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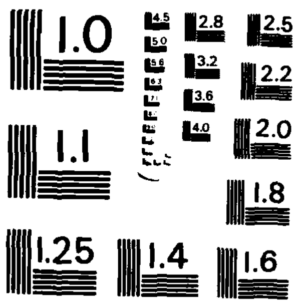

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FOREIGN TECHNOLOGY DIVISION

DESIGN AND MANUFACTURING TECHNOLOGY OF RADIOELECTRONIC EQUIPMENT

(CHAPTER V)

by

N.F. Vollerner

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DESIGN AND MANUFACTURING TECHNOLOGY OF RADIOELECTRONIC EQUIPMENT (CHAPTER V)

By: N.F. Vollerner

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

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Chapter V.

GUARANTEE OF THE RELIABILITY OF RADIO AND ELECTRONIC EQUIPMENT.

Radio and electronic equipment [REA] can go out of order as a result of internal and external effects on it. The more complicated the equipment, the greater the probability of its failures. However, technical progress is not thought without the complicated means of radio electronics. Therefore the problem of an increase in their reliability is one of the bases [2, 30, 40].

Failures of REA - random events; therefore reliability can be rated/estimated only statistically. The theory of reliability, as any other statistical theory, cannot predict the behavior of separate instrument, but sufficiently accurately it can rate/estimate the behavior of entire set - ensemble. For the ensemble of real instruments is known only the fact that on the average with a large number of tests the specific part of the instruments will malfunction, but it is unknown, what precisely.

Reliability - probabilistic category, which characterizes properties of REA (other devices/equipment), caused by its reliability, by life and maintainability, and ensuring the normal fulfillment of the assigned functions. Quantitatively reliability is rated/estimated by the product of the probability of the failure-free operation P to the readiness factor $K_{г}$.

Readiness factor

$$K_{г} = \Sigma T_{раб}/(\Sigma T_{раб} + \Sigma T_{рем} + \Sigma T_{проф}), \qquad \text{(V-1)}$$

where $\Sigma T_{раб}$ - total time of failure-free operation; $\Sigma T_{рем}$ - total time, spent on the repair, detection, position finding and clearing; $\Sigma T_{проф}$ - total time of preventive works, spent on the routine inspection, checking, scheduled maintenance, etc.

By reliability[1] is understood the property of REA to continuously remain operable under the specific modes/conditions and operating conditions.

FOOTNOTE [1]. Sometimes in the literature reliability is called reliability. ENDFOOTNOTE.

Efficiency quantitatively is rated/estimated by the probability of failure-free operation or by other indirect probabilistic indices - with rate of failures λ and by the mean time between failures T_{M} (SV-2).

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Efficiency - state of REA, in which it corresponds to requirements of TU, but only with respect to the fundamental parameters, which are determining the normal fulfillment of the assigned functions. Malfunction of REA - disturbance/breakdown of norms of TU from any fundamental or secondary parameter. The secondary parameters rate/estimate not fundamental characteristics of REA, for example convenience in the maintenance - signal lamps of safety devices/fuses, knob/stick for the transference, etc.

Failures divide into the sudden ones (catastrophic) and the gradual ones (parametric). The random failures appear as a result of sharp random changes in the parameters of elements/cells, for example the breakdown of capacitors or transistors, the break of wire or resistor, etc. The deterioration failures appear as a result of slow changes in the parameters of elements/cells, which derive/conclude the determining parameter beyond the limits of the tolerance range . For example, a change in the parameters (aging) of transistor leads to the disruption/separation of generation or the decrease of amplification.

Distinguish the complete failures, when REA not at all works, and partial, when REA works, but it does not completely satisfy the requirements for the fundamental parameters, for example the light rating of transmitter. According to the character of manifestation in the time failures divide into the stable ones, i.e., those continuing to their elimination by road-mending machines, and keeping aloof. The latter, in turn, are divided into the short duration failures (rare, short-duration failures) and the intermittent failures (repeated, frequently repeating short duration failures).

In connection with the reliability, REA it is possible to divide into restored, i.e., overhauled during the service life, and not restored, which in the case of the failure, for example, the radio detonators, transistors, capacitors replace.

SV-1. Economy of reliability.

The optimum reliability (SX-2), which corresponds to the minimum expenditures/consumptions of user for the operating time of REA, can be determined, using expression for the total cost/value (SI-4); additionally are considered the possible losses (losses), caused by malfunctions of REA in the service life. These losses are determined by idle times C'_{np} (for example, with the malfunction of the line of communications or of computer the operating organizations do not obtain payment), or by possible death of material and other values C'_r (for example, due to the malfunction of controller can occur the emergency). If losses per hour of idle time compose C_{np}, the mean time of one repair $T_{рем}$, an average in the service life T number of failures (repairs) $n_{cp} = T/T_н$, $T_н$ - the mean time between failures, then losses for time T, led to the time of the beginning of operation, by analogy with (I-4)

$$C'_{np} = C_{np} T_{рем}\, n_{cp} (T_0/T) [1 - \exp(1 - T/T_0)] = C_{np} T_{рем} (T_0/T_н) [1 - \exp(-T/T_0)]. \quad \text{(V-2)}$$

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If failure of REA can with probability P_r produce the death of property for sum C_r, then in (V-2) it is necessary to add the mathematical expectation of losses, equal to $P_r C_r$.

Thus, the generalized cost/value of equipment is equal to total cost/value (I-4) plus losses due to its malfunction:

$$C_{\Sigma н} = C_к + C'_э + C'_0 + C'_{np} + C'_r; \quad \text{(V-3)}$$

$$C_{\Sigma н} = C_к + T_0 [C_э + C_0 + (C_{np} T_{рем} + P_r C_r)/T_н] [1 - \exp(-T/T_0)]. \quad \text{(V-4)}$$

Simple relationship/ratio (V-4) helps to determine optimum reliability of REA (in the sense of the minimum generalized cost/value).

Let us find minimum cost/value of REA

$$dC_{\Sigma a}/dP = 0. \qquad \text{(V-5)}$$

After solving equation (V-5), it is possible to find optimum efficiency $P_{\text{опт}}$ (SV-2).

For solving equation (V-5) are necessary the analytical relationships/ratios, which connect efficiency P (reliability $P_{\text{э}}$) with first cost $C_{\text{к}} = \psi_{\text{к}}(P)$, expenditures for operation $C'_{\text{э}} = \psi_{\text{э}}(P)$ and maintenance

$$C'_{0} = \psi_{0}(P).$$

The first cost of REA $C_{\text{к}}$ is determined by expenditures for its development, cost/value of materials and parts, by wages, etc. For REA of the increased reliability the expenditures for development increase; the cost/value of parts, assemblies and materials, production of devices/equipment and so forth in this case considerably higher than usual (SV-3). There are no universal relationships/ratios, which numerically connect $C_{\text{к}}$ and P, since for all possible types of the equipment, manufactured in the different enterprises, the numerical characteristics can be changed. However, the expression

$$C_{\text{к}} = h/(1 - P^{a})^{b} \qquad \text{(V-6)}$$

during the appropriate selection of the constants h, a, and b correctly reflects dependence $C_{\kappa} = \psi_{\kappa}(P)$: sharp increase C_{κ} with approximation/approach P to one (Fig. V-1).

Operating costs virtually do not depend on the required reliability, since state/staff and qualification of operators little affect reliability of REA. In the approximate computations it is possible to consider that the operating costs do not depend on efficiency (reliability) of REA.

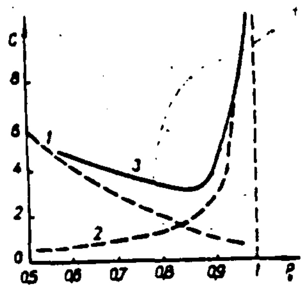

Fig. V-1. Optimum reliability of REA: 1.- $C_э$ the cost/value of maintenance; 2 - $c_к$ the first cost of REA; 3 -$c_{\Sigma э}$ general/common/total cost/value of REA.

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Expenditures for maintenance depend substantially on the reliability of equipment. A decrease in the efficiency raises the expenditures for repair, which are folded from the cost/value of the replaced parts and the wages of road-mending machines. Expenditures for routine checks and inspection of equipment little depend on the required efficiency.

Let us rate/estimate expenditures per unit time for maintenance, it is more precise to repair $(C_0' \approx C_{рем}')$:

$$C_э \approx C_{рем}/T_н = (T_{рем}C_{раб} + mC_{дет})/T_н, \qquad \text{(V-7)}$$

where $T_н$ - mean time between failures (repair); $C_{рем}$ - cost/value of one repair; $T_{рем}$ - average duration of repair; $C_{раб}$ - wages per hour; $C_{дет}$ - mean cost/value of one replaced part; m - average number of parts, replaced during one repair; according to the statistical data m=2.3, $T_{рем}$=3.3 hour.

After substituting equalities (V-6) and (V-7) into formula (V-4), after excluding operating costs $C_э$, we will obtain

$$C_\Sigma = h/(1-P^a)^b + (T_0/T_и)(T_{рем}C_{раб} + mC_{дет} + T_{рем}C_{пр} + P_rC_r)[1-\exp(-T/T_0)]. \qquad \text{(V-8)}$$

$P_{опт}$ - optimum efficiency in the sense of the smallest cost/value let us find, after substituting relationships/ratios (V-8) in (V-5). The obtained equations are transcendental, to solve them in general form is impossible. Under the specific conditions it is possible to solve them by numerical methods. The obtained relationships/ratios can be illustrated by the graph/curve (Fig. V-1), which reflects characteristic dependences for the general/common/total cost/value. The use/application of calculated relationships/ratios (V-5)-(V-8), that are determining optimum efficiency under the actual conditions, is impossible without the numerical values of coefficients. The numerical values of the coefficients can be obtained from the generalized technical-economic characteristics of REA (Chapter X) and the statistical evidence about the failures.

For the collection of materials about the failures of REA were developed the special maps/charts/cards, in which noted the conditions for work of REA at the moment of each failure; the reasons for failure; what elements/cells produced failure (independent failure) and what elements/cells as a result of this failure additionally refused (the dependent failure); how long it lasted the search for damage and strictly repair; what and how many parts they replaced and so forth.

As a result of similar statistic studies in the middle Fifties interesting averaged data (Table V-1) about the distribution of the reasons for failures (without taking into account electron tubes) [2] were obtained.

These data show that 43% of all failures of operable REA were caused by errors during the design, 20% - by incorrect operation, and 10% - by incorrect maintenance/servicing.

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Table V-1. Classification of the reasons for failures.

