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CONCEPT OF INCOMING INSPECTION OF MATERIALS AND COMPONENTS COMING INTO PRODUCTION

The paper offers the strategy of incoming inspection of components according to a level of deficiency of lots, with expenses for elimination of consequences of defective components coming into finished goods taken into account. The paper considers cost characteristics of complete, sample and uncontrolled incoming inspection of materials and components coming into production.

***Keywords**: reliability, electronic components, basic materials, manufacture of electronic units, inspection.*

The paper aims at showing the technical and economical efficiency of various strategies of incoming inspection under the conditions when the costs of full-scale testing of electronic components and materials are so huge that one has to think if it is reasonable to have complete or sample incoming inspection, or about selecting a bona fide supplier.

Choice of a strategy of incoming inspection is critical due to the fact that electronic equipment manufacturers suffer considerable expenditures caused by defective materials or components coming into production. Generally, these defects behave unpredictably in finished products affecting their reliability and manufacture of good products [1]. The ISO 9000 certification system allows us to hope for supply of good quality materials and components. Electronics manufacturers are forced to trust suppliers since the capital costs of specialized equipment for incoming inspection are too large. It is easier for a manufacturer to choose a bona fide supplier of components and materials than to organize their incoming inspection. And it is more so, since there is in-circuit and peripheral control on a production line which makes up for the lack of incoming inspection through identifying faulty components at the production stage. Nevertheless, manufacturers of vital hardware sometimes want to evaluate a strategy of incoming inspection in terms of reliability and economics of production [2].

Concepts of incoming quality in use

The incoming quality is understood as the quality of lots of components and materials coming into production. The quality of individual lots can be evaluated by the number of defective products in a lot $\boldsymbol{x}$, or by the portion of faultiness q.

The proportion of faultiness is typically calculated by the formula [2]:

$$q = \frac{x}{N} \tag{1}$$

where ***N*** is the size of a lot.

The incoming quality of a set of lots is characterized by the function *f(x)* of distribution of the number of defective products in lots, or by the function *f(q)* of distribution of faultiness portions.

The type of distribution of defective products is defined by the unreliability of the outgoing inspection at a manufacturer's premises, by storage time, by destructing impacts of various factors during transportation and storage, etc.

For more detailed characteristics of the incoming quality, we can further use the dispersion χ_x^2 or the dispersion of faultiness portions [2].

$$\chi_q^2 = \frac{1}{k-1}\sum_{i-1}^{k}(q_i - \bar{q})^2 \tag{2}$$

In case of constant volumes of the lot ***N***, the dispersions χ_x^2 and χ_q^2 are interrelated by the following dependence $\chi_x^2 = N^2\chi_q^2$.

Of great importance is the analysis of incoming quality of components and materials, which allows manufacturers to identify drawbacks of the components of a supplier in advance to take action to improve the reliability of components prior to any possible failure of equipment. Despite outgoing inspection at factories of suppliers, defective parts can come into equipment.

Purpose and essence of incoming inspection

The incoming inspection is an additional test of components and materials before using them in production as for parameters defining their operation and reliability [3]. This is because individual parts can be of lower quality due to negligent final inspection, as well as possible long storage of finished products at warehouses accompanied by deterioration of quality. In addition, one cannot rule out a possibility of components and materials being damaged during transportation, etc.

Incoming inspection implies at least visual check of components. If a manufacturer has some specialized testing equipment, components undergo some electrical testing in combination with thermal training [3].

During visual inspection, attention is paid to whether there are clearly visible inscriptions available at the component or package material indicating the type, nominal value, tolerance, technical conditions or product certificate, as well as whether there are any scratches, chips, cracks, dents, corrosion on the product.

During electrical testing, one checks if the electrical parameters of the components conform to those specified in the requirements and methods of technical conditions or certificates.

Parts which passed incoming inspection are additionally marked with a special inscription.

Incoming inspection of components or materials can be 100 per sent or selective.

