology is applied to the R.S. 7735, 100-number exchanges and to the 200—900-number institution exchanges, manufactured in Romania. A comparative study is carried out on 8 types of telephone exchanges, both the availability of the exchanges and the maintenance staff being determined.

The complex and multilateral development of our economy on the path to the final achievement of socialist construction has created the necessity to expand the network of automatic telephone exchanges in our country.

During the period 1960—1965, 502 new sections and enterprises were built and began to produce in all the branches of industry, more than 270,000 flats were built, cultural edifices, education and research institutes developed at a corresponding rate, the network of sanitary institutions widened. All of them were endowed with the necessary means of telecommunication.

The fundamental tasks of the economic plan for 1966—1970 still increase the requirements for rapid communication, determining the development of the existent telecommunication equipment and the creation of new, complex equipment also able to offer good reliability in operation.

The directives of the IX-th Congress of the Romanian Communist Party regarding the development of national economy in the period 1966—1970 provide that : "In the domain of telecommunications and in view of satisfying the increasing needs of economy and of the population, the extension of the capacity of the urban automatic telephone exchanges is planned, first in the main towns and industrial centres. During this period the action for automatizing long distance telephony will begin, automation of long distance telephone connections between localities with intensive traffic will be achieved and the long distance telephone cable network will be extended, cable connection of the capital with most of the regional centres being achieved*.

* IX-th Congress of the Romanian Communist Party. Editura Politică, 1965. pp. 773—774.

At present a wide variety of telephone products are manufactured in our country, starting from BL, BC apparatus, automatic, anti-spark and other telephones, up to institution, block, urban 7D type, or ST 3 and ST 24 transistorized systems of carrier currents telephone exchanges, manufactured at a high technical level.

For the future, the assimilation and achievement of automatic telephone exchanges at the level of world technique is planned, their electro-magnetic elements, whose reliability is smaller in operation, being replaced by semiconductors and transistors having particular reliability in operation. (Carrier current systems with several paths and Crossbar type exchanges).

For both the automatic telephone exchanges now manufactured in our country and for those to be manufactured in the near future, the component sub-assemblies and parts are built in Romania, this requiring problems of a high technicity to be solved, among which also the use of materials having special technical characteristics able, under the conditions of an intensive traffic, to stand up to millions of calls.

The study of the reliability in operation of automatic telephone exchanges is particularly important in view of finding out the manner in which they correspond to the purpose for which they have been manufactured.

By means of this study it is possible to estimate the availibility of telephone exchanges, the necessary maintenance staff which, in the case of automatic telephone exchanges based on electromagnetic switching elements is rather large, and the volume of faults and breakdowns of exchanges can be pre-determined in view of enabling their rational maintenance.

The analysis of results obtained in operation, completed by laborious laboratory tests, and by using methods of mathematical statistics and of the calculus of probabilities, make for a continuous improvement of the products both from the manufacturing and technological points of view.

The actual operating conditions of the various automatic telephone exchanges should determine both the manner in which they are designed and the establishment of corresponding norms provided with functional wear tests capable of reproducing these conditions as closely as possible.

The definition of reliability in operation characterizes the elements linked with the behaviour of the product in operation. By reliability in operation of a product is understood its capacity to accomplish all the functions for which it has been conceived, in accordance with the requirements demanded by the internal norms or standards, under given conditions of operation and during a determined time period.

The scientific analysis of the reliability in operation of automatic telephone exchanges will lead to a continuous improvement in the quality of telecommunication equipment.

1. COMPUTATION METHODOLOGY FOR THE RELIABILITY IN OPERATION OF AUTOMATIC TELEPHONE EXCHANGES MANUFACTURED IN OUR COUNTRY

Automatic telephone exchanges, during their period of normal operation — which follows the running-in period — only evidence a small number of faults, enabling both the reliability in operation of sub-assemblies and that of the final assembly to be studied by means of the Poisson distribution which is also called the distribution of rare events.

The Poisson distribution represents a boundary case of binomial distribution when the magnitude of the selection n tends towards infinity.

The probability for an event to be repeated x times in a large number of tests n (provided the probability for this event to occur, p, be small) is given by the formula

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

When $x = 0$, there results the probability P_0 that no breakdown should occur during the test time T (probability of operation without breakdown)

$$f(x) = e^{-a}$$

One can find, in tables, the values of the frequency function as a function of the variable x and of the average a, (for values comprised between 0.1 and 15 every 0.1 unit, and from 15 to 30 every 2 units). In case there are no tables, the recurrence formula is recommended:

$$f(x+1) = f(x) \frac{a}{x+1}$$

The utilisation of the Poisson distribution to the computation of reliability in operation implies the introduction of a series of reliability parameters. Thus:

a) **Frequency of element breakdown.**

The frequency of breakdowns is computed according to the formula

$$r = \frac{n}{T}$$

where r = frequency of breakdowns corresponding to a moment whatever;
n = number of breakdowns recorded in a given time interval;
T = operating period

b) **Probability of operation without breakdowns**

The probability without breakdowns is only estimated for a certain determined time interval t for each element in part.

Taking into account the fact that t is a chance variable, we have:

$$P_{(t)} = \int_t^\infty f(t)dt$$

If $Q(t)$ is the probability for the element to operate less than the given time and $P(t)$ the probability for it to operate more than the given time, then

$$P(t) + Q(t) + 1$$

or

$$P(t) = 1 - Q(t) = 1 - \int_0^t f(t)dt$$

which is always a number smaller than the unit.

c) **Average operating period**

It can be proved that the average operating period is a continuous type variable of the form

$$t_m = \int_0^\infty tf(t)dt$$

d) **Average frequency of breakdowns**

Considering $q(t)$ to be the probability for an element to operate for a time period t (see point b) one reaches the formula which gives the cumulative frequency of breakdowns

$$q(t) = F(t) = \int_0^t f(t)dt$$

The average frequency of breakdowns is precisely the cumulative frequency related to the unit elapsed after the period t.

$$\text{Hence : } f_m(t) = \frac{1}{t}\int_0^t f(t)dt$$

In case there are n elements whose operation is observed in use until the last element breaks down, by plotting the centres of the time interval when the elements have broken down (t_i) on the abscissae axis and the frequency of breakdowns (r_i) on the ordinate axis, then the points P_i (t_i, r_i) will be situated on a curve which is nothing but the graph of the frequency breakdown function.