(a) Раздел	(b) Причины	(c) Количество повреждений, %
(d) Проектирование (конструкционные отказы)	1. Электрические:	
	а) недостаток схемы	11
	(b) б) неправильный выбор электрических величин	10
	(c) в) неправильное применение элементов	12 / 33
	2. Механические:	
	а) неправильный выбор материала	5
	(b) б) неправильная механическая конструкция	5 / 10
(e) Эксплуатация (эксплуатационные отказы)	1. Климатические условия и механические нагрузки, не соответствующие заданным	12
	2. Неправильное обслуживание	10
	3. Неправильный режим эксплуатации	8 / 30
(f) Производство (технологические отказы)	1. Изготовление не в соответствии с техническими условиями	18
	2. Недоброкачественное сырье и полуфабрикаты	2 / 20
(g) Прочие	1. Износ, старение	4
	2. Разные и неустановленные	3 / 7

Key: (a). Section. (b). Reasons. (c). Number of damages, %. (d). Design (design failures). 1. Electrical. a) a deficiency/lack in the diagram. b) the incorrect selection of electrical values. c) the misapplication of elements/cells. 2. Mechanical. a) the incorrect selection of material. b) incorrect mechanical design. (e). Operation (operational failures). 1. Climatic conditions and mechanical loads, which do not correspond to given ones. 2. Incorrect maintenance/servicing. 3. Incorrect mode/conditions of operation. (f). Production (technological failures). 1. Production not in accordance with technical specifications. 2. Low-grade raw material and semi-finished products. (g). Other. 1. Wear, aging. 2. Different and not established.

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It is of interest and distribution of failures according to the types of the completing articles (Table V-2). Electron tubes undergo up to 50% of failures, which is one additional foundation for the replacement by their transistors, when this is technically possible and is permitted by operating conditions.

The high percentage of failures due to the resistors and the capacitors, in spite of their high reliability, it is determined by their large applicability in the diagrams of REA (Table V-3).

The analysis of data of Table V-3 shows that in REA for every tube (transistor) on the average there are 6-7 capacitors, 5-6 resistors, 20-30 solderings, 2-3 inductive elements, etc.; therefore the preliminary simplified evaluation/estimate of the complexity of devices/equipment according to a number of tubes or transistors is permitted.

Table V-2. Distribution of failures according to the circuit elements.

(1) Наименование радиодеталей	(2) Количество повреждений, %
Электронные лампы (3)	50
Резисторы (4)	15
Конденсаторы (5)	8
Трансформаторы и катушки индуктивности (6)	3
Выключатели, переключатели, штепсельные разъемы, реле (7)	9
Прочие (8)	15

Key: (1). Designation of radio parts. (2). Number of damages, %. (3). Electron tubes. (4). Resistors. (5). Capacitors. (6). Transformers and inductance coil. (7). Switches, switches, plugs, relay. (8). Other.

Table V-3. Applicability of circuit elements.

(1) Группа элементов	(2) % аппаратуры по принципиальной схеме		
	(3) радиолокационная и радионавигационная	(4) приемно-передающая	(5) приемная
Электровакуумные приборы (6)	5,3—11,6	3,5—6	3,6—7,3
Конденсаторы (7)	20—32	37—52	41—61
Резисторы (8)	37—51	22—31	16—28
Трансформаторы и дроссели (9)	3,2—14	4,2—12	0—7,1
Катушки индуктивности, фильтры, линии задержки (10)	1,2—14	3,6—10	8—22
Реле (11)	0—2,5	0—4,8	0—3,3
Сельсины, электродвигатели, преобразователи (12)	0—2,7	0—1,6	0—0,5
Измерительные приборы (13)	0—2,3	0—1,4	0—0,6
Осветительные и индикаторные лампы (14)	0—4	0—1,1	0—0,5
Кварцы (15)	0—0,4	0—7	0—2,8
Предохранители (16)	0,2—4,8	0,3—0,9	0,3—0,6

Key: (1). Group of elements/cells. (2). % equipment on schematic diagram. (3). radar and radio navigation. (4). transceiving. (5).

receiving. (6). Vacuum-tube instruments. (7). Capacitors. (8). Resistors. (9). Transformers and chokes/throttles. (10). Inductance coils, filters, delay line. (11). Relays. (12). Selsyns, electric motors, converters. (13). Measuring meters. (14). Lighting and indicator lights. (15). Quartzes. (16). Safety devices/fuses.

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SV-2. Calculation of efficiency according to the random failures.

The random failures of elements/cells - random events. Consequently, efficiency of these elements/cells after failure also random event. Let us test a set of N of the same-type, unrepaired elements/cells (systems) of exact ones with t=0. For the time from 0 to t reject n(t) of elements/cells, exact remain N-n(t). Efficiency of elements/cells at the end of the interval 0-t at moment/torque t, determined by the probability of their working order $P_i(t)$, is numerically expressed by the ratio of a number of favorable events - exact elements/cells - N-n(t), to a total number of events - number of elements/cells N [5]:

$$P_i(t) = [N - n(t)]/N = 1 - n(t)/N, \qquad (V\text{-}9)$$
$$dP_i(t)/dt = -[dn(t)/dt]/N \approx -\Delta n(t)/\Delta t N, \qquad (V\text{-}9a)$$

where Δn(t)/Δt - number of elements/cells, which refused per unit time, connected with the rate of failures $\lambda_i(t)$. Rate of failures they call the failure probability of the unrestorable (unrepaired) element/cell for the single time and numerically determine by the ratio of a number of elements/cells, which refused for the time from t to t+Δt, to the product Δt to a number of exact elements/cells at moment/torque t:

$$\lambda_t(t) \approx [n(t+\Delta t) - n(t)]/\Delta t\,[N - n(t)] = \\ = \Delta n(t)/\Delta t\,[N - n(t)]. \qquad \text{(V-10)}$$

After substituting relationship/ratio (V-10) in (V-9a), let us find

$$dP_t(t)/dt = \lambda_t(t)\,[N - n(t)]/N = -\lambda_t(t)\cdot P_t(t) \\ dP_t(t)/P_t(t) = -\lambda_t(t)\,dt.$$

Integrating, we will obtain

$$\ln P_t(t) = -\int_0^t \lambda_t(t)\,dt + c_1'; \quad P_t(t) = c_1 \exp\left[-\int_0^t \lambda_t(t)\,dt\right].$$

With t=0 all elements/cells are exact and efficiency $P_t(0) = 1$, so that arbitrary constant c_1=1.

$$P_t(t) = \exp\left[-\int_0^t \lambda_t(t)\,dt\right]. \qquad \text{(V-11)}$$

If rate of failures $\lambda_t(t)$ does not depend on time, then

$$P_t(t) = \exp(-\lambda_t t). \qquad \text{(V-12)}$$

Is obtained important relationship/ratio - exponential decay law of efficiency in the time when λ_t =const (SV-3).

Let us find the mean time of failure-free operation T_{cp} - the unrestorable elements/cells, by assuming that λ_t =const.

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For the random functions the mean time of the failure-free operation

$$T_{icp}=\int_0^\infty tq_t(t)\,dt=-\int_0^\infty t\,dP_t(t)=-tP_t(t)\Big|_0^\infty+\int_0^\infty P_t(t)\,dt=\int_0^\infty P_t(t)\,dt, \quad \text{(V-13)}$$

where $q_t(t)$ - probability density of the failures of elements/cells $q_t(t)=d\overline{P_t(t)}/dt=d[1-P_t(t)]/dt=-dP_t(t)/dt$; the first term it is equal to 0, since $P_t(t)$ with $t\to\infty$ it falls more rapidly than 1/t (for example, V-12). The group of the random events (element/cell is exact or refused) complete; therefore the failure probability of element/cell (unfitness for work) $\overline{P_t(t)}$ and the probability of working order (efficiency) $\overline{P_t(t)}$ in the sum were equal to one.

Under exponential decay law of efficiency (V-12)

$$q_t(t)=-dP_t(t)/dt=\lambda_t\exp(-\lambda_t t).$$

Integrating (V-13), we will obtain

$$T_{icp}=\int_0^\infty P_t(t)\,dt=\int_0^\infty \exp(-\lambda_t t)\,dt=1/\lambda_t. \quad \text{(V-14)}$$

After using relationship/ratio (V-14), (V-12) it is possible to record thus:

$$P_t(t)=\exp(-\lambda_t t)=\exp(-t/T_{icp}), \quad \text{(V-15)}$$

where T_{icp} - conditional (SV-3) mean time of failure-free operation with constancy λ_i, during which efficiency of element/cell decreases in e of times $P_i(T_{icp}) = 1/e \approx 0{,}37$.

During the design the procedure of calculation of efficiency of REA according to the reliability of the entering it instruments, assemblies and elements/cells is necessary. During the calculation of reliability they assume that all elements/cells are necessary for the exact work of REA and the failure of any element/cell leads to its failure. This circuit of elements/cells in the theory of reliability is called series connection of elements/cells. Let us assume also that the reasons for the failures of elements/cells are statistically independent; for the random failures - this is actual. With such prerequisites/premises probability $P_\Sigma(t)$ - the complicated random event of efficiency of REA as a whole - simultaneous efficiency all n of the elements/cells, entering series connection, is equal to the product of efficiencies $P_i(t)$ of all elements/cells:

$$P_\Sigma(t) = \prod_{i=1}^{i=n} P_i(t). \qquad \text{(V-16)}$$

If series connection n of elements/cells involves k different types with respect to n_j identical elements/cells $\sum_{j=1}^{j=k} n_j = n$, then

$$P_\Sigma(t) = \prod_{j=1}^{j=k} P_j(t)^{n_j}. \qquad \text{(V-17)}$$

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Under exponential law of decay of efficiency of elements/cells (V-12)

$$P_\Sigma(t) = \prod_{i=1}^{i=k} P_i(t)^{n_i} = \prod_{i=1}^{i=k} \exp[-\lambda_i n_i t] = \exp\left(-t\sum_{i=1}^{i=k}\lambda_i n_i\right) = \exp(-t/T_{\Sigma cp}), \quad \text{(V-18)}$$

where $T_{\Sigma cp} = 1/\sum_{i=1}^{i=k}\lambda_i n_i$ — mean time of failure-free operation of REA.

Relationship/ratio (V-18) analytically connects efficiency on the random failures of system with the rate of failures of separate elements/cells. For calculating the efficiency of system with series connection of elements/cells it is necessary to know a quantity and the rates of failures of these elements/cells.

Is of interest one additional statistical parameter - mean time between failures $T_н$. The mean time between failures is defined as the mean operating time of the restorable (overhauled) system between two adjacent failures. If system exactly studied (it produced) $T_p = \sum_{i=1}^{i=m} t_i$ the hours, where t_i — operating time between two adjacent failures, and m - total number of failures, then $T_н = T_p/m = \sum_{i=1}^{i=m} t_i/m$. (V-19)

If the law of a change of the efficiency with time after failures and restorations/reductions (repairs) is not changed, then mean operating time between the failures (mean time between failures) $T_{н}$ must not depend on the number of failure and it is equal to operating time to first failure T_{cp}. The law of a change in the efficiency of system after restorations/reductions is not changed, if $\lambda_i(t) = \lambda_i = \text{const.}$ failure rate does not depend on time, but in this case decay law of efficiency is exponential (V-12). Thus, under exponential decay law of efficiency $T_{н} = T_{\Sigma cp} = 1/\Sigma\lambda_i n_i$; the mean time between failures $T_{н}$ it is equal to the mean time of failure-free operation $T_{\Sigma cp}$.

With a large number of elements/cells efficiency $P_{\Sigma}(t)$ and mean time between failures $T_{н}$ of system are insignificant (Fig. V-2).

