Improved model for detection of homogeneous production batches of electronic components

L A Kazakovtsev\textsuperscript{1,2}, V I Orlov\textsuperscript{1}, D V Stashkov\textsuperscript{1}, A N Antamoshkin\textsuperscript{1,2} and I S Masich\textsuperscript{1,3}

\textsuperscript{1}Reshetnev Siberian State University of Science and Technology, 31 Krasnoyarskiy Rabochiy av., Krasnoyarsk, 660037, Russia
\textsuperscript{2}Siberian Federal University, 79 Svobodny av., Krasnoyarsk, 660041, Russia
\textsuperscript{3}Krasnoyarsk State Agrarian University, 90 Mira av., Krasnoyarsk, 660049, Russia

E-mail: levk@bk.ru

Abstract. Supplying the electronic units of the complex technical systems with electronic devices of the proper quality is one of the most important problems for increasing the whole system reliability. Moreover, for reaching the highest reliability of an electronic unit, the electronic devices of the same type must have equal characteristics which assure their coherent operation. The highest homogeneity of the characteristics is reached if the electronic devices are manufactured as a single production batch. Moreover, each production batch must contain homogeneous raw materials. In this paper, we propose an improved model for detecting the homogeneous production batches of shipped lot of electronic components based on implementing the kurtosis criterion for the results of non-destructive testing performed for each lot of electronic devices used in the space industry.

1. Introduction

The most important units are integrated from electronic devices manufactured as special production batches, which meet special quality requirements [1, 2]. Each device in each of the shipped batches is checked via many destructive and nondestructive tests [1, 3]. Data of the non-destructive testing can be used for analyzing the homogeneity of the shipped lot [3]. For splitting the lot of electronic devices into several assumed production batches, the k-means method [4, 5, 6] or fuzzy clustering methods [7] can be used.

American and European EEE component manufacturers produce electronic devices of special quality classes, Military and Space [8, 9]. Russian manufacturers do not form a special class of components for use in space systems [1, 2].

Some small part of each of the shipped lots of electronic devices is checked via destructive tests. If the homogeneous production batches have not been partitioned, the results of the destructive tests of small number of selected devices cannot be extended to the whole shipped lot.

Quality requirements of the electronic devices in space systems are so high that the range of characteristics measured via quality check tests is very narrow and the quality class and assumed production batch of each device in the lot must be determined via analysis of difference (distance) of test result data vectors which slightly exceeds the precision of the
measurement tools. Thus, results of each measurement form a finite (discrete) set of possible values defined by the measurement tool precision.

2. The model of production batch as a mixture of Gaussian distributions

Results of tests carried out during the incoming control, additional burn-in testing and other forms of non-destructive testing are represented in a form of data vectors of high dimensionality, up to several hundred dimensions.

If we have test results of a production batch of electronic devices proved to be produced as a homogeneous production batch from a single batch of raw materials, we can estimate the nature of probability distribution \([10]\) of each of measurements (dimension, parameters) of electronic devices in this batch.

Some results in assessment of the nature of distributions of these parameters are listed in \([11]\). It is shown \([11]\) that the hit frequency histograms of drift values of parameter values obtained from the measurements performed before and after the electrical and thermal trainings have a form close to normal distribution. Also, values of some parameters seem to be normally distributed.

Results of investigating of probability distributions of parameters of the homogeneous production batches of the integrated circuits 1526TL1 are listed below (see table 1). We investigated devices of three production batches of 199, 535 and 98 pieces. All measurements received during non-destructive tests are subjected to a research. Values of each measurement were grouped in 7 intervals.