The sample size ***n*** can be defined by the formula [1]:

$$n = \frac{t_p \sigma^2}{\varepsilon} \tag{3}$$

where $\boldsymbol{t_p}$ is factor dependent of the confidential probability P to be defined using Table 1 [4];
$\boldsymbol{\sigma}$ – standard deviate of the value equal to:

for Delta distribution $\sigma = \dfrac{\Delta A}{2}$,

for normal distribution, $\sigma = \dfrac{\Delta A}{6}$,

for uniform distribution $\sigma = \dfrac{\Delta A}{2\sqrt{3}}$.

Here ΔA is the difference between the upper and lower boundaries of the incoming parameter as to technical conditions; $\boldsymbol{\varepsilon}$ is the specified accuracy of mathematical expectation.

Table 1. The relation factor t_p and the confidential probability P [4]

P	t_P	P	t_P	P	t_P
0,80	1,392	0,88	1,554	0,95	1,960
0,81	1,310	0,89	1,597	0,96	2,053
0,82	1,340	0,90	1,643	0,97	2,169
0,83	1,371	0,91	1,694	0,98	2,25
6,84	1,404	0,92	1,750	0,99	2,576
0,85	1,439	0,93	1,810	0,9973	3,00
0,86	1,475	0,94	1,880	0,999	4,200
0,87	1,513				

Generally, the following rule is set: if sample inspection shows defective products, a double number of articles from the lot is subject to checking. In case checking a double number of products shows at least one defective component, 100 per cent of the products of the received lot is subject to inspection [5].

Reliability of incoming inspection

Ensuring the reliability of electronic equipment at the production phase can be represented with some approximation by the following expression [6]:

$$H_{np} = H_1 \cdot H_2 \cdot H_3 \tag{4}$$

where H_{np} is production reliability, H_1 is reliability of incoming inspection, H_2 is reliability of technological process of manufacturing equipment, H_3 is reliability of outgoing inspection.

The incoming inspection can be manual or automated, 100 per cent or selective. Reliability of incoming inspection H_1 will vary depending on the method and the nature of inspection. In the general case, the probability of inspection error is defined by a number of factors: testing method, testing speed, life time of testing apparatus, duration of an operator's nonstop work.

The probability of inspection error [4]

$$P_n = P_0(v,T) \tag{5}$$

where $v = n/t$ is testing speed, n is number of tested products, $\boldsymbol{t}$ is time required to check these products, T is age of testing equipment.

Figure 1 shows the probability of inspection error with manual and automated methods depending on time [2].

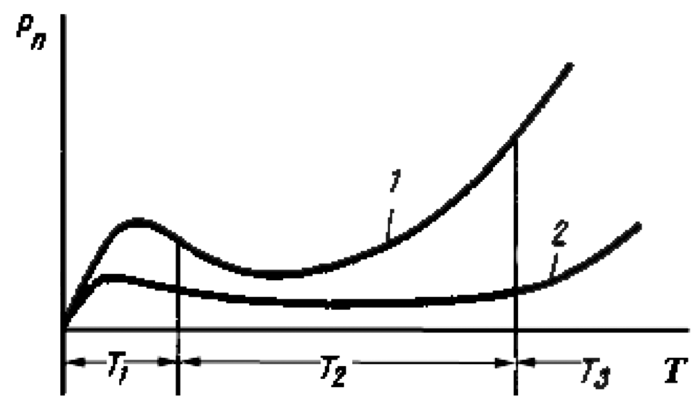

Fig. 1. The probability of inspection error with manual and automated methods depending on time: 1 is manual inspection, 2 is automated inspection

The initial period of inspection T_1 is characterized by a high probability of an error which is explained by the start-up period for the automated control method and mastering of testing process by an operator for the manual method.

The basic period of automated check T_2 is characterized by a constant probability of an error that corresponds to the straight-line portion of curve 2 in Figure 1. The manual method is characterized by the increasing likelihood of errors as an operator gets tired, as shown by the rising portion of curve 1 in Figure 1.

The last period of check T_3 is characterized by a sharp increase in an error probability due to depletion of testing equipment lifetime and an operator's fatigue.