Let us note two important special features/peculiarities of exponential decay law of efficiency. Efficiency in the interval of time τ does not depend on reference point of its.

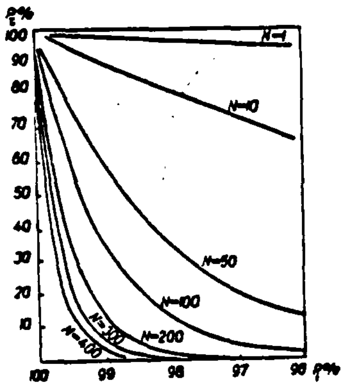

Fig. V-2. Dependence of efficiency of system P_Σ on efficiency P_i and number of elements/cells N.

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Actually/really, efficiency - this is the ratio of a number of exact elements/cells at the end of experiment to a number of exact ones in the beginning (V-9). In the beginning of experiment at moment/torque t from the N elements/cells with t=0 remained exact NP(t), at the end of experiment NP(t+τ) were exact. Then efficiency in interval of t-(t+τ)

$$NP(t+\tau)/NP(t) = \exp[-\lambda(t+\tau)]/\exp(-\lambda t) = \exp(-\lambda\tau) = P(\tau),$$

(V-12) is equal to efficiency in interval of t_1-(t_1+τ).

For the high efficiency in the interval τ its duration must be considerably less than the time of operating time $T_{\text{н}} = T_{\text{ср}} \gg \tau$:

$$P(\tau) = \exp(-\tau/T_н) \approx 1 - \tau/T_н \text{ (for } \tau/T_н \ll 1).$$

It is repeated, which said is correct only under exponential law ($\lambda_t = \text{const}$).

The structure of expressions (V-17) and (V-18) prompts that during the calculation of efficiency of complicated devices/equipment it is possible to calculate unit-by-unit efficiency, and after multiplying the obtained results, to find efficiency of system as a whole.

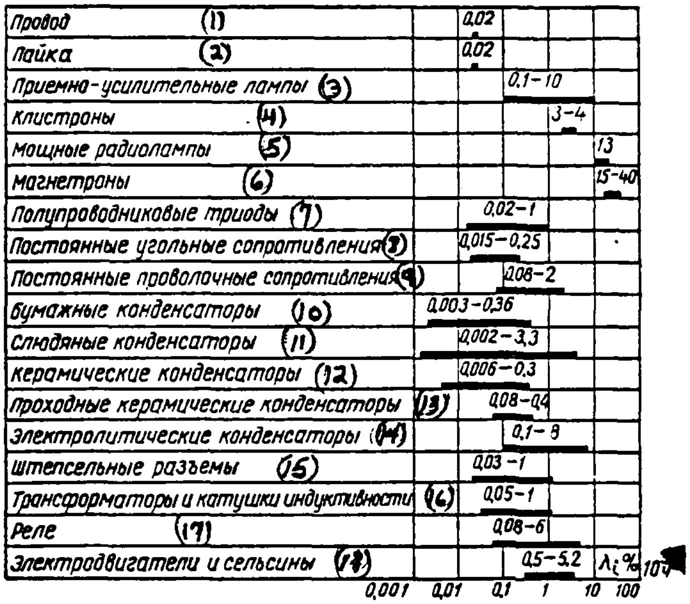

Fig. V-3. Rates of failures of circuit elements of REA.

Key: (1). Wire. (2). Soldering. (3). Receiver-amplifier tubes. (4). Klystrons. (5). Powerful/thick radio tubes. (6). Magnetrons. (7). The transistors. (8). Constant carbon resistors. (9). Constant wire-wound resistors. (10). Paper capacitors. (11). Mica capacitors. (12). Ceramic capacitors. (13). Passage ceramic capacitors. (14). Electrolytic capacitors/condensers. (15). Plugs. (16). Transformers and inductance coil. (17). Relay. (18). Electric motors and selsyns.

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For the estimate evaluations it is possible to find average/mean efficiency of one transistor (tube) with the parts (SV-1) connected with it:

$$P_{\text{т}}(t) = \exp[-t(\lambda_{\text{т}} + 5\lambda_{\text{р}} + 5\lambda_{\text{к}} + 2\lambda_{\text{и}} + 20\lambda_{\text{п}} \cdots)],$$

where $\lambda_{\text{т}}, \lambda_{\text{р}}, \lambda_{\text{к}}, \lambda_{\text{и}}, \lambda_{\text{п}}$ — rates of failures of transistors, resistors, capacitors, inductive elements/cells and solderings (Fig. V-3).

Let us recall also that the results of calculating the efficiency, as any probabilistic calculation, they are valid only on the average and have the specific, frequently sufficiently wide, confidence intervals, so that the results of calculation can considerably differ (due to the dispersion - statistical straggling) from the results, obtained in one or the other concrete/specific/actual realization.

SV-3. Failures of elements of REA.

The rate of failures of elements/cells of REA is determined experimentally. The possibility is not excluded that as a result of the more complete knowledge of physical processes it will be possible to calculate the reliability of elements/cells of REA [19]. Failure rate is determined, noting the time of failures and a number of refused elements/cells in the experienced/tested group of the N elements/cells, computing then according to relationship/ratio (V-10) value $\lambda_t(t)$. For the construction of histograms the interval of time $t-(t+\Delta t)$ should be selected so that into this interval several observed events would fall, but not very large so as not to distort (to smooth) distribution curve. The total number of tested objects N must be large, which will make possible to obtain statistically reliable results.

Numerous investigations showed that under normal conditions for the majority of elements/cells intensity curve of the random failures (Fig. V-4) has three fundamental sections. The first - supplementing relatively short-term (50-100) hours), on which the concealed/latent, relatively gross defects of production and initial materials are developed. In this section in proportion to breakdown of elements/cells from gross defects $\lambda_t(t)$ it falls to the nominal value. In the second section - normal operation - by duration from hundred to tens of thousands of hours $\lambda_t(t)$ it is changed little. On the third - wear section - $\lambda_t(t)$ sharply increases due to the aging, the wear and the fatigue of elements/cells.

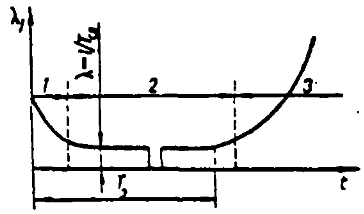

Fig. V-4. The dependence of failure rate of the time: 1 - break-in period; 2 - period of normal operation, the approximately/exemplarily equal to life T_r; 3 - period of wear failures.

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Supplementing section can be excluded by aging/training of REA before putting to use, keeping in mind its short duration. Aging/training is reduced to the work for 50-100 hours under the normal or rigid conditions in order to come to light/detect/expose the gross defects of production or initial materials and to replace unreliable elements/cells.

Time interval, during which $\lambda_1(t)$ is not changed or little is changed, is called life T_r of element/cell. Life in many respects depends on operating conditions, load, etc. It is necessary to emphasize that life T_r is not connected with T_{cp} - by the mean time of failure-free operation (Fig. V-4). Depending on the type of element/cell and operating conditions T_{cp} there can be more or less T_r.

For the radio engineering systems the mean time between failures $T_{в} = T_{\Sigma ср} \ll T_{э}$ since $T_{ср} \gg T_{\Sigma ср} = 1/\sum_{i=1}^{i=k} \lambda_i n_i$. (V-19a)

If service life of REA T is less $T_{э}$, then $\lambda_t \sim \text{const}$ and the calculation of efficiency according to the random failures can be fulfilled, using the exponential law (SV-2). Should be focused attention on the fact that $T_{э}$ — the life, determined by increase/growth $\lambda_t(t)$, does not correspond certified rating life $T_{п}$ of circuit elements, determined by the gradual permissible change in the parameters. For the circuit elements usually $T_{п} < T_{э}$ or even $T_{п} \ll T_{э}$ (SV-4). When $T > T_{э}$ $\lambda_t(t) \neq \text{const}$ (third section of curve, Fig. V-4) and exponential decay law of efficiency, in spite of its simplicity, it is not applied. The more accurately objective parameters of the probability density of efficiency are described by normal law, law of Weibull [1] or by their composition.

FOOTNOTE [1]. Weibull's law $P(x) = \exp(-\lambda x^{\alpha})$, (where α and λ - the parameters) with α=1 passes into the exponential. ENDFOOTNOTE.

Aging, besides an increase in the rate of failures $\lambda_t(t)$, leads to the change in the parameters of elements/cells, which calls gradual (parametric) failures. Let us emphasize that increase/growth $\lambda_t(t)$ and a change of the parameters - two different in the general case, at least outwardly, not mutually connected processes.

It is possible with more or smaller success to forecast the deterioration failures and to replace the aging elements/cells. For example, during the routine checks it is possible to reveal/detect the decrease of mutual conductance of tube during the aging. During the correctly set routine checks all deterioration failures of elements/cells virtually can be forecast and avoided.

Routine checks must be carried out in the rigid mode/conditions in order to come to light/detect/expose the aging elements/cells, whose parameters approach maximum permissible. If elements/cells are operational in the rigid modes/conditions, then it is possible to expect that they will not fail before the following routine checks.

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The stiffening of mode/conditions is produced from the fundamental parameters of this element/cell. For example, the lowered/reduced filament voltage decreases the fundamental parameter of tubes - mutual conductance. The stiffening of mode/conditions for some circuit elements partially permits forecasting the random failures. For example, the probability of the breakdown of capacitor with the worsened/impaired as a result of aging of dielectric during the rigid mode/conditions (increased voltage/stress) increases more than in exact capacitor; the failure probability of resistor with the worsened/impaired conducting layer at the increased dissipated power is more than in exact resistor.

To establish/install the forecasting parameters and the rigid mode/conditions is complicated, since incorrect selection can accelerate aging elements/cells, and this in turn, their reliability will lower. The correctly set routine checks help to reduce the number of the deterioration failures and to somewhat decrease a quantity of the random failures. Therefore during the design of REA (SXII-I) should be allowed for the possibility of conducting such tests without the high expenditure of time, in order not to lower readiness factor (SV-1).

The confident forecasting of the random failures is still impossible, since the advancing/attacking failure outwardly clearly is not developed, but if precisely this, and not other element/cell malfunctioned, then this, obviously, was determined by some reasons, which we yet do not know how to find. The search for the parameters for forecasting the sudden and deterioration failures is one of the fundamental tasks in the region of reliability. The forecasting parameters are necessary for the selection of the elements/cells of REA, which will not fail during the assigned period and during the operation will help to come to light/detect/expose the elements/cells losing efficiency.

Unfortunately, the forecasting parameters are known only for a small number of elements/cells. For example, in the production of semiconductor diodes failures forecast on the increased slope/transconductance of volt-ampere characteristic.

