Statistical Methods in Assembly Quality Management of Multi-Element Products on Automatic Rotor Lines

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Abstract. To control the assembly quality of multi-element mass-produced products on automatic rotor lines, control methods with operational feedback are required. However, due to possible failures in the operation of the devices and systems of automatic rotor line, there is always a real probability of getting defective (incomplete) products into the output process stream. Therefore, a continuous sampling control of the products completeness, based on the use of statistical methods, remains an important element in managing the quality of assembly of multi-element mass products on automatic rotor lines. The feature of continuous sampling control of the multi-element products completeness in the assembly process is its breaking sort, which excludes the possibility of returning component parts after sampling control to the process stream and leads to a decrease in the actual productivity of the assembly equipment. Therefore, the use of statistical procedures for continuous sampling control of the multi-element products completeness when assembled on automatic rotor lines requires the use of such sampling plans that ensure a minimum size of control samples. Comparison of the values of the limit of the average output defect level for the continuous sampling plan (CSP) and for the automated continuous sampling plan (ACSP) shows the possibility of providing lower limit values for the average output defects level using the ACSP-1. Also, the average sample size when using the ACSP-1 plan is less than when using the CSP-1 plan. Thus, the application of statistical methods in the assembly quality management of multi-element products on automatic rotor lines, involving the use of proposed plans and methods for continuous selective control, will allow to automating sampling control procedures and the required level of quality of assembled products while minimizing sample size.

Key words. Assembly, automatic rotor line, statistical methods, continuous sampling.

1. Introduction

Modern assembly production of mass-produced products is characterized by the continuity of the technological process, high degree of automation and high productivity of technological assembly equipment. Automated rotor lines are used to assemble multi-element mass-produced products in various branches of machine and instrument engineering, both in our country and abroad [1 – 3]. The productivity of automatic rotor lines, depending on the type and size of the assembled multi-element product, can be from 100 to 1000 pieces/min.

The quality of multi-element products assembly is ensured by high requirements to the component parts quality, as well as to the reliability of the main technological systems in the automatic rotor line. From the standpoint of reliability, automatic rotor lines belong to complex reconstructed systems, the features of which are a multi-level structure and the ability to function with different levels of actual
performance. Technological rotors form a multi-channel part of the line, which has the property of increased survivability, characterized by the fact that if a functional device or tool fails in one of the rotors, the line retains the ability to function, but with less productivity.

The reliability of the main technological systems of the automatic rotor line is ensured by constructive methods, for example, by reserving the automatic loading of component parts, and organizational methods, in particular, by choosing the optimal maintenance strategy for the multi-channel part of the automatic rotor line [4].

To control the assembly quality of multi-element mass-produced products on automatic rotor lines, control methods with operational feedback are required. The quality control of automated assembling of multi-element products is carried out by using control devices (rotors) and an information-control system in the automatic rotor line structure that provide complete control over the availability of component elements in the process stream, control of automatic loading systems (refusal to load the subsequent element to the assembly in the absence of the previous element), removal of incomplete products from the process stream, etc.

However, due to possible failures in the operation of the devices and systems of automatic rotor line, there is always a real probability of getting defective (incomplete) products into the output process stream. Therefore, a continuous sampling control of the products completeness, based on the use of statistical methods, remains an important element in managing the quality of assembly of multi-element mass products on automatic rotor lines [5 – 9].

The feature of continuous sampling control of the multi-element products completeness in the assembly process is its breaking sort, which excludes the possibility of returning component parts after sampling control to the process stream and leads to a decrease in the actual productivity of the assembly equipment. Therefore, the use of statistical procedures for continuous sampling control of the multi-element products completeness when assembled on automatic rotor lines requires the use of such sampling plans that ensure a minimum size of control samples.

2. Theoretical part

In general, the continuous sampling procedure is an alternation of periods of continuous and spot checks. In a one-stage inspection, the transition from continuous monitoring to selective control is carried out under the condition that \( n \) products are successfully received in a stream. Selective control is carried out with a frequency \( f \) and at the first appearance of a defective (incomplete) product go to a continuous control. In multi-stage control, several different frequencies are used.

For the first time, Dodge and Romig [10] proposed the models of continuous sampling plan (CSP). Therefore, when using the one-stage CSP-1 plan, the control begins with a continuous inspection of the products, beginning with the first product being manufactured. Such verification is carried out until the control device has passed a contract of \( i \) good products. After this, the sampling control begins with a frequency \( f \), continuing until a defective product is found. Immediately a continuous inspection is resumed, which continues until the demand for passing through the control device in a row of \( i \) suitable products is fulfilled.

The alternation of selective control procedures and continuous monitoring of the appearance of incomplete products in the process stream leads to the fact that the control devices of the automatic rotor line must work with variable capacity.