The probability of an error of inspection of n products can be defined as [4]

$$P_n = \int_0^n P_0(v,T)\,dn \tag{6}$$

where $n = vt$, P_0 is defined by a method of inspection.

With 100 per cent inspection, the reliability is

$$H_n = 1 - P_n = 1 - \int_0^N P_0(v,T)\,dn \tag{7}$$

where ***N*** is number of items in the lot inspected.

The reliability of sample inspection is defined by the relation:

$$H_{nв} = H_n \cdot H_в^{/} = (1 - P_n)(1 - P_в^{/'}) \tag{8}$$

where $H_в^{/}$ is reliability of sample inspection, H_n is reliability of inspection of the sample itself, $P_в^{/}$ is probability of defective products for this method of inspection, P_n is probability of defective products in the sample.

Based on the conditions

$$P_n « 1;\ P_в^{/} « 1,$$

for Equation (8)

$$H_в^{/} \approx 1 - \mathrm{P_п} - \mathrm{P_в}^{/}$$

Taking into account (7) and (8), we obtain the formula of reliability of sample inspection

$$H_{nв} = 1 - P_{в.0}^{/}(n_1) - \int_0^{n_1} P_0(v, T)\,dn \tag{9}$$

where n_1 is size of the sample, $P_{в.0}^{/}(n_1)$ is probability of defective products for this method of testing that is a function of the size of the sample.

Define the optimal value $H_{nв}$. Simultaneously, consider two special cases:

a) $P_0\,(v,T) = const = P_0$. This case corresponds to the automated inspection on the horizontal segment of curve $P = f(T)$;

б) $P\,(n) = a/n$; $P_0 = bn$. This case corresponds to manual inspection or low reliable operation of testing equipment. The factor b characterizes the slope of the curve for manual testing on the portion T_2 (see Figure 1) and is defined by direct measurement under specific conditions

$$\mathrm{b = k/Tm},$$

where k is number of inspection errors for the last time period, m is total number of inspection errors for the time T.

The value $P_{в.0}^{/}(n_1)$ is found for the purpose of reliability of the sample volume

$$P_{в.0}^{/} = a/n_1$$

where a = 0.25 ... 1 depending on the chosen reliability of testing.

For a sample automated inspection, we will have the following expression of reliability [2]:

$$H_{nв} = 1 - \frac{a}{n_1} - P_{в.0}n_1 \tag{10}$$

The optimal value of reliability of automated incoming inspection will be derived from the conditions

$$\frac{\partial H_{пв}}{\partial n_1} = 0;\ n_1 = \sqrt{\frac{a}{P_{в.0}}};\ H_{n\max} = 1 - 2\sqrt{aP_{в.0}}$$

For a sample manual inspection, or low reliability designs of testing and measuring devices, the expression of inspection reliability looks like

$$H_{пв} = 1 - \frac{a}{n_1} - \frac{bn_1^2}{2} \tag{11}$$

The optimal value of reliability of manual incoming inspection is derived from the conditions:

$$\frac{\partial H_{пв}(n)}{\partial n_1} = 0;\ n_1 = \sqrt[3]{\frac{a}{b}};\ H_{пв\max} = 1 - \frac{3}{2} b^{\frac{1}{2}} a^{\frac{2}{3}}.$$

With 100 per cent inspection, the expression of reliability looks like:
For automated testing, $H_n = 1 - P_0 N$;
For manual testing, $H_n = 1 - bN^2/2$.

Figure 2 shows the areas of reliability of sample and 100 per cent inspection valid both for automated and manual methods of testing. There is a characteristic first area where 100 per cent inspection is more reliable, and a characteristic second area where sample inspection is more reliable.