There are tubes and circuit elements of the increased reliability, for example the receiver-amplifier tubes of series E with the increased life - with respect to a change in the parameters - (instead of 500-5000 hours) or series B and BB with the increased reliability - in 1.5 and 2-3 times with smaller failure rate. The tubes of series BB approximately/exemplarily 2-3 times, and series B are 1.5-2 times more expensive than usual. This is explained by the larger labor expense of production and checking, i.e., by the more complete and stricter checking of initial materials, manufactured parts and assemblies, by the finish of technological operations/processes and so forth [32]. In the USA there are five levels of the reliability of the circuit elements, used in REA, with T_{cp} increased into 13, 35, 400 and 4000 times, and by the sharply increasing cost/value in comparison with the market elements of overall use/application.

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By the character of curve $\lambda_t(t)$ (Fig. V-4) it is possible to judge the conditions for production and applying the elements/cells of REA. The tightening itself supplementing section testifies about the poor organization, the low culture of production and checking of parts. The prematurely advancing/attacking aging (third section) testifies about the incorrect mode/conditions of operation, the overloading, etc. Aging, fatigue and wear to a considerable degree are determined by the mode of operation - by prolongedly continuous, short-term, cyclic, etc. The most complicated conditions - during the cyclic mode/conditions with the short period of cycles, since working conditions continuously are changed, and during the transient processes are possible the overloading of elements/cells. Are dangerous periodic inclusions and disconnections of the incandescence/filament of electron tubes - especially powerful/thick, since during the heating the linear dimensions of the parts of tube differently are changed, which causes mechanical overloadings. Therefore with the short-term breaks incandescence/filament is better not to turn off/disconnect - this will increase the life of tubes; however as a result of prolonged inclusion/connection of REA energy, etc is abraded, aimlessly is expended/consumed. Thus, the mean time of the failure-free operation of elements/cells T_{cp} depends on the site of installation, operating conditions and applying of REA. In order to consider the conditions of applying the elements/cells of REA during the calculation of reliability is introduced the stiffness coefficient of operation $k_{ж}$, which characterizes a change in mean time T_{cp} in comparison with the laboratory conditions (Table V-4).

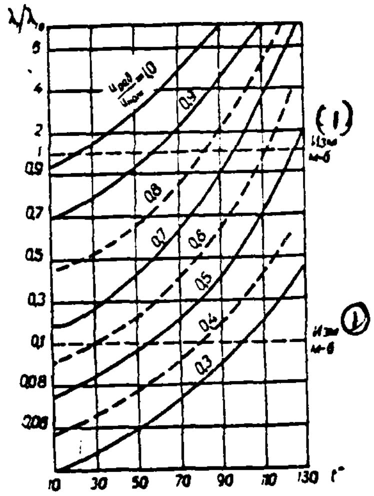

Fig. V-5. The rate of failures of the capacitors: λ_t – with the given load n to temperature; λ_{t0} – with the nominal load and t=20° C. Broken lines indicate the reference grid scale change.

Key: (1). Change of scale.

Table V-4. Stiffness coefficient of operation.

Место эксплуатации (2)	Вид оборудования (1)			
	радиоэлектронное (3)	электромеханическое (4)	механическое (5)	прочее (6)
Искусственные спутники (7)	2,60	2,40	2,10	2,50
Лаборатория (8)	1,00	1,00	1,00	1,00
Испытательный стенд (9)	0,55	0,51	0,50	0,54
На земле (полевая) (10)	0,31	0,26	0,25	0,30
Корабли (11)	0,21	0,17	0,15	0,19
Самолеты (12)	0,18	0,14	0,12	0,16
Управляемые снаряды (13)	0,17	0,13	0,11	0,15

Key: (1). Type of equipment. (2). Place for operation. (3). radio-electronic. (4). electromechanical. (5). mechanical. (6). it is other. (7). Artificial satellites. (8). Laboratory. (9). Test bench. (10). On the earth/ground (field). (11): Ships. (12). Aircraft. (13). Guided missiles.

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Rate of failures $\lambda_t(t)$ in the middle section of characteristic (Fig. V-4) depends on the load of element/cell. The ratio of net load to the nominal, permitted by technical specifications, is called the factor of the load of element/cell $k_н$. For example, load for the capacitors - this is working voltage/stress (Fig. V-5); for the electron tubes - are working the voltage/stress, the current and the power, scattered on the electrodes (Fig. V-6); for the transistors - power, scattered on the collector/receptacle (Fig. V-7, a), voltage/stress on the collector/receptacle and the current of emitter; for the resistors - scattered power (Fig. V-8), etc. With overloading $(k_н > 1)$ and increase in ambient temperature λ_t/λ_{t0} sharply it grows/rises. Dropping of load $k_н < 1$ and decrease of temperature leads to incidence/drop λ_t/λ_{t0}.

Let us examine the special features/peculiarities of the failures of some elements/cells of REA [2, 40] briefly. Transistors and semiconductor diodes (especially germanium), more precise p-n junctions (Fig. V-7, b) are sensitive to an increase in the temperature and, therefore, to the electrical power, scattered on the electrodes, which is explained by the possibility of the onset of avalanche-like processes.

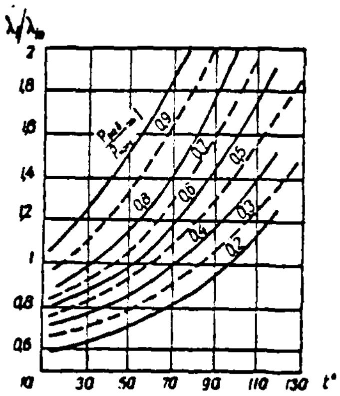

Fig. V-6. Rates of failures of electron tubes.

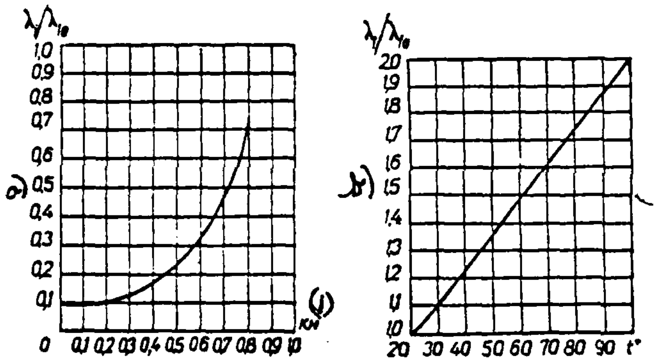

Fig. V-7. Rate of failures of the transistors: a) depending on the power, scattered on the collector/receptacle; b) from the ambient temperature.

Key: (1). Kn.

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It is especially thoroughly necessary to monitor thermal condition with the pulsating load, since due to a small thermal inertia of p-n junctions instantaneous overheating is feasible. Because of small sizes/dimensions semiconductor devices maintain/withstand well large mechanical loads into ten and hundred g. During a good hermetic sealing/pressurization of housing the humidity virtually does not affect the work of transistors. The radiation exposure (SI-5) affect semiconductor devices.

Vacuum-tube instruments usually the most unreliable elements/cells of REA (table V-2, Fig. V-3). The deterioration failures of electron tubes appear as a result of the loss of emission and decrease of slope/transconductance, the random failures - due to the burn-out of the filament of preheating, closing/shorting or break of electrodes, deterioration in vacuum, etc. Failure rate in magnetrons and high-power tubes is especially great. Is desirable voltage regulation of feed, especially the incandescence/filament of tubes, since in this case it is possible to establish/install filament voltage on 2-5% lower than norm, this is decreased λ_t (Fig. V-9). Is necessary the checking of the temperature at the different points of the tank/balloon of tube - permissible on the certificate temperature of 100-200°C, since at a higher temperature deterioration in vacuum due to the spallation of glass is possible. Vacuum-tube instruments fear mechanical overloadings. For decreasing the mechanical overloadings are made miniature and subminiature tubes (series B, etc.) [1].

FOOTNOTE [1]. From the course the "strength of materials" is known that with the curvature of beam/gully mechanical stress $\sigma=M/W$, where $M=\alpha bhl^2$ - bending moment of the beam/gully of rectangular cross section $b\times h$ and length l under the action of its own mass α - the constant, which depends on the density of material of beam/gully, the applied acceleration and anchorage of the beam/gully; W - moment of resistance, for the rectangular cross section $W=bh^2/6$. $\sigma=M/W=6\alpha l^2/h$; with the proportional decrease of linear dimensions q times σ under the action of its own mass of beam/gully also decreases q times. ENDFOOTNOTE.

The intensity of the random failures of electron tubes is more than an order higher than the semiconductor instruments. The life of electron tubes also is considerably less than semiconductor devices.

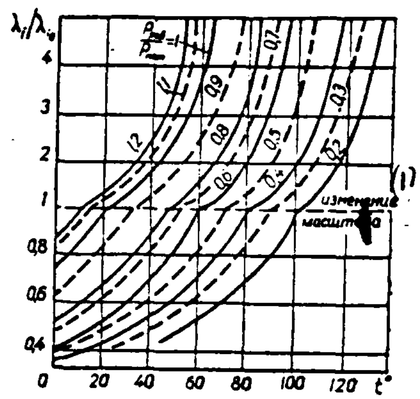

Fig. V-8. Rate of failures of nonwire resistors.

Key: (1). scale change.

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Winding articles reject due to the break of wires, turn-to-turn faults, breakdown of the insulation of windings, etc. The break of wires can arise as a result of a) mechanical stresses due to the careless coil/winding; b) the poor attachment, which leads to the repeated bends of wires with the agitation; c) corrosions in the humid atmosphere as a result of electrochemical reaction. For decreasing the electrochemical corrosion of wires in the direct-current circuits it is necessary that the windings would be electronegative with respect to the surrounding metallic objects/subjects (§III-7). By control gauges for the prevention of the failures of winding articles is protection from the effect of humidity and mechanical attachment saturation, by covering or by hermetic sealing/pressurization (SVI-6). An increase in the temperature leads to the failures, mainly, due to a deterioration in the insulating properties (SVI-4).

The failures of capacitors, in essence, are reduced to the breakdown of insulation, less often - to break or to the loss of qualitative indices. Humidity little affects the work of the hermetically sealed capacitors. The pressed and unsealed capacitors, for example ceramic, are subjected to the unfavorable effect of moisture and with 95-98% of humidity are unreliable. Low reliability is characteristic to chemical capacitors, which negatively react to the insignificant overheating and the overloading.

The failures of nonwire resistors, in essence, are reduced to the burn-out of conducting layer, the disturbance/breakdown of the contact between the conclusion/output and the conducting layer. Noticeable changes in the resistor/resistance are encountered more rarely. Tape/film resistors are less reliable than volumetric, especially with the high ratings (more than 0.5-1 MΩ). The rate of failures of the nonwire resistors of variable resistance is especially high due to the disturbances/breakdowns of the friction electrical contact sliding contact - conducting layer.

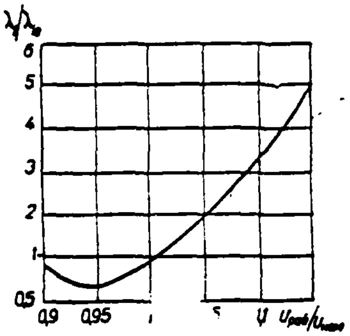

Fig. V-9. Rate of failures of electron tubes with a change in the filament voltage.