In order to eliminate this drawback, models for the automated continuous sampling plan (ACSP) were developed [11]. These plans allow the control to be carried out rhythmically, which greatly simplifies the design of the control devices themselves and their integration into automatic rotor lines. For example, in the one-stage ACSP-1 plan, each \( f^{-1} \) collected product is monitored. At the same time, the current sequence of \( i \) products, produced by the automatic rotor line, is in the store. When an incomplete product appears among the selectively controlled products, the volume of the storage is taken from the process stream to be scrapped, and the line is adjusted.
Since the products in the automatic rotor line are in the process of continuous transportation, when use of the plan ACSP-1 in the volume of the store can also be included the product, subjected to automatic control, but inside the group of $i$ accumulated products. In this case the volume of the storage can be calculated according to the expression: $[(1 - f) i - 1]$.

In the case when suitable ones, do not replace the defective (incomplete) products, which is typical for the automated assembly of multi-element mass-produced products, the expression for the average output defects level will take the form:

- for one-stage plan CSP-1: $q_{av} = \frac{(1 - f)(1 - q)^{i-1}}{(1 - f)(1 - q)^{i-1} + f}$,  \hspace{1cm} (1)

- for one-stage plan ACSP-1: $q_{av} = \frac{1 - (1 + iq)f}{1 - (1 + iq)f_q} q$,  \hspace{1cm} (2)

where $q$ - the probability of detection of defective (incomplete) product.

The expression for the average sample size will take the form:

- for one-stage plan CSP-1: $n_{sam} = \frac{f}{f + (1 - f)(1 - q)^{i}} \times 100 \%$,  \hspace{1cm} (3)

- for one-stage plan ACSP-1: $n_{sam} = \frac{(1 + iq)(1 - q)}{1 - (1 + iq)f_q} f \times 100 \%$.  \hspace{1cm} (4)

3. Discussion of results

We perform a comparative analysis of the average level of output defects and the average sample size for the above plans. Analysis of the dependencies (1) and (2) shows the possibility of providing lower limit values for the average output defects level using the ACSP-1 (Figure 1).

**Figure 1.** Comparison of the values of the limit of the average output of defect level when using the CSP-1 plan and the ACSP-1 plan (for $i=20$).

**Figure 2.** Comparison of the average sample size when using the CSP-1 plan and the ACSP-1 plan (for $i=20$).

Analysis of the dependencies (3) and (4) shows, that the average sample size in the ACSP-1 plan is smaller than in the CSP-1 plan (Figure 2).

Thus, the simulation results showed that the application of the ACSP-1 plan improves the quality control for both parameters – $q_{av}$ and $n_{sam}$.
4. Applications of research results

The application of continuous sampling control plans for the management of the automated assembly quality of multi-element mass products on automatic rotor lines made it possible to propose a new method for the implementation of automated statistical control. The aim of the method is to ensure the limit of the average output of defective results. The essence of the proposed method is that the collected products are taken from the process stream for monitoring at a certain frequency and accumulates uncontrolled products in the storage. The storage is located behind the control device. If the monitoring device detects one or several defective products, the products contained in the storage are removed from the stream and must to discard. The volume of the storage exceeds the number of products manufactured during the period between the sampling control, and selective control is performed by several similar or different control devices with separate storages or shared storage.

In Figure 3 shows a scheme for implementing the proposed method for continuous sampling assembly quality control of multi-element products on an automatic rotor line.

![Figure 3](image)

**Figure 3.** Scheme for implementing the proposed method for continuous sampling quality assembly control on an automatic rotor line: 1 – control rotor; 2 – storage; 3 – device for removing products; 4 – storage and sorting device; 5 – conveyor.

The assembled products are loaded from the conveyor 5 to the appropriate control devices located in the control rotor 1 with frequency f. After the sampling in the control devices, the unchecked products remain inside the storage 2, which may be a continuation of the conveyor 5, or a separate transport element of the automatic rotor line. If a defective product is found, the device for removing products 3, discards uncontrolled products in the storage and sorting device 4. The products in device 4 are scrapped with or without return of suitable products to the conveyor 5 in accordance with the control technology.

The proposed solutions will allow us to proceed to the creation of automated quality control systems that provide a comprehensive solution to the problem of improving the assembly quality of multi-element products in mass production based on the application of statistical methods and procedures, automated technical means for managing the technological stream and computerized information management systems [12].

5. Conclusion

Thus, the application of statistical methods in the assembly quality management of multi-element products on automatic rotor lines, involving the use of proposed plans and methods for continuous selective control, will allow to automating sampling control procedures and the required level of quality of assembled products while minimizing sample size.

The proposed method for the statistical assembly quality control of multi-element products allows for controlled products limit the level of defects to a certain value inherent in the customer requirements.
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