Fig. 1 shows this curve which is also called the typical curve of breakdowns.

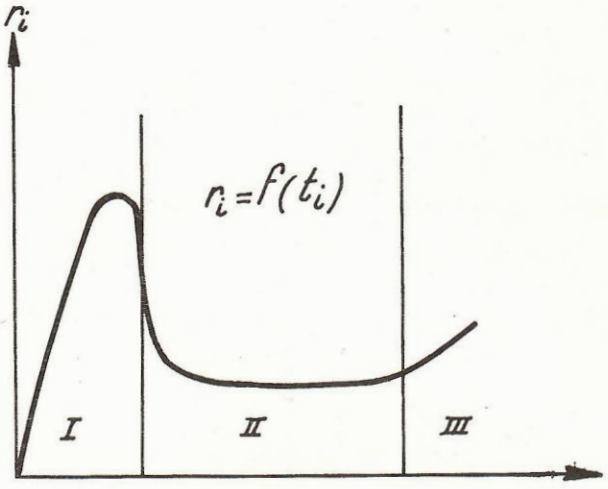

Fig. 1 : Typical curve of breakdowns

This curve has three distinctive parts corresponding to the following situations :

I. The initial operating period when the breakdown frequency is very large. After running-in the breakdown frequency decreases.

II. Normal operating period or basic period, characterized by a low and constant breakdown frequency;

III. Wearing out period, characterized by an increase in the number of faults and hence by a sudden increase of breakdown frequency.

The study of reliability in operation of automatic telephone exchanges will only be made in this paper for the basic or normal operation period.

e) Intensity of breakdowns

The intensity of breakdowns is the ratio between the number of elements which break down after the instant t, during the interval t and the number of elements in operating condition at the instant t. Hence

$$\lambda(t) = \frac{n\,f(t)}{n\,P(t)} = \frac{f(t)}{P(t)}$$

where:

$P(t)$ is the probability for an element to have a larger operating time than t;

$f(t)$ — operating period.

$$\text{Taking relation } P(t) = 1 - \int_0^t f(t)dt$$

into account, there results that the intensity of breakdowns is:

$$\lambda(t) = \frac{f(t)}{1 - \int_0^t f(t)dt}$$

By considering f = number of faults found during the time interval Δt and N the number of elements in operating condition, then the intensity of breakdowns can be expressed by means of the simple formula

$$\lambda = \frac{f}{N}$$

2. COMPUTATION OF RELIABILITY IN OPERATION FOR VARIOUS TYPES OF AUTOMATIC TELEPHONE EXCHANGES

The computation of reliability in operation can be effected from the very phase when the design of the automatic telephone exchanges is elaborated, as a function of their component elements whose reliability in operation is known and as a function of the mode in which they are located in the general assembly diagram. Thus, the designer can have at his disposal a numerical index for comparison between the quality of the designed product and similar products existing on the world market, from the standpoint of duration of operation, frequency of breakdowns, availability, etc.

Reliability in operation can likewise be computed on basis of measurements obtained for type tests (tests for wear, climate tests, etc.), as well as on basis of the results obtained consequently to prolonged use.

Since there is a possibility of expressing the reliability in operation quantitatively, there results that any design or technological error, any de-

viation from the process of manufacture or in the condition of transportation and use, may be made to stand out by the scientific study of this important qualitative index.

The computation of reliability in operation allows us to investigate the influence of manufacturing changes on the quality of the assembly. Thus, the use of superior quality materials which increase the operating period of the mechanical elements (alpacca, phosphor bronze springs, brass gear wheels, contacts made of various types of alloys) bear a positive influence on the reliability in operation of the assembly.

The study effected in view of replacing some elements of automatic telephone exchanges by others of increased reliability in operation is particularly important. Thus, coiled resistors can be replaced by chemical resistors, various types of capacitors, windings, etc. may be used.

From the standpoint of increasing reliability in operation of automatic telephone exchanges and implicitly of increasing their availability and period of operation the replacement of the electromagnetic switching elements (relays) by transistors is particularly important.

2.1. **Actual computation of reliability in operation for the R.S. 7735 100-number exchange**

The 100—number exchange is formed of a series of component elements which influence its reliability in operation. These are: 12 step-by-step markers; 884 electromagnetic relays, 204 capacitors; 108 resistors, 64 step-by-step selectors.

Table No. 1 hereunder shows the reliability in operation of each element in part, determined consequently to type tests carried out periodically on a reduced number of products subjected to wear tests, as well as the average fault percentages for one year of operation (recorded in use).

Table 1

Reliability of elements	Sub-assembly	Pieces/exchange	Average percentage of faults for one year	Average number of faults	Reliability of one element
P_1	Markers	12	20%	2.4	0.950
P_2	Relays	884	10%	88.4	0.975
P_3	Capacitors	204	5%	10.2	0.999
P_4	Resistors	108	5%	5.4	0.999
P_5	Selectors and finders	64	10%	6.4	0.850

The relatively low reliability in operation of the selectors does not influence to any great extent the reliability in operation of the exchange since they operate in parallel (by groups of 5 selectors and 6 finders in the register circuit). Thus, 4 groups of $6 + 6$ in parallel and one group of $8 + 8$ in parallel are formed, $[4(6+6) + 1(8 + 8) = 64$ selectors + finders].