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SV-4. Calculation of efficiency according to the sudden wear and deterioration failures.

Sudden wear failures occur in the third section of the characteristic of rate of failures (Fig. V-4), when exponential decay law of efficiency is not applied $\lambda_t \neq \text{const}$. This section, as is shown experiment it more correctly represents the normal law of density distribution of failure probabilities:

$$q_t(t) = (1/\sqrt{2\pi}\sigma_\tau)\exp[-(t-M)^2/2\sigma_\tau^2], \qquad \text{(V-20)}$$

where t - time; M - the average life; σ_τ^2 - dispersion of life. Efficiency (Fig. V-10)

$$P_t(t) = 1 - \int_0^t q_t(t)\,dt = \int_t^\infty q_t(t)\,dt =$$
$$= (1/\sqrt{2\pi}\sigma_T)\int_t^\infty \exp[-(t-M)^2/2\sigma_T^2]dt. \qquad \text{(V-21)}$$

In the beginning of service life (Fig. V-10) there are no failures virtually, since the probability of values of random variable with the normal law of distribution out of the limits of interval $6\sigma_T$ is less than 0.03% (SIV-2) also during the time $0-(M-3\sigma_T)$ ailure probability to 0.15%. An increase in the number of failures and the replacement of elements/cells as a result of the wear begins when $t>M-3\sigma_T$ and it reaches maximum with t=M.

To replace elements/cells is possible simultaneously or gradually in proportion to failures. During the simultaneous replacement of elements/cells, for example, with t=M, on the average it rejects 50% of elements/cells (Fig. V-10), which is inadmissible, since reliability sharply descends; replacement when $t=m-3\sigma_T$ decreases the failure probability to 0.15%; however, many completely suitable elements will be prematurely replaced, but this is not always economically expedient. Is the less σ_T (more precise σ_T/M)the less the relative losses due to the exchange of exact elements/cells and the more advisable their simultaneous replacement. However, usually for the elements/cells of REA $\sigma_T/M\approx0.15-0.25$, and losses are considerable.

The optimum order of the replacement of the worn out elements/cells is determined by the technical-economic calculation according to one or the other criterion (SX-2). During these calculations it is necessary to remember about the random failures, which exist in the second section of characteristic $\lambda_1(t)$ (Fig. V-4), not considered by normal law (V-20). Efficiency in the case of the random failures of real devices/equipment is more completely described by the composition of the exponential and normal laws

$$P(t) = \exp(-\lambda t)\,(1/\sqrt{2\pi}\sigma_T)\int_t^\infty \exp[-(x-M)^2/2\sigma_T^2]\,dx. \quad \text{(V-22)}$$

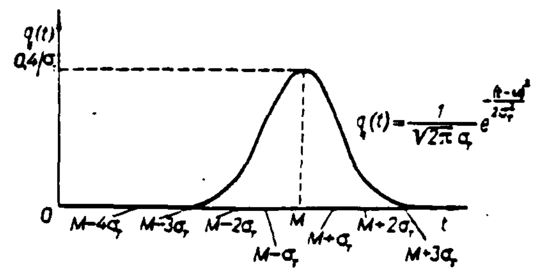

Fig. V-10. Normal law of density distribution of the probabilities of sudden wear failures.

end section.

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The first factor is essential in the second section of characteristic $\lambda_1(t)$, the second - in the third wear section. In the critical devices/equipment the exchange of the worn out elemenes, for which there are no forecasting parameters, is produced simultaneously under the condition of aging/training the elements/cells for the purpose of the decrease of the supplementing failures, which are capable to considerably lower the effect of an increase in the reliability with the simultaneous exchange of the worn out elements/cells.

It is necessary to make some observation, which relate to the circuit elements. Electron tubes or voltaic batteries are usually the mass abraded circuit elements. Remaining circuit elements, as a rule, longer-lasting and many times exceed the period of action of REA as a whole. Experience of operating electron-tube devices/equipment (for example, ETsVM [digital computer]) shows that the post of the intensity of the random failures of electron tubes begins considerably later than their parameters they exceed the permissible by the deterioration failures limits. Therefore tubes will be replaced during the routine checks, which warn the deterioration failures, i.e., it is earlier than wear failures will be begun. The same it is possible to speak also about voltaic batteries. Therefore the simultaneous replacement of mass circuit elements not in all cases is justified. After the specific period the exchange of the electromechanical elements/cells, in which the fatigue or wear are possible, is completely substantiated. However, for this REA it is not very substantial, since such elements/cells are many. That presented is confirmed contemporary by the practice of reliability of REA - attention is fundamentally paid to the gradual (parametric) failures, which are forecast satisfactorily. Thus, in the majority of the cases let us allow the calculation of the random failures of REA without taking into account the wear of circuit elements.

Difference in density distribution of the probabilities of sudden and sudden wear failures during the gradual replacement of the worn elements/cells is developed only with the duration of the total operation of REA, the smaller several average lives of these elements/cells (Fig. V-11). The smoothing of the curve of density distribution of failure probabilities in the course of time is explained by the fact that the elements/cells begin to work not simultaneously, but in proportion to the replacement of the refused elements/cells, in this case the dispersion of their life stores/adds up to the dispersion of the beginning of work. After several exchanges of the refused elements/cells the intensity of wear failures is averaged, $\lambda_{in} \approx 1/M = \text{const}$ and the calculation of efficiency can be made, using the exponential law (SV-2).

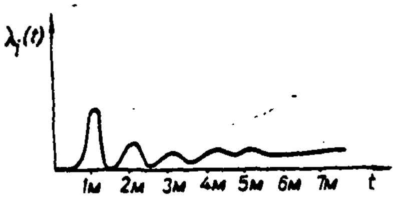

Fig. V-11. Failure rate upon the gradual exchange of the worn elements/cells.

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However, efficiency of REA in this case decreases, since the averaged intensity of sudden wear failures λ_{H} is higher than the intensity of wear failures in the second section of curve $\lambda_t(t)$.

Upon the simultaneous exchange of the worn out elements/cells, for example into moment/torque $t = M - 3\sigma_T$ or previously intensity of the random failures it decreases, since wear random failures are eliminated and remain only usual, characteristic for the second section of curve $\lambda_T(t)$, but, as noted, in this case are changed completely exact elements/cells.

Two methods of calculation of reliability according to the deterioration failures are applied: the first - is similar/such to the calculation of reliability according to the random failures, only failure rate in this case considers sudden and deterioration failures; the second - is reduced to the determination of the conditions, under which slow changes in the parameters of elements/cells due to the aging or wear do not exceed those permitted for this diagram.

During the calculation according to first method (V-18) instead of $\lambda_t(t)$ they substitute the intensity of gradual (gradual and sudden) failures $\lambda_{tn}(t)$. This method is in principle incorrect, since the basis of the calculated methods of the evaluation/estimate of the reliability of complicated devices/equipment is the rate of failures of an element/cell of this type, which does not depend on the concrete/specific/actual diagram, in which it is used, when the factor of the load, the operating mode and so forth are taken into consideration. Meanwhile failure due to slow changes of the parameters in many respects depends on the schematic of device/equipment. If diagram is weakly critical to a change in the parameters of elements/cells, entering the generalized dimensional circuit (SIV-1, IV-6), then equipment does not reject even with the large divergences of the parameters from the rating; in the susceptible diagrams is feasible the failure, also, with small divergences of the parameters. Therefore the intensity of the deterioration failures of elements/cells $\lambda_{tn}(t)$ in each diagram must be determined experimentally. Consequently, this calculation is deprived of sense.

In Chapter IV was discussed a question about field distribution of the allowable divergences of the parameters of elements/cells δ_{Σ} of components, determined by climatic and mechanical effects $\delta_{кл}$ and $\delta_{мех}$. production spreads - series capability of REA $\delta_{пр}$ and aging (wear) $\delta_{ст}$. Without examining the optimum conditions for division δ_{Σ} (Chapter X) into the components, let us suppose that separation carried out and into aging of the parameters of each element/cell is isolated interval $\delta_{iст}$. Then the calculation of the deterioration failures is not complex, although labor-consuming.

For the evaluation/estimate of efficiency of REA according to the deterioration failures it is necessary to know the characteristics of the coefficients of aging elements/cells.

At present they are determined experimentally (§IV-2); in TU they usually give only permissible changes in the parameters to the elements/cells or nodes of REA during the assigned period. For example, in resistors of the type MLT in 2000 hours a change in the resistor/resistance must not exceed 4%.

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With the limited information they accept the uniform law of a change of the parameters with time and the normal law of the distribution of the value of the coefficient of aging within the limits of its tolerance range. Then it is possible to find the coefficient of aging $\beta_i = \beta_{icp} + \beta_{icn}$, where β_{icp} - average/mean value of a change of the parameter in the time (per hour), and β_{icn} - root from the dispersion of the coefficient of aging, equal at the normal law of the distribution 1/6≈0.17 of the tolerance range. The information about the coefficients of aging some elements/cells is given in Table V-5.

After using formulas (IV-8) (IV-9) for the addition of regular and probable deviations, it is possible to find β_A the coefficient of aging the determining parameter A. The divergence of the determining parameter A (average/mean value and dispersion) for time T due to the aging can be found, after multiplying β_A by T, since the uniform law of a change in the parameters was accepted. For the efficiency REA with respect to the deterioration failures the component of the standard deviation of the determining parameter A on aging $\delta_{c\tau A}$ must be less than its change (aging) for time T i.e. $\beta_A T < \delta_{c\tau A}$. If condition $\beta_A T < \delta_{c\tau A}$ is not satisfied, is necessary either to increase $\delta_{c\tau A}$, after redistributing the general/common/total standard deviation of determining parameter $A - \delta_{\Sigma A}$ between the components, or to decrease β_A, after selecting the best elements/cells with smaller β_i, or to use (to develop) another noncritical ~~OR~~ or gate construction/design (SV-5) with large $\delta_{\Sigma A}$.

In conclusion let us emphasize that the calculation of efficiency of REA according to the deterioration failures, in the essence, is reduced to the determination of the noncriticality of diagrams and construction/design with a change in the parameters of elements/cells and the optimum distribution of the total standard deviations between the components.

§V-5. Noncriticality of diagrams.

The values of the standard deviations of the parameters from the nominal values, at which still remains operable of diagrams and constructions/designs, characterize their noncriticality.

Table V-5. Coefficients of aging circuit elements.

Наименование (1)	Срок службы, час. (2)	β_{tcp}	β_{tcn}
Резисторы непроволочные МЛТ (3) . .	10 000	0	$0{,}6\cdot10^{-5}$
Конденсаторы типа БГМ (4)	1000	0	$0{,}3\cdot10^{-4}$
Электронные лампы (5)	500—1000	10^{-4}	$0{,}3\cdot10^{-4}$
Электронные лампы серии Е (6)	5000	$2\cdot10^{-5}$	$0{,}6\cdot10^{-5}$

Key: (1). Designation. (2). Service life, hour. (3). Resistors nonwire MLT. (4). Capacitors/condensers of the type BGM. (5). Electron tubes. (6). The electron tubes of series E.

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The greater the standard deviations of the parameters, the more reliably and more stably REA works.