**Table 1.** Results of a research of probability distributions of measurements (parameters) of the IC 1526TL1 (production batch of 199 pieces)

| Parameter | Avg. | Standard deviation | Kurtosis criterion | Value intervals | Hit frequency | Theoretical hit frequency if the probability distribution is Gaussian |
|-----------|------|--------------------|-------------------|----------------|--------------|-------------------------------------------------------------|
| T2        | -0.03464 | 0.000355 | -0.669 | \(-\infty -0.0353\) 2 | 12.1112 |
|           |       |                   |                   | \(-0.0353 -0.03509\) 27 | 22.24904 |
|           |       |                   |                   | \(-0.03509 -0.03487\) 34 | 38.67464 |
|           |       |                   |                   | \(-0.03487 -0.03466\) 45 | 47.19217 |
|           |       |                   |                   | \(-0.03466 -0.03444\) 34 | 40.42747 |
|           |       |                   |                   | \(-0.03444 -0.03423\) 23 | 24.31193 |
|           |       |                   |                   | \(-0.03423 -0.03401\) 22 | 10.26153 |
|           |       |                   |                   | \(-0.03401 +\infty\) 12 | 3.772006 |
|           |       |                   |                   | \(-0.0353 -0.03509\) 25 | 22.21356 |
|           |       |                   |                   | \(-0.03509 -0.03487\) 36 | 38.97081 |
|           |       |                   |                   | \(-0.03487 -0.03466\) 48 | 47.66004 |
|           |       |                   |                   | \(-0.03466 -0.03444\) 31 | 40.63498 |
|           |       |                   |                   | \(-0.03444 -0.03423\) 26 | 24.15167 |
|           |       |                   |                   | \(-0.03423 -0.03401\) 19 | 10.00465 |
|           |       |                   |                   | \(-0.03401 +\infty\) 13 | 3.537402 |