Considering $P_5 = 0.85$ to be the reliability in operation of one finder, its non-reliability in operation will be

$$Q_5 = 1 - P_5 = 0.15 \text{ respectively } 15\%.$$

Developing the binomial $(P_5 + Q_6)^n$ where n is the number of elements in parallel (*6*), we can compute the probability of the simultaneous breakdown for 2, 3, 4, 5, 6 selectors or finders in the exchange circuits.

$$(P_5 + Q_5)^6 = P_5^6 + 6P_5^5Q_5 + 15P_5^4Q_5^2 + 30P_5^3Q_5^3 + 15P_5^2Q_5^4 + 6P_5Q_5^5 + Q_5^6$$

We have the following probabilities:

— for no element to break down: $P_5^6 = 0.85^6$

— for one element to break down: $6P_5^5\ Q_5 = 6 \cdot 0.85^5 \cdot 0.15$

— for two elements to break down: $15P_5^4Q_5^2 = 15 \cdot 0.85^4 \cdot 0.15^2$ and so on, the probability results for all the six elements to break down, respectively the total non-reliability in operation is:

$$Q_5^6 = 0.15^6 = 0.000011385$$

According to the formula previously given the reliability in operation of the six selectors in parallel results as being:

$$P_T = 1 - Q_T = 1 - 0.000011385 = 0.99988615$$

respectively 99.9988615%. This may practically be considered as 100% safety.

During the period of normal operation of automatic telephone exchanges the frequency of breakdown is reduced and for this reason it may be assumed that the number of breakdowns follows Poisson's law, the distribution of which has been previously shown. According to Poisson's law, the probability for x breakdowns to occur during the period T is:

$$P_{(x)} = \frac{a^x}{x!}\, e^n$$

In the case where $x \to 0$ there results the probability P_0 for no breakdown to appear during the test period T, respectively

$$P_0 = e^{-n}$$

or

$$P_0 = e^{-rT}$$

where:

r is the frequency of breakdowns (yearly, weekly, hourly, etc. breakdowns);

T — total time of operation.

Considering n to be the total number of breakdowns, the breakdown frequency may be written:

$$h = \frac{n}{T}$$

On basis of the results in Table No. 1 we may now pass on to the actual computation of reliability in operation for this exchange. The total reliability in operation of the 100 number exchange is the product of the reliability in operation for its component elements.

$$P_{100T} = P_{01} \times P_{02} \times P_{03} \times P_{04} \times P_{05}$$

The average breakdown percentages being given for one year, the reliability in operation for a week has been computed, respectively

$$T = \frac{1}{52}$$

There results:

$$P_{100T} = 0.950^{\frac{2.4}{52}} \cdot 0.975^{\frac{88.4}{52}} \cdot 0.999^{\frac{10.2}{52}} \cdot 0.999^{\frac{5.4}{52}}$$

considering $P_{05} = 100\%$.

Applying logarithms there results

$$P_{100T} = 0.04615 \cdot \bar{1}.9777 + 1.7 \cdot \bar{1}.9890 + 0.1961 \cdot \bar{1}.9996 +$$

$$+ 0.10384 \cdot \bar{1}.9996$$

hence $P_{100T} = 0.9541$, respectively $P_{100T} = 95.41\%$

2.2. **Actual computation of reliability in operation for 200—900-line automatic telephone exchanges.**

Institution automatic telephone exchanges of 200 lines having the possibility to be expanded up to 900 lines represent a more complex manufacture. These exchanges are used for large industrial units, plants, combinates etc., as well as for state institutions. The institute exchanges are composed of a series of panels having distinct functions (final, cord, register, special service, cord finders, town selectors, motor starting, various and control desk).

The reliability in operation of the component elements being known (approximately the same as for the RS 7735, 100-number exchange, operating on the same principle), one can compute the reliability in operation by functional panels in order to be better able to localize the occurence of faults (initially, faults in design and manufacturing, later one localizes the faults in use).

Table No. 2 shows (in the last two lines) the computation of reliability in operation for the component panels for a week and for a year.

Table No. 2 contains the component elements of the automatic exchange distributed by manufacturing types of panels. The same average percentage of breakdowns per year is taken into consideration as for the 100-number exchange.

Table 2

COMPONENT ELEMENTS OF 200-LINE AUTOMATIC EXCHANGE DISTRIBUTED BY MANUFACTURING TYPES OF PANELS RELIABILITY IN OPERATION BY MANUFACTURING TYPES OF PANELS FOR ONE WEEK AND ONE YEAR

Component sub-assemblies	Mean percentage of breakdowns in one year		Final RS—70625 A	Cord RS—70634 A	Cord RS—70634 B	Register RS—70638	Desk RS—71377	Spec. Serv. RS—70639	Search Cord. RS—70635	Town Select-RS—71156	Motor Starting RS—70647	Various RS—71213	Reliability for one element	Remarks
			1	2	3	4	5	6	7	8	9	10		
1. Flat relays Ø	Rp	E	240	281	281	440	4	58		880	19	59	$P_1 = 97.5\%$	
	R'p	10% D	24	28.1	28.1	44	0.4	5.8	—	88	1.9	5.9		
2. Test relays	Rt	E	24	4	4	8		2		18			$P_2 = 95\%$	
	R'_t	10% D	2,4	0.4	0.4	0.8		0.2	—	0.8				
3. Finders	C	E	14	14	14	2.1		14	16	14			$P_3 = 85\%$	
	C'	15% D	9,1	2.1	2.1				2.4	2.1				
4. Markers	M	E	6	2	2	20	0.4	4		4			$P_4 = 95\%$	
	M'	20 % D	1.2	0.4	4			0.4		0.8				
5. Resistors	R	E	90		165		2	39		180	2	18	$P_5 = 99.9\%$	
	R'	5% D	4.5		8.25		0.1	1.95		9	0.1	0.9		
6. Capacitors	C_d	E	24		20	18	2	1		72	1	18	$P_6 = 99.9\%$	
	C'_d	5% D	1.2		2	0.9	0.1	0.5		3.6	0.05	0.9		
7. Telephone keys	C_t	E				22						9	$P_7 = 98\%$	
	C'_t	10% D				2.2						0.9		
8. Reliability in operation 1 week			P_{1T} 96.24	P_{2T} 98.50	P_{3T} 98 48	P_{4T} 97.20	P_{5T} 99.98	P_{6T} 99,65	P_{7T} 100	P_{8T} 95.54	P_{9T} 99 91	P_{10T} 99.64		
9. Reliability in operation 1 year			45.10	47.10	46,67	24.52	98.97	83.54	99.98	9.30	95,29	84.42		