For developing the noncritical diagrams it is possible (Chapter X) to recommend the method of successive approximations or the method of synthesis, through the analysis of the preliminarily proposed versions. Developer on the basis of preliminary analytical or experimental research on the schemes (constructions/designs), proposed on the base of existing or on the base new ideas, gives preliminary mathematical description of the diagrams - first approximation being investigated. Investigations permit refining, what parameters can be disregarded/neglected, what orders of magnitude are possible, what spurious coupling are essential and the like. Initial versions further taking into account corrections finish - are made the second approximation/approach, etc. To compare the versions in question is possible experimentally or analytically.

The experimental studies of the noncriticality of diagrams and devices/equipment for the selection of the optimum values of the parameters are called marginal testing. For conducting the marginal testing is selected the determining parameter, for example, for the self-excited generator - frequency stability or amplitude of oscillations, for the flip-flop - overbanking of one position of stable equilibrium into another by the standardized/normalized trigger pulse. Further they plan, the divergences of what circuit parameters must be found at the given conditions and a change in other parameters. The results of investigations will be plotted (Fig. V-12). Point A corresponds to the nominal value of tested parameter $R_{ном}$, in this case the diagram ceases normal functioning in voltage/stress $U_1 < U_{ном}$; point Г corresponds to an increase in the tested parameter R by 10%, in this case the diagram functions to voltage/stress $U_2<U_1$ and so on, until entire/all curve, which limits the shaded region of stable operation, is plotted/applied. The results of marginal testing of some parameters of circuit R at a change in others help to select the optimum parameters. For example,

from Fig. V-12 it is evident that the nominal value of the tested parameter R should be increased by 10%. This will raise the noncriticality of diagram. For the more precision determination of the optimum parameters under working conditions the marginal testing must be carried out at the different levels of external agencies, for example temperature, humidity.

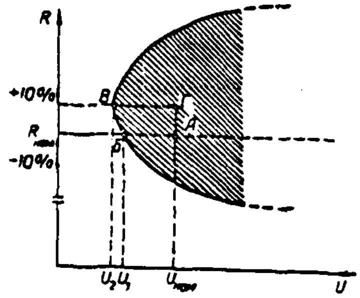

Fig. V-12. Diagram of marginal testing.

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Conducting marginal testing - work labor-consuming; therefore it is technical-economicly expedient to carry out marginal testing of the standard blocks (moduli/modules), published by the large-quantity printings (§II-5).

Labor-consuming marginal testing can be replaced with calculations by ETsVM. For this in analytical dependence (IV-1), which connects the determining parameter of circuit A with the parameters of elements/cells a_i, $A = \psi(a_1, a_2, ..., a_i, ..., a_n)$, they substitute the value of parameters a_i and they calculate the determining parameter A. Calculation (simulation) can be fulfilled by two methods: regular, substituting the boundary values of parameters a_i; to statistical ones (by Monte Carlo method), substituting the random values of parameters

--selected in accordance with the statistical laws of the distribution of the parameters (SIV-2). The random values of parameters a_i are developed by random-number transducers with statistical characteristics ($\overline{a_i}$, D (a_i), the law of distribution), by the determined parameters of elements/cells a_i, being simulated.

Calculations-simulation - give objectively correct, appropriate to actual conditions, result, if analytical expression $A = \psi(a_1, a_2, \ldots, a_i, \ldots, a_n)$ correctly reflects physical processes in the diagram, i.e., if they are taken into consideration all fundamental and parasitic parameters, and the statistical characteristics of the parameters of elements/cells encompass the given ones - production spread, the effect of climatic factors, aging, etc.

Let us give some considerations on the creation of noncritical diagrams. Diagrams (device/equipment) are simple and complicated; single-function and multifunctional [1]; theoretically precise and approximate approximating (SIV-6).

FOOTNOTE [1]. With the fulfillment of identical functions simple diagram has a smaller (minimum) number of elements/cells, compound circuit contains more than elements/cells. Multifunctional instrument, device/equipment, simultaneously or consistently make several functions, for example, dual-amplifications circuit of receivers, transceiver diagrams of transceivers, etc. ENDFOOTNOTE.

In the first examination it seems that efficiency must decrease with an increase in the quantity of elements/cells, which characterize the complexity of diagram. However, after detailed, careful analysis this categorical confirmation is imprecise. Actually/really, efficiency on random failures (V-18) is determined not only by a number of elements/cells n, but also by the rate of failures λ_T, that depends on mode/conditions and conditions of applying the elements/cells. Let us give the simplest example (Fig. V-13).

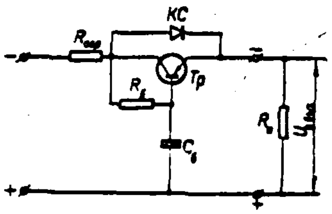

Fig. V-13. Schematic of transistor filter with the shielding stabilitron tube KS.

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In the transistor filters of power supplies "excess" silicon stabilitron tube KS and limiting resistor R_{orp}, shielding the controlling transistor Tr from the overloading, increase a quantity of parts, but they considerably raise efficiency of diagram.

Compound circuits with a large number of elements/cells can have the lowered/reduced efficiency on the random failures; however, because of the noncriticality efficiency on the deterioration failures and general/common/total efficiency can be considerably higher than in simple diagrams with a small number of elements/cells.

The multifunctional diagrams of construction/design are more susceptible to a change in the parameters, because the parameters of elements/cells in such diagrams are usually selected compromise between the contradictory conditions, necessary for fulfilling the separate functions. In connection with this the standard deviations of the parameters, which do not disrupt not one of the functions of diagram, are insignificant and efficiency on the deterioration failures of such diagrams is small.

However, one ought not this to consider as recommendation to the excessive complication of construction/design or diagram, although the reasonable redundancy - complication - diagrams and construction/design of REA raises efficiency on the deterioration failures, just as the introduction to redundancy during the transmission of information raises the interference shielding of the communication channel. Diagrams with the compensation for divergences, the rigid installation of the determining parameters, the automatic control of the parameters, the feedback, etc can serve the aforesaid as illustration.

An example of diagrams with the severe limitation of the parameters can be self-excited oscillators with clamping diode (Fig. V-14), multivibrators or flip-flops with those limiting - fixing diodes, etc. In the self-excited oscillator the amplitude of oscillations cannot increase to the level, greater than $U_{\text{огр}}$, since it is steeply limited to the diode OD, to "supported" voltage/stress $U_{\text{огр}}$. This decreases the level of grid excitation, and the total conduction angle is small, since edge stress does not manage increase; therefore harmonic distortions are small.

To the weakly critical diagrams with the more stable oscillatory period can be attributed multivibrators with the positive grid - positive or negative base for the transistors with respect to n-p-n or p-n-p ones.

Diagrams with the automatic control of the determining parameter are complicated; however, they are reliable with respect to the deterioration failures.

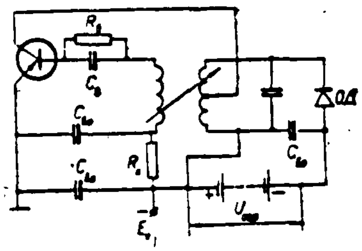

Fig. V-14. Diagram of self-excited oscillator with clamping diode OD.

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Diagrams with the automatic control can be made noncritical over a wide range of a change in the parameters of elements/cells a_i, eliminating the divergences of the supporting/reference elements/cells, whose number is small. Noncritical diagrams with the automatic control of power output, frequency, sensitivity and so forth are complicated; however, their use/application in the equipment with the high requirements for the reliability is completely justified.

Can be attributed diagrams with automatic control and limitation of the determining parameter A to a broader class of devices/equipment and diagrams, whose stability is determined by the passive linear elements/cells (resistors, capacitors/condensers, etc.): usually more resistant to any effects, than active nonlinear elements/cells (transistors, electron tubes, etc.); for example, the diagram of the piecewise-linear approximation of functions. In such diagrams of the characteristic of nonlinear elements/cells is not exerted a substantial influence on the functioning of devices/equipment, since the nonlinear elements/cells are connected together with the linear, high-stability elements/cells. The role of nonlinear elements/cells is reduced to the switching - the transmission of current in one direction.

To the diagrams, whose noncriticality is determined by passive elements/cells, relate negative-feedback circuits. The amplifier gain with the negative feedback

$$K_{oc} = K/(1 + K\beta) = 1/(1/K + \beta) \approx 1/\beta, \qquad \text{(V-23)}$$

where $K\beta >> 1$, K - amplification factor without the feedback; β - amount of feedback. Relative change in the determining parameter - K_{oc} (IV-8):

$$\begin{aligned} \Delta K_{oc}/K_{oc} &\approx (1/K_{oc}\,[(\partial K_{oc}/\partial K)\,\Delta K + (\partial K_{oc}/\partial\beta)\,\Delta\beta] = \\ &= (1/K_{oc})\,[\Delta K/(1/K + \beta)^2 K^2 - \Delta\beta/(1/K + \beta)^2] \approx \\ &\approx (\Delta K/K)\,[1/(1 + \beta K)] + \Delta\beta/\beta. \end{aligned} \qquad \text{(V-24)}$$

With $K\beta >> 1$, $\Delta K_{oc}/K_{oc}$ is determined, mainly, by the passive linear element/cell β, which can be made sufficiently to stable ones (for example, from the wire resistors), since with the the large $1+K\beta$ even any changes K little affect. In the contemporary sensitive analog voltmeters and the ammeters of class 0.5 electron-tube and transistor amplifiers without the installation of amplification in the process of operation are applied; in the digital voltmeters the accuracy still above - in the limits of one hundredths of a percent; therefore the instability of amplifiers must be above approximately/exemplarily by an order $-10^{-3}-10^{-4}$. In order to obtain $\Delta K_{\infty}/K_{\infty} = 10^{-3}\Delta K/K$ $(\Delta\beta \rightarrow 0)$, assuming/setting $K_{\infty} = 10^3 \approx 1/\beta$, it is necessary that $K\beta \approx 10^3$ $(K = 10^4)$, and amplifier is considerably more complicated $K/K_{\infty} \approx 10^3$.

On the basis of that outlined above, one ought not to assert that the simple diagram is more operational complicated. With the reasonable fulfillment of diagram and the constructions/designs, which are determining the parameters, in essence depend only on the stability of linear passive elements/cells.

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Let us point out also to other specific methods of the creation of noncritical diagrams, for example modulation measuring circuits, in which the susceptible devices/equipment, which work at the very low frequencies, replace by less susceptible ones. For example, the dc amplifiers, subjected to zero drift by use/application of a modulator, that crushes process with it is necessary the frequency, they replace by the amplifiers of alternating current.

In conclusion it is expedient to compare efficiency of analog and discrete/digital units with the binary code. Solution of the majority of technical problems by the analog possible and discrete/digital methods. With the analog methods in the diagrams it is considerably less than elements/cells, but the allowable divergences of their parameters (without the use/application of special measures) are small. This decreases efficiency of devices/equipment on the deterioration failures. Discrete/digital devices/equipment with the binary code have only two steady states. The operating mode "yes-no" is most appropriate to active elements/cells, since during the aging a change in the parameters within sufficiently wide limits does not affect steady states. The majorities of impulse circuits - flip-flops, the coincidence circuits and so forth work precisely under these conditions; therefore they possess high efficiency on the deterioration failures. The value of discrete/digital methods increased in connection with the creation of the microminiature integrated circuits, which are applied in the pulsers (Chapter IX).