| T5        | 0.000351 | -0.62321 | -0.03465 | \(-\infty -0.0353\) 1 | 11.88415 |
|           |       |                   |                   | \(-0.0353 -0.03509\) 27 | 22.35092 |
|           |       |                   |                   | \(-0.03509 -0.03487\) 32 | 39.14586 |
|           |       |                   |                   | \(-0.03487 -0.03466\) 49 | 47.74116 |
|           |       |                   |                   | \(-0.03466 -0.03444\) 32 | 40.54652 |
|           |       |                   |                   | \(-0.03444 -0.03423\) 27 | 23.97934 |
|           |       |                   |                   | \(-0.03423 -0.03401\) 18 | 9.87299 |
|           |       |                   |                   | \(-0.03401 +\infty\) 13 | 3.479068 |
| T12   | 1E-07  | 96.95  |
|-------|--------|--------|
|       | -∞     | -1E-06 | 2   | 4.08E-18 |
|       | -1E-06 | -8.6E-07 | 0  | 8.66E-13 |
|       | -8.6E-07 | -7.1E-07 | 0  | 2.47E-08 |
|       | -7.1E-07 | -5.7E-07 | 0  | 9.55E-05 |
|       | -5.7E-07 | -4.3E-07 | 0  | 0.081495 |
|       | -4.3E-07 | -2.9E-07 | 0  | 4.039777 |
|       | -2.9E-07 | -1.4E-07 | 0  | 49.57459 |
|       | -1.4E-07 | 0       | 197 | 145.3348 |
|       | -1E-06  | -8.6E-07 | 0  | 5.23E-06 |
|       | -8.6E-07 | -7.1E-07 | 0  | 0.000949 |
|       | -7.1E-07 | -5.7E-07 | 0  | 0.063484 |
|       | -5.7E-07 | -4.3E-07 | 0  | 1.587031 |
|       | -4.3E-07 | -2.9E-07 | 0  | 15.01864 |
|       | -2.9E-07 | -1.4E-07 | 0  | 54.49758 |
|       | -1.4E-07 | 0       | 195 | 127.8323 |
| T21   | 2.93E-07 | 17.52  |
|       | -∞     | -2E-06 | 1   | 9.77E-08 |
|       | -2E-06  | -1.6E-06 | 0  | 0.000331 |
|       | -1.6E-06 | -1.1E-06 | 0  | 0.14289 |
|       | -1.1E-06 | -7.1E-07 | 5  | 8.289913 |
|       | -7.1E-07 | -2.9E-07 | 0  | 70.85328 |
|       | -2.9E-07 | 1.43E-07 | 185 | 97.15819 |
|       | 1.43E-07 | 5.71E-07 | 0  | 22.0597 |
|       | 5.71E-07 | 0       | 8   | 0.766687 |
|       | -∞     | 2.274286 | 8   | 12.57832 |
|       | 2.274286 | 2.378571 | 15  | 34.21205 |
|       | 2.378571 | 2.482857 | 55  | 55.05061 |
|       | 2.482857 | 2.587143 | 55  | 52.43781 |
|       | 2.587143 | 2.691429 | 38  | 29.56636 |
|       | 2.691429 | 2.795714 | 20  | 9.860443 |
|       | 2.795714 | +∞     | 7   | 2.184191 |
| T76   | 0.306458 | -0.6699 |
|       | -∞     | -8.17   | 1   | 6.834989 |
|       | -8.17   | -9.6286 | 15  | 18.2802 |
|       | -9.6286 | -7.75571 | 31  | 38.50211 |
|       | -7.75571 | -7.54857 | 40  | 52.22657 |
|       | -7.54857 | -7.34143 | 49  | 48.6357 |
|       | -7.34143 | -7.13429 | 38  | 25.68493 |
|       | -7.13429 | -6.92714 | 21  | 9.30728 |
|       | -6.92714 | +∞     | 4   | 2.528227 |
| T143  | 0.000829 | 0.1044  |
|       | -∞     | 0.0122  | 1   | 5.575501 |
|       | 0.0122  | 0.012829 | 12  | 19.21635 |
|       | 0.012829 | 0.013457 | 34  | 42.21939 |
|       | 0.013457 | 0.014086 | 46  | 38.78908 |
|       | 0.014086 | 0.014714 | 64  | 45.1765 |
|       | 0.014714 | 0.015343 | 31  | 20.05781 |
|       | 0.015343 | 0.015971 | 5   | 5.19224 |
|       | 0.015971 | +∞     | 6   | 0.826082 |
| T154  | 0.011065 | -0.692  |
|       | -∞     | 4.73    | 12  | 7.381403 |
|       | 4.73    | 4.735714 | 0   | 12.95928 |
|       | 4.735714 | 4.741429 | 39  | 24.6027 |
|       | 4.741429 | 4.747143 | 0   | 35.98084 |
|       | 4.747143 | 4.752857 | 60  | 40.5394 |
|       | 4.752857 | 4.758571 | 0   | 35.18796 |
|       | 4.758571 | 4.764286 | 61  | 23.53026 |
|       | 4.764286 | +∞     | 27  | 18.81862 |
Graphically, statistical results provided in table 1 together and results of data handling of the second production batch (535 pieces) are provided in figures 1-3.

**Figure 1.** Hit frequency histogram of the IC 1526TL1 T2 parameter. The batch No. 1 (199 pieces) above, the batch No. 2 (535 pieces) below.
Figure 2. Hit frequency histogram of the IC 1526TL1 T13 parameter. The batch No. 1 (199 pieces) above, the batch No. 2 (535 pieces) below.
Analysis of the hit frequency histograms shows that the nature of distributions of parameters in different batches is identical, mean standard deviations are commensurable.

All measurements (parameters, dimensions) of nondestructive tests can be divided into three groups:

A) A group of parameters for which normal the nature of distribution is evident. For the integrated circuit 1526TL1, it is possible to carry T2-T5 (figure 1), T76 to those.

Figure 3. Hit frequency histogram of the IC 1526TL1 T154 parameter. The batch No. 1 (199 pieces) above, the batch No. 2 (535 pieces) below
B) Parameters for which the normal nature of probability distribution is visible on the hit frequency histogram, however, the accuracy of measuring instruments is such low that the possible values of this measurement forms a small finite set of values. In this case, the hit frequency histogram contains essential gaps regarding the actual frequency of hit of values in intervals. Please note that assessment of normality of the probability distribution by Pearson's criterion (Chi-square) \cite{10} gives negative answer (hypothesis of normal distribution seems to be wrong). For example, it is possible to carry to such parameters T154 (figure 2).