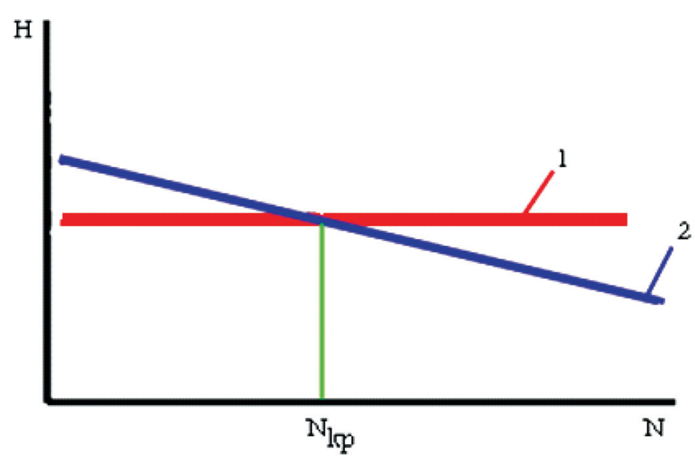

Fig. 2. Areas of reliability of 100 per cent (1) and (2) sample testing

To define the number of products $N_{кр}$, with less than this the reliability being higher than 100 per cent inspection, and with more than this the reliability being higher than sample inspection, use the condition

$$H_{n\max} = H_n$$

Then for automated inspection

$$N_{\kappa p} = 2\frac{\sqrt{aP_{a0}}}{P_0}.$$

For manual inspection

$$N_{\kappa p} = 3\sqrt{\frac{a}{b}}.$$

Incoming testing cost

Economic evaluation of incoming inspection provides a possibility of obtaining a relation between the cost of inspection of components and materials coming into production and the cost of replacement of defective items in equipment or repairing to correct defects in materials [6]. Thus, we tackle the issue whether it is reasonable to apply this or another type of incoming inspection. Such inspection is appropriate for components that do not ensure to some significant extent reliability parameters of equipment.

Let us introduce the concept of total cost to imply the amount of expenditures spent on incoming inspection and repair of defective components in equipment.

We'll define the concept of total cost for three possible practical cases.

No incoming inspection

The total cost is equal to the cost of replacement of defective items in equipment or repair of substrates for elimination of defects of materials. It is equal to the product of the number of faulty elements in the lot and the cost of withdrawing defective parts from assembled products and replacing them with good parts or repairing cost:

$$C'_0 = PNC_R \tag{12}$$

where P is proportion or probability of faulty elements among incoming parts, C_R is cost of replacement of one part, N is total number of parts.

100 per cent inspection

The total cost amounts to the sum of the costs of inspection and screening of parts. The number of missed defective parts is defined by the qualification of a controller and the quality of testing equipment. The total cost in this case is defined by Equation

$$C_0^{//} = NCT + K_1PNC_R \tag{13}$$

where C_T is cost of one item inspection, K_1 is proportion of faulty items overlooked with 100 per cent inspection.

Sample inspection

For the case of sample inspection, the total cost consists of two parts:

The cost of acceptance of a lot based on a sample, which can be represented by the following expression:

$$C = P_A[nC_T + (N - n)PC_R + nK_2PC_R] \tag{14}$$

where nC_T is cost of sample inspection consisting of n items, $(N - n)PC_R$ is cost of replacement of faulty items from the portion of a lot that is not inspected, nK_2PC_R is cost of replacement of faulty items from the portion of a lot that is inspected (sample) but overlooked by a controller, P_A is probability of acceptance of a lot.

The cost of a rejected lot is equal to the cost of inspection of a sample multiplied by the probability of rejection is $1 — P_A$.

The expression for an expected total cost of rejected lots will look like

$$nC_T(1\text{-}P_A)/P_A$$

The total cost for the case of sample inspection is defined by the expression

$$C^{///} = P_A[nC_T + (N - n)PC_R + nK_2PC_R] + nC_T(1\text{-}P_A)/P_A \tag{15}$$

Graphic expression of inspection cost

Using the derived equations, we can build charts of the total cost of inspection depending on the quality of a given lot characterized by the value P, i.e. the proportion of faulty items.

The graphs of the total cost of inspection are shown in Figure 3.