For serviced REA of prolonged action, of which high accuracy is required, it is expedient to apply discrete/digital methods. With this REA is resistant to the deterioration failures, since it is possible to provide the routine checks (serviced equipment) for the development/detection and the replacements of the aging elements/cells or nodes. Reliability on the random failures of the complicated devices/equipment, in particular discrete/digital, they raise by redundancy (§V-6).

For the unattended equipment for one-shot action in the simplest cases it is possible to recommend analog units, more operational (less than elements/cells) on the random failures, than discrete/digital. The spread failures are less essential, since equipment - one-shot action works brief time.

In all cases it is expediently reasonable to combine analog and discrete/digital methods.

§V-6. Ways of increasing the reliability.

The factors, which affect reliability, conditionally can be divided into two interdependent/interconnected groups - given ones by user (client) and selected by producer.

Reliability of REA on the gradual and random failures is determined by many factors (Table V-6).

Table V-6. Factors, which affect reliab.lity and life of radio-electronic equipment.

№ (a) п. п.	(b) Задаются потребителем (заказчиком)
1.	Назначение (габариты, масса)
2.	Технические требования (точность, быстродействие, чувствительность, диапазон частот, мощность, динамический диапазон, качественные показатели и т. д.)
3.	Квалификация обслуживающего и эксплуатирующего персонала
4.	Тираж (общий и годовой выпуск)
5.	Требуемая долговечность (технический ресурс), характер и длительность непрерывной работы
6.	Условия и длительность хранения. Транспортировка
7.	Потери при неисправности из-за простоев и возможной гибели имущества
8.	Условия эксплуатации: температура воздуха на поверхности устройства (предельные величины, длительность воздействий, амплитуда колебаний, скорость изменений, цикличность); влажность воздуха (предельные величины, длительность воздействий, цикличность); загрязнение воздуха; высота над уровнем моря (уменьшение рассеяния тепла, повышенный износ трущихся частей, интенсивность действия ультрафиолетового излучения, уменьшение электрической прочности воздуха); вода (морская вода, иней, роса); солнечная и др. радиация; период года (климатическая обстановка, резкость изменения и длительность климатических воздействий); биологические факторы (грибковые микроорганизмы, насекомые и мелкие животные — грызуны); пыль, песок (усиленная коррозия, среда для микроорганизмов)
9.	Механическая нагрузка (ветровая и т. д.)
10.	Удары и вибрации при эксплуатации и перевозках

№ (a) п. п.	(c) Определяются изготовителем
1.	Технико-экономическая квалификация разработчиков (уровень знаний и опыт)
2.	Сознание важности задач (уровень воспитательной работы)
3.	Систематизация опыта эксплуатации. Учет требований технической психофизиологии (удобство эксплуатации и технического обслуживании)
4.	Применение методов оптимального технико-экономического проектирования по критериям
5.	Отношение администрации к службе надежности и контролю качества
6.	Вид производства — массовое, серийное, индивидуальное
7.	Унификация, нормализация и стандартизация в производстве Применение модульного (функционально-блочного) производства Применение апробированных схем и конструкций
8.	Некритичность схем и конструкций (серийноспособность, устойчивость к климатическим и механическим воздействиям, старению и износу)
9.	Простота логической схемы и конструкции Количество (простота функций, выполняемых отдельными блоками схемы (конструкции)

№ п. п.	Определяются [illegible]
10.	Количество и требуемые точности элементов схемы и конструкции для реализации принятых решений. Возможность компенсации допусков регулировкой
11.	Принятые запасы (коэффициенты нагрузки). Условия охлаждения
12.	Принятые меры для упрощения профилактики, прогнозирующей отказы. Ремонтопригодность. Применение встроенного контроля. Величина коэффициента готовности
13.	Способы и кратность резервирования блоков и аппаратуры в целом
14.	Физико-химические свойства, номенклатура применяемых материалов и комплектующих изделий, их стоимость
15.	Технико-экономическая оптимальность, уровень и освоение требуемой технологии
16.	Уровень культуры производства, технической квалификации и производственной гигиены исполнителей
17.	Упаковка. Методы консервации
18.	Контроль проектирования и производства. Методы и средства контроля
19.	Уровень и объем лабораторных, заводских и полигонных проверок и испытаний
20.	Количество технической документации (проектной, производственной и эксплуатационной), полнота, и четкость изложения
21.	Технико-экономический анализ принятых решений

Key: (a). p. p. (b). They are assigned by user (client). 1. Designation/purpose (overall sizes, masses). 2. Technical requirements (accuracy, operating speed, sensitivity, frequency band, power, dynamic range, qualitative indices, etc.). 3. Qualification of the service and operating personnel. 4. Print run (general/common/total and annual production). 5. Required life (technical service life), character and the duration of continuous operation. 6. Conditions and the duration of storage. transportation. 7. Losses with the malfunction due to idle times and the possible death of property. 8. Operating conditions: the temperature of air on the surface of device/equipment (limiting values, the duration of effects, the amplitudes of oscillations, rate of change, cyclic recurrence); air humidity (limiting values, the duration of effects, cyclic recurrence); air pollution; height/altitude above sea level (decrease of dissipation of heat, the increased wear of the friction parts, the effective force of ultraviolet radiation, the decrease of dielectric strength of air); water (sea water, hoarfrost, dew); solar, etc. radiation; the period of year (climatic situation, the definition of change and the duration of climatic effects); biological factors (fungus microorganisms, insects and small animals - rodents); dust, sand (intensive corrosion, media for the microorganisms). 9. Mechanical load (wind, etc.). 10. Impacts and vibration with the operation and the transport. (c). They are determined by producer. 1. Technical-economic qualification of developers (standard of knowledge and experiment). 2. Consciousness of the importance of tasks (level of educational work). 3. Systematization of operating experience. Account of the requirements of anthropometric engineering (convenience in the operation and maintenance). 4. Use/application of methods of optimum technical-economic design on the criteria. 5. Ratio of administration to service of reliability and quality control. 6. Form of production - mass, series, individual. 7. Unification, normalization and standardization in the production. the use/application of modular (function-block) production. the use/application of the approved diagrams and constructions/designs. 8. Noncriticality of diagrams and constructions/designs (series capacity, stability to the climatic and mechanical effects, the aging and the wear). 9. Simplicity of logic circuit and construction/design. a quantity (simplicities of the functions, fulfilled by the separate blocks of diagram (construction/design). 10. Quantity and the required accuracy of the elements of diagram and construction/design for the realization of the solutions accepted. Possibility of the compensation for tolerances by adjustment. 11. The reserves (load factors) accepted. Cooling conditions. 12. Taken measures for simplification in the preventive maintenance, which forecasts failures. Maintainability. the use/application of the built-in checking. the value of readiness factor. 13. Methods and the redundancy rate of blocks and equipment as a whole. 14. Physicochemical properties, the nomenclature of the materials used and completing articles, their cost/value. 15. Technical-economic optimality, level and the mastery/adoption of required technology. 16. Level of the culture of production, technical qualification and production hygiene of executors/performers. 17. Packing. the methods of conservation. 18. Checking of design and production. methods and the means of checking. 19. Level and the space of laboratory, plant and polygon checkings and tests. 20. Quantity of technical documentation (design, production and operating), completeness, and clearness of presentation. 21. Technical-economic analysis of the solutions accepted.

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By effect on any of them it is possible to raise reliability.

Some measures for an increase in the reliability are already in detail examined, some will be studied in the following chapters. In this paragraph let us examine redundancy and fundamental recommendations regarding an increase in the reliability.

Redundancy - this is the use/application of supplementary (surplus) elements/cells or devices/equipment, which work in the case of the failures of bases. A number of stand-by devices/equipment to each worker is called redundancy rate m.

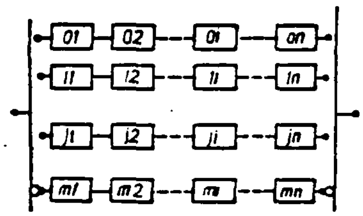

Fig. V-15.

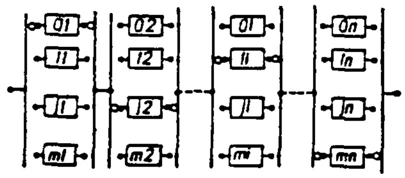

Fig. V-16.

Fig. V-15. Block diagram of general/common/total redundancy.

Fig. V-16. Block diagram of separate redundancy.

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Redundancy can be general/common/total (Fig. V-15), when instead of the refused system are connected alternately others stand-by, and by separate, when they reserve system unit-by-unit, i.e., in the case of the failure of system they determine and they replace the refused blocks (Fig. V-16). In the case of the failure spare unit can accept load on itself, replace with basis, by switching by hand or is automatic, the so-called reserved replacement value; or spare units (elements/cells) are connected and work simultaneously with the bases - parallel redundancy, while in the case of the failures load is redistributed. Stand-by elements/cells (blocks) can be found in the operational conditions - this the so-called loaded reservé;

incomplete operational conditions - this is the lightened reserve; nonoperating state - unloaded reserve. The selection of mode/conditions is essential, for example, for the vacuum-tube instruments, since the heating of cathode continues from tens of seconds to several minutes. The lightened mode/conditions of REA in many instances is reduced to decrease in the supply voltage, this sharply shortens the time of the establishment of normal mode and at the same time decreases aging elements/cells and nodes.

During the investigation of reliability is examined series connection of elements/cells, with which failure of one of the n elements/cells causes failure of entire system (S V-2) and parallel connection, with which the failure even m of elements/cells from m+1 does not cause the failure of system. Let us rate/estimate efficiency of REA in the simplest cases of general/common/total and separate redundancy. For simplicity of linings/calculations let us assume that the failures of blocks are independent, the refused blocks are not overhauled, the reliability of switching systems is one hundred percent. The effect of the unreliability of switching systems can be rated/estimated, after multiplying the reliability of the redundant system by the reliability of switching systems.

With the general/common/total redundancy (Fig. V-15) in each j system n of the i blocks they are connected in series, and m+1 of the j systems - in parallel. Assuming/setting the reliability of the blocks of the basic and stand-by systems of identical $P_{0il} = P_0$, let us find the reliability of one j system with series connection n of blocks (§ V-2) $P_{0cl} = P_{0c} = \prod_{i=1}^{i=n} P_{0i} = P_0^n$. Probability that the system with the m-fold redundancy will refuse, unreliability $\bar{P}_{0\Sigma}$ - is determined by failure probability all m+1 systems (m of stand-by ones and by one fundamental), of the equal to the product of the probabilities of their failure $\bar{P}_{0\Sigma} = \prod_{l=1}^{l=m+1} \bar{P}_{0cl} = \prod_{l=1}^{l=m+1} \bar{P}_{0c} = \bar{P}_{0c}^{m+1}$. The unreliability of each system is identical and equal to $\bar{P}_{0c} = 1 - P_{0c}$. Reliability with the general/common/total redundancy of the system

$$P_{0\Sigma} = 1 - \bar{P}_{0\Sigma} = 1 - \bar{P}_{0c}^{m+1} = 1 - (1 - P_{0c})^{m+1} = 1 - (1 - P_0^n)^{m+1}. \quad \text{(V-25)}$$

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With the separate redundancy (Fig. V-16) the i blocks of all systems are connected in parallel, so that the group of the i blocks remains operational, until at least one of m+1 blocks of group it is operational; all of the i group of blocks are connected in series, and if one of the n groups refuses, the redundant system will be inefficient.