C) Parameters for which the hit frequency histogram has the appearance not corresponding to normal distribution (for example, T12, T13, T21, see figure 3). In certain cases, it is possible to make the assumption of a probability distribution similar with the exponential distribution.

Apparently from table 1, the kurtosis criterion \cite{12}

$$C_{ex} = \frac{\sum_{i=1}^{N}(x_i - \frac{1}{N}\sum_{j=1}^{N}x_j)^4}{(\sum_{i=1}^{N}(x_i - \frac{1}{N}\sum_{j=1}^{N}x_j)^2)^2} - 3 = \frac{\sum_{i=1}^{N}(x_i - \bar{x})^4}{\sigma^4}$$

allows to separate group B parameters from remaining. Here, $x_1 \ldots x_N$ are values of measurements of some parameter of products of a batch from N pieces, $\bar{x}$ is the average value of this parameter, $\sigma$ is standard deviation. For such parameters, the values of this criterion are high (more than 10). For normally distributed random variable, this criterion has zero expectation.

Let us note that for different products, parameters of group A form the very considerable part of the whole set of parameters, from 40% to 70%. For parameters of this group and for parameters of group B, admissible boundaries of drift of parameters are set \cite{13}.

Model of a combined batch of electronic devices in the form of a mix of spherical or uncorrelated Gaussian distributions \cite{7, 14} allows to separate components of combined batches. At the same time the percent of errors is rather high.

The model of division of a combined batch of electronic devices based on the k-means model \cite{15-17} is also well investigated. At the same time is shown that data normalization with use of the admissible boundaries of parameter drift \cite{13} allows to lower percent of errors in case of division of a combined batch.

Having separated parameters which normality of distribution is not confirmed with use of the kurtosis criterion parameters, it is possible to create a new shortened dataset which parameters have normal distribution with which normality of distribution isn't confirmed. In this case, it is possible to make the reasonable assumption that use of this new dataset allows to increase the adequacy of a model based on a mixture of Gaussian distributions and lower errors ratio.

3. Verification of adequacy of the model

To check of adequacy of the model of division of a combined batch of electronic devices, we used two combined batches as a test example, the batch of integrated circuits 1526IE10 of 870 pieces produced as four homogeneous and a combined batch of amplifiers 140UD25AVK of 53 of pieces \cite{18}. The results for integrated circuits 1526IE10 are presented in Table 2.

4. Conclusion

The nature of probability distributions of separate parameters of electronics devices allows us to conclude that a considerable part of these parameters forms a multidimensional Gaussian distribution. Elimination of the parameters having a distribution other than normal
allows to increase adequacy of the model of homogeneous production batches detection based on a mixture of Gaussian distributions.

**Table 2.** Comparative results of dividing of a combined batch of the IC 1526IE10 (870 pieces)

| Model                                      | Batch No 1 | Batch No 2 | Batch No 3 | Batch No 4 | Errors ratio |
|--------------------------------------------|------------|------------|------------|------------|--------------|
|                                            | Quantity of errors in this actual production batch | Quantity of errors in this actual production batch | Quantity of errors in this actual production batch | Quantity of errors in this actual production batch | Errors ratio |
| In fact                                    | 146        | 229        | 424        | 71         | -            |
| Uncorrelated Gaussians with original dataset with all parameters | 244        | 25         | 196        | 41         | 72           | 1            | 16.7%        |
|                                            | 125        | 26         | 221        | 8          | 110          | 0            | 5.05%        |
| Spherical Gaussians [7]                    | 251        | 0          | 189        | 40         | 71           | 0            | 13.3%        |

**Acknowledgments**
Results were obtained in the framework of the state task No. 2.5527.2017/8.9 of the Ministry of Education and Science of the Russian Federation.