As an example the mode of computation of reliability in operation is shown for various panels. For a week:

$$P_{1T} = P_1^{-\frac{2,4}{52}} \cdot P_2^{-\frac{2.4}{52}} \cdot P_x \cdot P_4^{-\frac{1.2}{52}} \cdot P_5^{-\frac{4.5}{52}} \cdot P_6^{-\frac{1.2}{52}}$$

or

$$P_{1T} = 0.975^{-0.461} \cdot 0.950^{-0.069} \cdot 0.999^{-0.110}$$

since

$$P_2^{-\frac{2.4}{52}} \cdot P_4^{-\frac{1.2}{52}} = 0.95^{-\frac{3.6}{52}} = 0.069$$

and

$$P_5^{-\frac{4.5}{52}} \cdot P_6^{-\frac{1.2}{52}} = 0.99^{-\frac{5.7}{52}} = 0.110$$

When computing P_x it should be taken into account that the 14 finders operate in parallel 7 by 7.

Under these conditions the non-reliability in operation is $Q_x = 1 - P_x$.

$$Q_x = 1 - 0.85 = 0.15$$

$$Q_x^{14} = 0.15^{14} = 14\, lg\, 0.15 = 14 \cdot \bar{1}.17609$$

or

$$Q_{xT} = 0.000000000002919$$

$$P_{xT} = 1 - Q_{xT} \simeq 100\%$$

Hence there results that

$$P_{1T} = 0.461 \cdot \bar{1}.98900 + 0.069 \cdot \bar{1}.97772 + 0.110 \cdot \bar{1}.99957 = \bar{1}.98334$$

wherefrom

$$\boxed{P_{1T} = 0.9624 = 96.24\%}$$

Similarly for one year

$$P_{1T} = 0.975^{24} \cdot 0.950^{2.4} \cdot 0.950^{1.2} \cdot 0.999^{5.7}$$

wherefrom there results

$$P_{1T} = 0.45104$$

or

$$\boxed{P_{1T} = 45.104\%}$$

In the above example the manner was shown in which the reliability in operation of the final RS 70625 *A* panel in column 1 was computed. The reliability in operation for the other types of panel in columns 2—10 was computed in the same way. *

There results from this computation that, taking into account the average percentage of breakdowns per year of the component parts equally for all the panels, the lowest reliabiliy in operations is shown by the RS 71156 town selector panel (respectively, 95.54% for a week and 9.30% for a year). This reduced reliability influences negatively the entire telephone exchange, and the town selector panel requires more serious maintenance (also to be justified by the 880 flat relays and the 18 test relays).

It should be pointed out that the data computed were for faults, since the number of breakdowns in the normal operating period was much too low.

There results from the above computations that the 200—900 line telephone exchanges require periodical maintenance due to the fact that their availability in time decreases considerably.

Total reliability of the 200-line exchange can be computed by two methods:

a) By making the product of reliability in operation for the component panels

$$P_{T\,200} = P_{1T} \times P_{2T} \times P_{3T} \times \ldots\ldots \times P_{10T} \text{ (for a week, a year, etc.)}$$

or

b) By totalising the component sub-assemblies of the same kind for all the panels and computing a single reliability in operation.

To this end we note by

R_p the sum of flat relays in the exchange and by

R'_p the sum of the average percentage of faulty flat relays

R_t and R'_t represent the sum of the test relays for the exchange and the sum of the average percentage of faulty test relays, and so on.

The above sums as well as those of the other component parts are computed according to Table 2.

Total reliability in operation for one year will be

$$P_{T\,200} = P_1^{-R'_p} \times P_2^{-P'_t} \times P_3^{y} \times P_4^{-M'} \times P_5^{-R'} \times P_6^{-C'_d} \times P_7^{-C'_t}$$

In this manner reliability in operation is not computed for every panel in part, the possibility for errors by successive approximations being thus avoided.

Institution automatic telephone exchanges of 200 lines and more are manufactured on basis of combinations of existing panels. For instance, in order to create a 300-line exchange it is not necessary to double all the panels of the exchange. Only the cord panel and that of town selectors is double, and the RS 70638 register panel is trebled. There results that if the reliability in operation of the exchanges is computed by the "a" method (as a

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* The relatively large volume of computations for each panel in part was carried out at the Centre of Economic Computation and Economic Cybernetics, Bucharest.

function of panel reliability) it is necessary, for the panels multiplied, to raise to the respective power the probability of their breakdown (since the probability of a breakdown is less than the unit and, raised to the respective power it decreases as a function of the number of panels used). For instance, for a 300-line exchange reliability in operation would be

$$P_{T300} = P_{1T} \times P_{2T}^2 \times P_{3T} \times P_{4T}^3 \times P_{5T} \times P_{6T} \times P_{7T} \times P_{8T}^2 \times P_{9T} \times P_{10T}$$

The exchange with the lowest reliability in operation (respectively the one requiring maximum maintenance) is that for 900 lines. The total reliability of this exchange is:

$$P_{T900} = P_{1T}^4 \times P_{2T}^5 \times P_{3T}^4 \times P_{4T}^9 \times P_{5T}^4 \times P_{6T}^4 \times P_{7T} \times P_{8T}^4 \times P_{9T} \times P_{10T}$$

Computing the reliability in operation for each type of exchange the results shown in Table No. 3 were found.