The blocks of the i group are connected in parallel; therefore the unreliability of the group

$$\bar{P}_{0irp} = \prod_{l=1}^{l=m+1} \bar{P}_{0il} = \bar{P}_{0i}^{m+1} = (1 - P_{0i})^{m+1} = (1 - P_0)^{m+1}.$$

Reliability of the i group of the blocks

$$P_{0i\,\mathrm{rp}} = 1 - \overline{P}_{0i\,\mathrm{rp}} = 1 - (1 - P_0)^{m+1}.$$

All of the i group of blocks are connected in series; therefore the reliability of the separately redundant system from n (m+1) of blocks with the identical reliability P_0

$$P_{0\Sigma} = (P_{0i\,\mathrm{rp}})^n = [1 - (1 - P_0)^{m+1}]^n. \quad \text{(V-26)}$$

The reliability of each block is changed in the time, respectively the reliability of system also depends on the time

$$P_{0\Sigma}(t) = \{1 - [1 - P_0(t)]^{m+1}\}^n. \quad \text{(V-27)}$$

Let us compare an increase in the reliability with the general/common/total and separate redundancy for the different values of m, n and P_0. The results of calculations according to (V-25) and (V-26) are given in table V-7.

Redundancy is an effective means of an increase in the reliability, moreover separate redundancy is better, although switching system here is considerably more complicated. The advantage of separate redundancy is completely explained, system will be operational even in the case of failure nm from n (m+1) of blocks (elements/cells), if in each i group of blocks one operational remains.

Table V-7. Reliability of general/common/total and separate redundancy.

m \ n	$P_0 = 0.75$				$P_0 = 0.9$				$P_0 = 0.95$			
	0	1	2	3	0	1	2	3	0	1	2	3
2	0,56	$\frac{0,81}{0,89}$[1]	$\frac{0,91}{0,97}$	$\frac{0,96}{0,99}$	0,81	$\frac{0,96}{0,98}$	$\frac{0,993}{0,998}$	$\frac{0,999}{\sim 1}$	0,9	$\frac{0,99}{0,995}$	$\frac{0,999}{\sim 1}$	$\frac{\sim 1}{\sim 1}$
5	0,24	$\frac{0,42}{0,73}$	$\frac{0,56}{0,92}$	$\frac{0,66}{0,98}$	0,59	$\frac{0,84}{0,95}$	$\frac{0,94}{0,995}$	$\frac{0,97}{\sim 1}$	0,78	$\frac{0,95}{0,99}$	$\frac{0,98}{0,999}$	$\frac{0,998}{\sim 1}$
10	0,06	$\frac{0,11}{0,52}$	$\frac{0,16}{0,85}$	$\frac{0,23}{0,96}$	0,35	$\frac{0,59}{0,9}$	$\frac{0,74}{0,99}$	$\frac{0,83}{0,999}$	0,6	$\frac{0,86}{0,98}$	$\frac{0,94}{0,999}$	$\frac{0,97}{\sim 1}$

FOOTNOTE [1]. In the numerator - reliability of general/common/total, in the denominator - separate redundancy. ENDFOOTNOTE.

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The mean time of failure-free operation with redundancy T_{cp} increases only 1.5-2 times, if all systems are simultaneously connected with the work (constant loaded redundancy) and after failure are not overhauled. During the restoration/reduction of system after the failures, when relation $T_{cp}/T_{рем}$ is sufficiently great ($T_{рем}$ - recovery time of system after failure), the mean time of trouble-free work of the redundant system considerably (into dozens of times to each stand-by system) grows/rises with an increase in the redundancy rate.

With an increase in the reliability with the aid of the redundancy the redundancy of equipment appears, increases also a quantity of service personnel for the stand-by systems. Redundancy leads to a change in the total cost/value of reserved REA. The general/common/total cost/value of system with the redundancy, on one hand, increases with an increase in the multiplicity, since increases a quantity of equipment, and on the other hand, it decreases, since the required reliability and cost/value (V-6) of basic and stand-by systems descends. There is an optimum redundancy rate, with which the cost/value of the redundant system is minimum.

In the elaborate expensive complexes of REA they solve the problem of redundancy compromise. Let us examine this based on the example of the powerful/thick radio transmitting equipment. The cost/value of the powerful/thick transmitter is determined by the cost/value of the output stage. This cascade/stage is made along the unit-block system from m blocks, in this case the failure of one block does not disable entire system (partial failure), but by the period of repair it only decreases the power output. Low-power, less expensive blocks, reserve completely. In this case reliability and the average/mean mean time between failures of the redundant overhauled system considerably is raised with a relatively small increase in the cost/value.

In the REA, which includes many same-type blocks, is applied fractional redundancy, for example, at the large/coarse radio centers with a large number of same-type restorable (overhauled) devices/equipment one or several each type stand-by devices/equipment provide for.

Let us examine other measures for an increase in the reliability of REA. Efficiency P and readiness factor k_r (V-1) determine reliability of REA. For increase k_r it is necessary to shorten $T_{рем}$ - the time of the repair of the refused block and $T_{проф}$ - time of the preventitive checks.

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To create maintainable REA is possible, 1) if we apply the built-in control, which resolves without the break of normal operation to monitor the determining parameters of equipment (§ XIII-6); 2) if construction/design makes it possible to easily change blocks; 3) if the location of blocks, indicators, control knobs is mnemonic substantiated; 4) if they are satisfied other requirements of the anthropometric engineering, which facilitate minimum enervation of operators and road-mending machines (§ XII-2); 5) if they are created the quality-control and testing stations for the preventitive check (§ XIII-5); 6) if it is applied the function-block layout of diagram with the control points, which resolve to rapidly determine the place of damage (§ XIII-6).

The fundamental ways of increasing the efficiency of the REA are the following:

1. The search for criteria for forecasting the sudden and deterioration failures; the translation/conversion of the random failures into the category of those forecasted, since the correctly set routine checks together with the use/application of the noncritical diagrams checked and constructions/designs virtually permit excluding the forecasted failures of the REA.

2. Increase in the qualification of developers, strict construction engineering discipline (tables V-1), which prevents errors during the design of REA (Fig. 1-2, table V-6), the use/application of materials and elements/cells in those not admitted, not provided for them by standards/normals, or maximum modes/conditions under the influence of the assigned by user heavy ambient conditions. It is necessary to focus attention not only to the macroclimate - average/mean values on the block, the strut, etc., but also for the microclimate of each element/cell, which completes

articles. Is important heating not the radiator, but p-n junctions, is important not the external temperature of winding article, but the temperature of insulation within the winding article, or the micro-temperature of the tanks/balloons of vacuum-tube instruments.

3. Use/application of standard ones and the development of the new checked under the actual conditions elements/cells, nodes and constructions/designs with small rates of failures and large life.

4. Facilitation of the mode/conditions of circuit and structural elements/cells, which lowers rate of failures (§ V-3). Usually this leads to an insignificant increase in the overall sizes and mass of REA, although the mass and the overall sizes of more powerful/thicker elements/cells are more, since in the real devices/equipment in the loaded mode/conditions it works not more than 20-30% elements/cells, which must be unloaded; remaining elements/cells are loaded not completely (grid or base circuits of low-power devices/equipment, etc.).

5. We do not recommend switching microstrain (§ VII-4), the applying of thin winding (0.07-0.1 mm) wires, etc.

In conclusion let us present the exemplary/approximate order of calculation (Table V-8) of efficiency according to the random failures. The detailed data about the rates of failure λ_i, the factors of load k_{ni} and the stiffness coefficient of operation $k_{\text{ж}}$ (table V-4), necessary for calculating the efficiency, are in the literature [2, 40] and RTM of the departments of the reliability of enterprises. The data about a number of parts n_i and information about the mode/conditions for determining the factor of load $k_{\text{н}}$ are taken from the schematic diagram and the calculated note of block, $k_{\text{ж}}$ they determine according to the designation/purpose of the REA.

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Table V-8. Calculation T_{cp} of block during the lightened mode/conditions of elements/cells.

Наименование i-го элемента	Количество i-х элементов n_i (2)	Коэффициент нагрузки $K_н$ (3)	Поправочный коэффициент нагрузки α_{in} при $t = 20°$ C (4)	Коэффициент влияния микротемпературы α_{it} при $t = 70°$ (5)	Интенсивность отказов номинальная (рис. V-3) λ_{i0} % на 10^4 (6)	Приведенная интенсивность отказов $\lambda_i = \lambda_{i0} \cdot \alpha_{in} \alpha_{it}$ (7)	$\lambda_i n$ %	$\alpha_{in} = \varphi(K_н)$
Транзистор (8)	3	0,7	0,5	1,6	0.04	0,032	0,1	(9) рис. V-7
»	2	0,45	0,2	1,6	0,04	0,013	0,026	» »
Полупроводниковый диод (10)	8	0,65	0,4	1,6	0.02	0,013	0,1	» »
»	5	0,35	0,15	1,6	0,02	0,005	0,025	» (9) »
Резистор МЛТ (11)	25	0,8	0,65	4	0,02	0,05	1,25	рис. V-8
» »	20	0,2	0,3	2	0,02	0,012	0,24	» (9) »
Конденсаторы (12)	15	0,75	0,35	3	0,01	0,01	0,15	рис. V-5
КГБ (13)	10	0,65	0,1	4	0,01	0,004	0,04	» »
Пайки (14)	150	—	—	—	0,02	0,02	3	(9) —
Электронные лампы (15)	2	0,4	0,7	1,3 (80° C)	2	1,8	3,6	рис. V-6
Разъем (16)	3	—	—	—	0,3	0,3	0,9	—

$\Sigma \lambda_i n_i = 9,4\%$.

Hence: $T_{cp} = 10^6/\Sigma \lambda_i n_i =$ $10^5/9.4 \approx 10^4$ hour; $P(t) = \exp(-t \cdot 10^{-4})$.

Keys: (1). Designation of the i element/cell. (2). Quantity of i elements/cells. (3). Load factor. (4). The correction factor of load with t=20°C. (5). Influence coefficient of micro-temperature with t=70°C. (6). Failure rate is nominal (Fig. V-3) on 10^3 h. (7). Given failure rate. (8). Transistor. (9). Fig. (10). Semiconductor diode. (11). Resistor MLT. (12). Capacitors. (13). KGB. (14). Solderings. (15). Electron tubes. (16). Coupling.

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