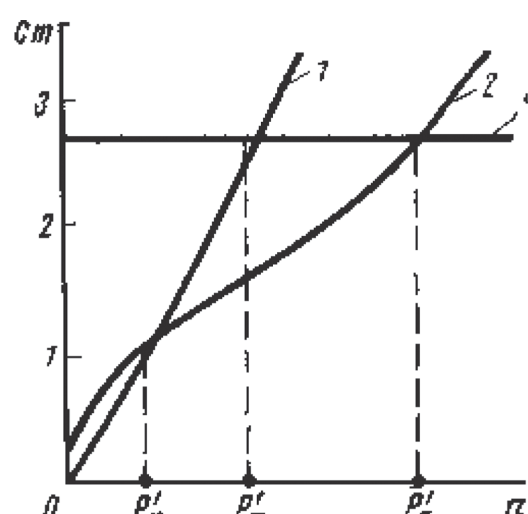

Fig. 3. Graphs of the total cost for various methods of inspection:
1 is lack of incoming inspection, 2 is sample inspection, 3 is 100 per cent inspection

The chart of the total cost for 100 per cent inspection (3) represents a nearly horizontal straight line declining slightly depending on the value of K and P.

The chart of the total cost for no incoming inspection of components (1) is a sloping straight line passing through the origin of coordinates.

For $P = 0$, the total cost is equal to zero, and as the quality of items deteriorate, the total cost grows linearly. The intensity of total cost growth depends on the total number of items and expenditures related to their replacement.

The chart of the total cost for sample inspection (2) is non-linear. For $P = 0$, the cost is defined by the value of nC_T, with a growing P, it increases but less intensively than for no incoming inspection.

Using charts of total cost, we can find the optimum variant of incoming inspection of components and materials in terms of cost.

The way of inspecting components will be defined by the size of a lot N and the proportion P of faulty items in the lot, as well as by a number of other parameters that can be either specified, for example C and C_R, or represent a function of N or P, for example n or P_A.

The proportion P of defective items is usually unknown before inspection of a lot, and, therefore, when evaluating this value, we should use statistic data previously obtained [6].

The optimal assessment of inspection can be also obtained by an analytical way, without using charts. To this end, we shall define critical points, i.e. points wherein one control scheme becomes cheaper than another. Denote these critical points as $P_x^/$, $P_y^/$, $P_t^/$.

No incoming inspection and 100 per cent inspection

The critical point $P_x^/$ of intersection of total cost curves for no incoming inspection and 100 per cent inspection is derived from Equations (12) and (13):

$$P_x^/ NC_R = NC_T + K_1 P^/ NC_R$$

$$P_x^/ = \frac{C_T}{C_R(1-K_1)} \tag{16}$$

100 per cent inspection will be more reasonable when the quality of incoming parts P' is more than the value $P_x^/$, and vice versa, with P' being less than the value $P_x^/$, no incoming inspection is more reasonable.

No incoming inspection and sample inspection

The critical point $P_y^/$ of intersection of total cost curves for no incoming inspection and sample inspection is derived from Equation

$$P'NC_R = P_A[nC_T + (N - n)P/C_R + K_2nP/C_R] + [nC_T(1 - P_A)]/P_A$$

$$P_y^/ = \frac{nC_T}{C_R[N - P_A(N - n + nK_2}} \tag{17}$$

The probability of lot acceptance P_A is expressed as the function *P'* and *n* and can be defined using the Poisson formula [4]

$$P_r = \frac{(nP^{/})^r}{r!} e^{-nP^{/}} \tag{18}$$

where *n* is number of items chosen for inspection, *P'* is percentage of rejects, P_r is probability of the event that there will be the ***r*** faulty items in the sample.