Tabel 3

Number of exchange lines	Reliability in operation	Reljability in operation P_x %
200	$P_{200} = 0.8357$	83.57
300	$P_{300} = 0.7470$	74.70
400	$P_{400} = 0.7015$	70.15
500	$P_{500} = 0.6152$	61.52
600	$P_{600} = 0.5889$	58.89
700	$P_{700} = 0.5165$	51.65
800	$P_{800} = 0.4944$	49.44
900	$P_{900} = 0.4733$	47.33

The analysis of Table No. 3 allows us to make a comparative study of reliability in operation for the 8 types of automatic exchanges. Based on this analysis it is possible to establich both the availability of the echanges and the required maintenance staff.

Likewise, using as a basis for computation the actual breakdowns having occurred for these exchanges (taken from the exchange breakdown records) a comparison can be made between the reliability in operation theoretically determined for a certain time interval and the one determined empirically.

2.3. **Determination of the variation in time of reliability in operation of 200—900 line exchanges in view of their optimum maintenace.**

The computation system shown at point 2.2.b was used to determine the variation in time of reliability in operation of automatic telephone exchanges.

Table No. 4 gives in column *3*, *4*, *5*, *6*, *7*, *8*, *9* and *10* the total component parts of the *200—900* line automatic telephone exchanges.

Reliability in operation for the various types of exchanges was computed by using the formulae at point 2.2.b.

Since the average percentage of faulty parts was given for one year of operation, when applying the formula

$$P_0 = e^{-rT}$$

various time intervals were taken. ($\frac{T}{365}$ for computing reliability in operation for one day; $\frac{T}{122}$ for 3 days; $\frac{T}{52}$ for a week; $\frac{T}{26}$ for 2 weeks; $\frac{T}{12}$ for a month; $\frac{T}{4}$ for a quarter and T for a year.)

The computation of reliability in operation for three types of exchanges is given for one day as an example:

$$P_{200} = 0.975^{\frac{270.2}{365}} \times 0.95^{\frac{6.3}{365}} \times 0.99989^{*} \times 0.95^{\frac{11.2}{365}} \times 0.999^{\frac{24.8}{365}} \times 0.999^{\frac{8.7}{365}} \times 0{,}98^{\frac{5.3}{365}}$$

$$P_{500} = 0.975^{\frac{722.9}{365}} \times 0.95^{\frac{19.2}{365}} \times 0.99989^{*} \times 0.95^{\frac{29.2}{365}} \times 0.999^{\frac{64.15}{365}} \times$$

$$\times 0.999^{\frac{22.3}{365}} \times 0.98^{\frac{11.9}{365}}$$

$$P_{900} = 0.975^{\frac{1129.5}{365}} \times 0.95^{\frac{28.4}{365}} \times 0.99989^{*} \times 0.95^{\frac{49.2}{365}} \times 0.999^{\frac{96.2}{365}} \times$$

$$\times 0.999^{\frac{32.85}{365}} \times 0.98^{\frac{20.7}{365}}$$

By applying logarithms one obtains (after adding the powers of the elements having the same reliability in operation):

$$P_{200} = 0.740 \cdot \bar{1}.98900 + 0.049 \cdot \bar{1}.97772 + 0.091 \cdot \bar{1}.99957 +$$

$$+ 0.014 \cdot \bar{1}.99123 = \bar{1}.99052$$

or $P_{200} = 97.84\%$ for one day of operation

$$P_{500} = \bar{1}.980 \cdot \bar{1}.98900 + 0.132 \cdot \bar{1}.97772 + 0.237 \cdot \bar{1}.99957 +$$

$$+ 0.032 \cdot \bar{1}.99123 = \bar{1}.97489$$

or $P_{500} = 94.38\%$ for one day of operation

$$P_{900} = 3.094 \cdot \bar{1}.98900 + 0.212 \cdot \bar{1}.97772 + 0.354 \cdot \bar{1}.99957 +$$

$$+ 0.056 \cdot \bar{1}.99123 = \bar{1}.96060$$

or $P_{900} = 91.33\%$ for one day of operation

The same computation is repeated for 3 days, 1 week, 2 weeks, 1 month, 1 quarter and 1 year.

The results obtained are specified in Table no. 4

Considering, for example, that reliability in operation higher than 90% satisfies the required conditions of use during the period of normal operation, there results that, for the 200 line exchange, a revision of breakdowns at a 3-day interval is sufficient, for a 500 number exchange a 1-day interval, and for the 900 line exchange (for greater reliability) it is recommended to effect it twice a day.

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* Since the elements are mounted in parallel their reliability in operation is practically 100%.