**References**
[1] Fedosov V V and Orlov V I 2011 Minimal necessary extent of examination of microelectronic products at inspection test stage Izvestiya Vuzov. Priborostroenie 54(4) 68-62
[2] Kharchenko V S and Yurchenko Yu B 2003 Rating of fault-tolerant onboard complexes frames at usage electronic components industry Tekhnologiya i konstruirovanie v elektronnoy apparature 2 3–10
[3] Kazakovtsev L A, Orlov V I, Stupina A A and Masich I S 2014 Zadacha klassifikatsii elektronnikh komponentov [Problem of electronic components classifying] Vestnik SibGAU 4(56) 55-61
[4] Ackermann M R et al 2012 StreamKM: A Clustering Algorithm for Data Streams J. Exp. Algorithmics 17 2.4:2.1-2.30
[5] Kanungo T, Mount D M, Netanyahu N S, Piatko C D, Silverman R and Wu A Y 1999 Computing nearest neighbors for moving points and applications to clustering Proc. of the tenth annual ACM-SIAM symp. on Discrete algorithms (Society for Industrial and Applied Mathematics) 931-932
[6] Kazakovtsev L A, Stupina A A and Orlov V I 2014 Modification of the genetic algorithm with greedy heuristic for continuous location and classification problems *Sistemy upravleniya i informatsionnye tehnologii* 2(56) 31-34

[7] Orlov V I, Stashkov DV, Kazakovtsev LA and Stupina AA 2016 Fuzzy clustering of EEE components for space industry *IOP Conference Series: Materials Science and Engineering* 155 P 012026

[8] Hamiter L 1991 The History of Space Quality EEE Parts in the United States ESA *Electronic Components Conf. ESTEC* (Noordwijk, The Netherlands, 12–16 Nov 1990 ESA SP-313)

[9] Kirkconnell C S et al 2014 High Efficiency Digital Cooler Electronics for Aerospace Applications *Proc. SPIE* 9070, Infrared Technology and Applications XL 90702Q (June 24, 2014)

[10] Ader H J 2008 Phases and initial steps in data analysis *Advising on Research Methods: A consultant's companion* Ed H J Ader and G J Mellenbergh (Huizen, the Netherlands: Johannes van Kessel Publishing) 333–356

[11] Fedosov V V 2015 *Voprosy obespecheniya rabotosposobnosti elektronnoy komponentnoy bazy kosmicheskikh apparatov* [Questions of operability support of an electronic component basis in the spacecraft equipment] (Krasnoyarsk: Siberian State Aerospace University)

[12] Hazewinkel M 2001 Excess coefficient *Encyclopedia of Mathematics* (Springer)

[13] Fedosov V V, Kazakovtsev L A and Masich I S 2016 Metod normirovki ishodnyh dannyh ispytaniy elektroradioizdeli y kosmicheskogo primenenija dlja algoritma avtomaticheskoj gruppirovki [Normalization method for initial testdata of electrical radio products in space application for automatic grouping algorithm] *Sistemy upravleniya i informatsionnye tehnologii* 65(3) 92-96

[14] Stashkov D V 2017 Algoritmy poiska s cheredujushhimisja okrestnostjami dlja zadachi razdelenijias mesi raspredelenij [Variable neighborhood search algorithms for problem of separating of a mix of distributions] *Sistemy upravleniya i informatsionnye tehnologii* 1 18-24

[15] Kazakovtsev L A, Orlov V I and Stupina A A 2015 Vybor metriki pri klassifikacii elektroradioizdeli y po proizvodstvennym partijam [On distance metric for the system of automatic classification of the EEE devices by production batches] *Programnye produkty i sistemy* 2 124–129

[16] Kazakovtsev L A, Antamoshkin A N and Masich I S 2015 Fast Deterministic Algorithm for EEE Components Classification *IOP Conf. Series: Materials Science and Engineering* 94 article ID 012015

[17] Stupina A A and Kazakovtsev L A 2015 Fast genetic algorithm with greedy heuristic for p-median and k-means problems *2014 6th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT 2014)* 602-606

[18] Orlov V I, Kazakovtsev L A and Masich I S 2016 Silhouette Criterion for Automatic Grouping Algorithm of Spaceship Electronic Components *Vestnik SibGAU* 17 (4) 883-890