Obviously, $P^{/}_y$ should be calculated according to a specific sampling plan, since for each sampling plan, P_A values will be different. Procedure for defining $P^{/}_y$ is as follows:

1. Outline a sampling plan, then specify the number of items chosen *n*, the size of a lot *N*, and acceptance criteria *AC*. An acceptance criterion means a minimum acceptable number of defective parts from the parts chosen for inspection (sample). The value of P_A, corresponding to any value of *AC*, can be obtained from Tables of a Poisson distribution, with an expected value *P' P_A* taken into account. It is equal to the sum of all P_r up to $r = AC$.
2. Define $P_y^{/}$ taking into account the calculated value of P_A.
3. No incoming inspection will be more reasonable with the expected value of *P'* being less than $P^{/}_y$. When *P'* is more than $P^{/}_y$, a sample inspection method is more reasonable economically.

100 per cent inspection and sample inspection

The critical point $P_x^{/}$ of intersection of total cost curves for 100 per cent inspection and sample inspection is derived from Equation

$$NC_r + K_1P^{/}NC_R = P_A[nC_r + (N-n)P^{/}C_R + k_2nP^{/}C_R] + [nC_r(1 - P_A)]/P_A,$$

Hence,

$$P^{/}_Z = \frac{P_A C_T [N - P_A n + n] - nC_r}{P_A^2 C_R [(N-n) + K_2 n] - P_A C_R K_1 N}$$

The value of $P_Z^{/}$ is calculated the same way as in the previous case. When the value $P^{/}$ is less than the estimated value $P_Z^{/}$, a sample inspection method is more advantageous.

When $P^{/}$ is more than $P_Z^{/}$, a hundred per cent inspection method is economically more reasonable.

Optimal strategy of incoming inspection

Currently, the issues related to quality and reliability of electronic equipment has become of great importance, both for component manufactures and their consumers. The hottest disputes are related to the fact that an equipment manufacturer is forced to make a significant amount of expensive and time-consuming tests of components coming into production within incoming inspection [6]. These tests follow the procedures of testing already carried out by a company-supplier who spent quite substantial money on it. However, the extent of such duplication should constantly decrease. This is due to a process of continuous quality improvement of components which allows for closer cooperation between suppliers and consumers in tackling the problem of extreme importance, i.e., at first to drastically reduce the amount of operations as to incoming inspection of components and materials, and then to abandon them completely.

In order to reduce the cost of testing and restrict the sample size to the minimum, acceptance criteria are to be restricted such a way that a single fault should cause rejection of the whole lot. In those cases where the level of faults for incoming inspection of components is less than 100 faults per one million, i.e. 0.01 per cent, incoming inspection is usually economically unreasonable. It is more reasonable for the vast majority of productions to identify such rare cases when testing nodes, blocks, or even equipment [7, 8].

Conclusion

Calculations show unobvious results when evaluating the reasonability of complete, sample and uncontrolled inspection. Certainly, in the real fast changing environment of production it is difficult to make the above calculations. However, the conclusions which can be drawn from these calculations allow us to consciously build the strategy and tactics of inspection in the face of uncertainty as to quality of components and materials coming into production.

References

1. GOST 24297-87. Incoming inspection of products. Guidelines.

2. **Bekishev A.P., Medvedev A.M.** Incoming inspection of electronic components. *Components and technologies*. 2008, No.10, 161-164.

3. **Fyodorov V.K., Sergeev N.P., Kondrashin F.F.** Inspection and testing in designing and production of radio-electronic equipment. Moscow, Technosphere, 2005. – 504.

4. **Frolov A.D.** Theoretical fundamentals of design and reliability of electronics. Moscow: Vysshaya Shkola, 1970, 457.

5. **Anufriev D.L.** Construction methods for improving the reliability of integrated circuits. *Tutorial*. Minsk, Integralpoligraf, 2007, 264.

6. **Gorlov M., Stroganov A., Andreev A.** Incoming inspection of semiconductor products. /CHIP NEWS, No. 3 (66). March, 2002, 40-46.

7. **Medvedev A., Mozharov V., Mylov G.** Printed Circuit Boards. State-of-the-art of Basic Materials. *Electronics. Science. Technology. Business*. 2011, No.6, 148-162.

8. Technology in production of electronic equipment. *Part III. Flexible printed circuit boards*. Ed. A. Medvedev and G. Mylov. Moscow, IDT Group, 2008, 488.