Telephone exchanges				Telephone		
Necessary elements				200 lines	300 lines	400 lines
0	1		2	3	4	5
1.	Flat relays	ΣRp	T	2 702	4 303	5 326
		$\Sigma R'p$	10%	270.2	430.3	532.6
2.	Test relays	ΣRt	T	68	98	136
		$\Sigma R't$	10%	6.8	9.8	13.6
3.	Finders	ΣC	T	78+78	106+106	148+148
		$\Sigma C'$	15%			
4.	Markers	ΣM	T	56	82	112
		$\Sigma M'$	20%	11.2	16.4	22.4
5.	Resistors	ΣR	T	496	676	972
		$\Sigma R'$	5%	24.8	33.8	48.6
6.	Capacitors	ΣCd	T	174	264	329
		$\Sigma C'd$	5%	8,7	13.2	16.45
7.	Telephone keys	ΣC	T	53	75	97
		$\Sigma C't$	10%	5.3	7.5	9.7
1.	Reliability in operation for one day		%	97.84		
2.	for 3 days		%	93.73		
3.	for 1 week		%	83.01	78.75	74.11
4.	for 2 weeks		%	73.80		
5.	for 1 month		%	51.74		
6.	for 1 quarter		%	14.07		
7.	for 1 year		%	36.8×10^{-5}		

Table 4

OF „N" LINE AUTOMATIC TELEPHONE EXCHANGES

exchange with					Reliability of elements in operation (probabilistic reliability)	Remarks.
500 lines	600 lines	700 lines	800 lines	900 lines		
6	7	8	9	10	11	12
7 229	7 950	9 853	10 571	11 295	97.5%	
722.9	795	985.3	1 057.1	1 129.5		
192	204	260	272	284	95%	
19.2	20.4	26	27.2	28.4		
204+204	218+218	274+274	288+288	302+302	85 %	
146	168	202	224	246	95 %	
29.2	33.6	40.4	44.8	49.2		
1 283	1 448	1 759	1 924	1 924	99.9%	
64.15	72.4	87.95	96.2	96.2		
446	484	601	639	657	99.9%	
22.3	24.2	30.05	31.95	32.85		
119	141	163	185	207	98 %	
11.9	14.1	16.3	18.5	20.7		
94.38				91.33		
84.11				76.22		
66.64	63.94	57.50	53.04	52.88		
44.39				27.97		
17.22				6.32		
0.51				0.025		
$43.47\times10-50$				$40.18\times10-16$		

In case the distance between exchanges is not too great, there results that a service man can maintain (service) 3—5 200 line exchanges, 1—3 500 line exchanges and, at most, 2 900 line exchanges. The number of exchanges that can be serviced also depends on the skill of the service man who services them, but for equal skill it can be determined according to the above.

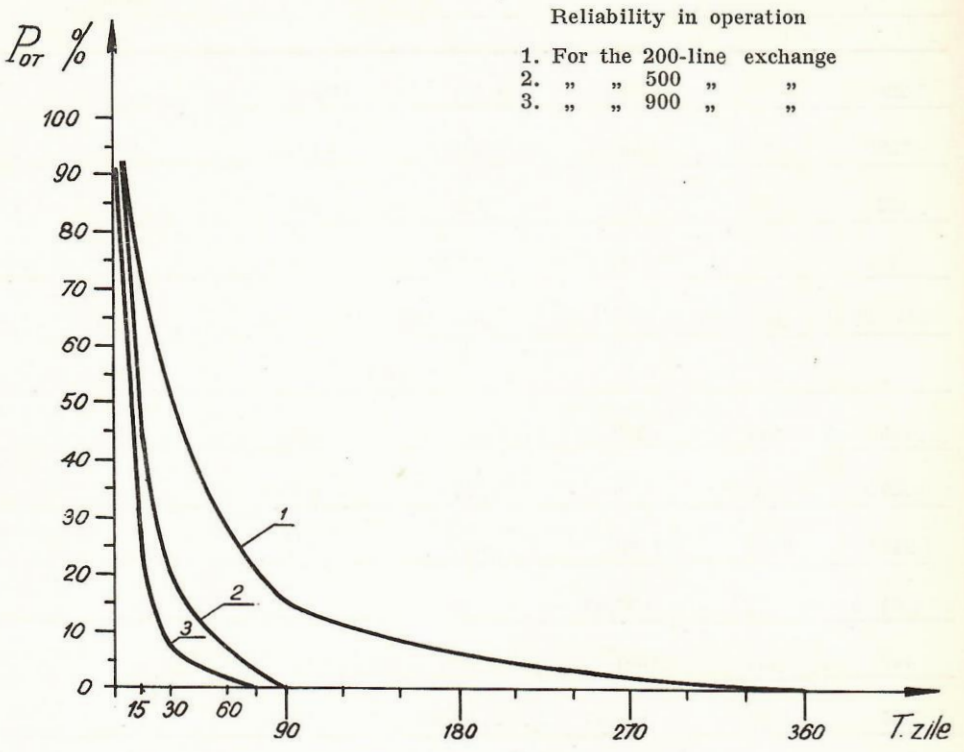

Fig. 2 : Reliability in operation for 200—500 and 900 line telephone exchanges ($P_{OT} = e^{-rt}$)

The variation in time thus determined shows us the frequency of breakdown service necessity also for cases when, owing to less numerous maintenance staff, lower reliability in operation is accepted, thus reducing the availability of the exchange in the same proportion (a part of its circuits do not operate).

If, for example, a minimum reliability in operation of 80% is admitted, it is sufficient to repair breakdowns at a time interval of one week for the 200 line exchange, 3 days for the 500—line exchanges and one day for the 900 line exchanges, a greater coefficient of risk, obviously, assumed under these conditions.

Fig. 2 shows graphically the curves of reliability in operation for the 200, 500, and 900 line exchanges as a function of time through the points determined in Table No.4.

The typical variation of reliability in operation for these 3 types of exchanges results from the graphs plotted, while the reliability in operation for other time intervals than those computed may also be approximated.

We notice the sudden variation of reliability in operation for the 900—line exchange, indicating that large exchanges require either permanent servicing or the use of new elements having increased reliability in operation.

The use of transistors as switching elements, to replace electromagnetic relays, is of particular interest for automatic telephony. Practically, after the running-in period is over, the reliability in operation of transistors during the period of normal use is close to 100%.

It results from the tables shown that the largest number of elements consists precisely of the flat and the test electromagnetic relays, which will mean that the reliability in operation of the complete assembly will increase considerably.

Transistorized telephone exchanges for carrier currents with 3 and 24 simultaneous lines (ST 3 and ST 24) have been manufactured in our country. Their reliability in operation for the basic period is particularly high.

2.4. **Computation of reliability in operation for telephone exchanges over a lengthy time period.**

Reliability in operation for a lengthy time period can be computed in the main on basis of the data recorded for a lengthy use. This time the computation is no longer made as a function of an average percentage of breakdowns, but reported to the effective number of breakdowns recorded for every sub-assembly in part.

The method of computation is the same, the total reliability in operation being, also in this case, the product of the reliability in operation for each element in part, rising to a power equal to the number of breakdowns recorded within a given time period.

There results from the computations effected that the frequency of breakdowns is much larger during the first year after installation, since it is then necessary to remedy defficiencies resulting from transportation, storage, lack of accuracy or due to unsatisfactory adjustments made by the supplying enterprises.

In view of obtaining values close to the ones necessary for a good availability of the exchanges, the reliability in operation was computed for several 200-line exchanges for a time interval Δt of 3 days operation (based on cumulated breakdowns for 6 months, 1 year, 2 years, etc.).

Reliability in operation has the aspect shown in Fig. 3.

The study of these curves shows the low reliability in operation during the running-in period. Fig. 4 shows the curve of reliability in operation computed for fixed 1-year time intervals (extracted from Fig. 3 for the 3-day operation interval).

Reliability in average operation for various Δt time intervals.

The curve in Fig. 4 shows the running-in period (I) characterized by a high frequency of faults and the basic period (II) characterized by a small and constant frequency of faults. The variation of reliability in operation has been further assumed in dots, without yet reaching the wearing-out period (III) where, normally, the frequency of breakdowns must increase suddenly (most of the component elements reaching their computed lifetime).

A particularly important problem is to reduce the frequency of breakdowns during the running-in period (when they are more numerous).

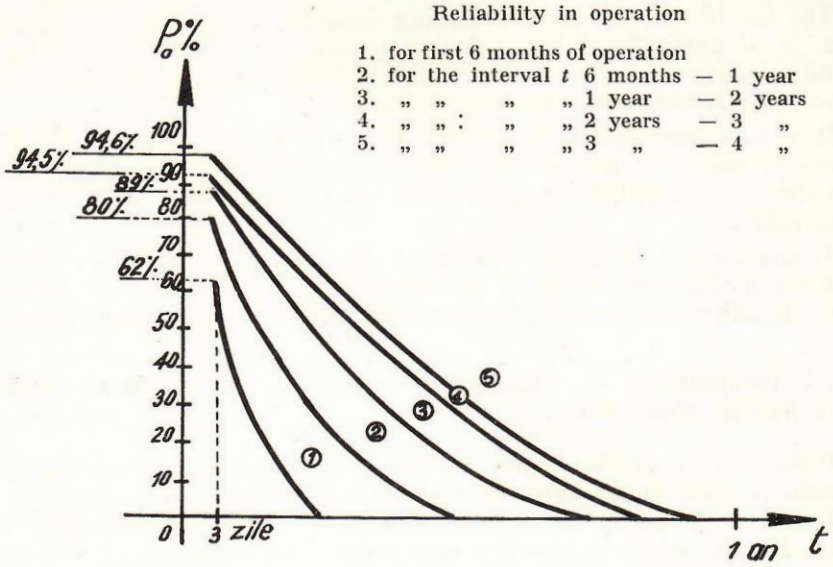

Fig. 3. — Reliability in operation without breakdowns for the same exchange during various time intervals

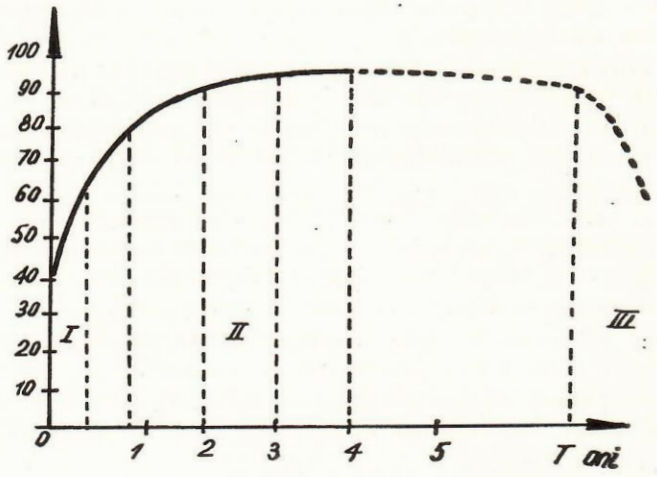

Fig. 4. — Average safety in operation for various Δt time intervals

Table No. 5 shows the manner in which the probability of operation without breakdown has evoluated for RS 7735 100-number exchanges manufactured by the Bucharest „Electromagnetica" plant, during the running-in period (first 1000 hours operation).

Table 5

PROBABILITY OF OPERATION WITHOUT BREAKDOWNS FOR 100-NUMBER TELEPHONE EXCHANGES DURING THE RUNNING-IN PERIOD

Item	Sub-assembly	Pieces / exchange	1959		1960		1961		1962		1963		1964	
			Break-downs/ 1000 h	$-rT$ $P_0 = l$	Break-downs/ 1000 h	$-rT$ $P_0 = l$	Break-downs/ 1000 h	$-rT$ $P_0 = l$	Break-downs/ 1000 h	$-rT$ $P_0 = l$	Break-downs/ 1000 h	$-rT$ $P_0 = l$	Break-downs/ 1000 h	$-rT$ $P_0 = l$
0	1	2	3		4		5		6		7		8	
1.	Marker	12	9	47.2	9	47.2	8	51.7	5	66.4	4	71.9	9	84.8
2.	Selectors and finders	64	48	47.2	47	47.7	48	47.2	29	63.5	28	62.9	12	83.5
3.	Relays	884	750	42.7	680	46.3	470	58.8	320	69.7	184	81	105	88.6
4.	Capacitors	204	2	99	0	100	1	99.5	1	99.5	0	100	0	100
5.	Resistors	108	32	74.5	41	68.4	34	72.5	22	81.8	19	84	5	96
6.	Fuses	110	25	79.8	22	81.8	20	83.5	18	85	12	89.5	8	93.2
	Total reliability	1 372	PoT=5.6%		PoT=5.9%		PoT=8.8%		PoT=20.5%		PoT=27.5%		PoT=55%	

The increase of reliability in operation during this period is explained, in the first place, by the manufacturing and technological measures adopted, as for instance:

1) Introduction of running-in tests for a series of component sub-assemblies;

2) Re-designing of circuit in view of assuring the minimum operating voltages and currents for all the relays and machines in the circuits.

3) Increased diameter of relay tightening screws and supply of adequate tightening presses.

4) Re-designing of tools, devices and checking gauges which did not ensure the required accuracy.

5) Introduction of a series of technological operations in view of sorting the parts by groups of tolerance and others.

To the above should be added measures in organization which led to reinforcement of technical checking, improved worker, technician and engineer qualification at their working place, extension of up-to-date working methods, etc.

CONCLUSIONS

An important parameter linked to the quality of industrial products is their reliability in operation, which expresses the capacity of the products to fulfill all the functions for which they have been conceived, for as long a time as possible under certain given operating conditions.

Using the methods of mathematical statistics and the calculus of probability, the reliability in operation of some complex products such as automatic telephone exchanges, can be computed as a function of their component elements. Thus, the designer is able to make the performances of the conceived product agree with the requirements demanded by operation.

This paper has established the basis of the computing methodology used to estimate the reliability in operation of a few types of automatic telephone exchanges used in our country, then passing on to the actual computation of reliability in operation. This computation allows us to compare the manufactured products from the standpoint of their life, frequency of breakdowns, availability, required maintenance staff, etc.

The manufacturing and technological changes influence one way or another the frequency of breakdowns, so that, on basis of the computation of reliability in operation it becomes possible to appreciate the influence of these changes on the quality of the products. The improvement of the reliability in operation of the component elements of telephone exchanges always leads to total assemblies which yield increased reliability in operation.

The computation of reliability in operation is particularly important when closing agreements for products from abroad or when choosing the licenses that are most efficient in operation.

In the domain of automatic telephone exchanges, a criterion in choosing the new types to be adopted by our industry, should be their reliability in operation in view of achieving their increased life in the conditions of a higher availability.

The adoption of transistorized telephone exchanges will lead to the increase of reliability in operation due to the increased safety of transistors in comparison with electromagnetic switching elements.

Prolonged investigation during the operation of telephone exchanges, proper systematizing of the results obtained and their scientific interpretation make for manufacturing and technological betterment of telephone exchanges, and for the elimination of deficiencies along the entire technological flow of manufacture.

The study of reliability in operation of automatic telephone exchanges can also be extended to other complex industrial products in view of obtaining their qualitative betterment.

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CALCUL DE LA SÛRETÉ DE FONCTIONNEMENT DES CENTRALES TÉLÉPHONIQUES AUTOMATIQUES FABRIQUÉES DANS LA RÉPUBLIQUE SOCIALISTE DE ROUMANIE

L'auteur expose le mode de calcul de la sûreté de fonctionnement pour l'ensemble des centrales téléphoniques, tenant compte de la sûreté de fonctionement des éléments composants.

Le calcul de la sûreté de fonctionnement est appliqué aux centrales RS 7735 de 100 numéros et aux centrales d'institution, de 200—900 numéros. L'article fait une étude comparative de 8 types de centrales téléphoniques, établissant autant la disponibilité des centrales que le personnel d'entretien nécessaire.

Dans la dernière partie de l'article on montre la variation de la sûreté de fonctionnement des centrales pour un temps plus prolongé, d'où résultent la période de rodage où on rencontre une plus grande fréquence des défections, une période de fonctionnement normal et une d'usure. On démontre en conclusion l'importance que présente le calcul de la sûreté de fonctionnement des produits pour les diverses étapes de leur exploitation, en commençant depuis l'élaboration de leurs projets et jusqu'à leur fonctionnement prolongé dans les conditions effectives d'exploitation.

РАСЧЕТ БЕЗОПАСНОСТИ В ФУНКЦИОНИРОВАНИИ ЦЕНТРАЛЬНЫХ АВТОМАТИЧЕСКИХ ТЕЛЕФОННЫХ СТАНЦИЙ, СДЕЛАННЫХ В СОЦИАЛИСТИЧЕСКОЙ РЕСПУБЛИКЕ РУМЫНИИ

В работе представлен метод расчета безопасности в работе для целого ансамбля центральных телефонных станций, учитывая безопасность функционирования составных элементов.

Расчет безопасности во время функционирования применяется на телефонных станциях на 100 номеров RS-7735 и на телефонных станциях учреждений на 200—900 номеров.

В работе проводится сравнительное исследование восьми типов телефонных станций и одновременно определяются как резервы станций, так и персонал, необходимый для их обслуживания.

В последней части работы показана вариантность безопасности в работе станций на протяжении долгого периода времени, из которой вытекает период освоения с увеличенной частотой дефектов, период нормального функционирования и период износа. В конце показано значение, которое имеет расчет безопасности в работе аппаратуры на различных этапах её эксплуатации, начиная с проектирования и до продолжительной работы в реальных эксплуатационных условиях.