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MODEL OF FAILURE OF PRINTING AND PACKAGING EQUIPMENT AT THE STAGE OF DECOMMISSIONING

The article considers the methodology of statistical modeling of reliability of printing and packaging equipment. Here is given the principal form of dependence of the reliability function on the time of operation of equipment with 4 periods. For the purposes of constructing a function describing all periods of operation, the article suggests using the life-cycle of equipment operation (LCESL). Here is constructed a generalized analytical function of the failure rate, which describes the nuances of the change in the failure rate of real printing and packaging equipment. The failure rate functions developed in the article made it possible to simulate a change in the failure rate at the decommissioning stage for printing and packaging equipment put into operation in different years. The article gives the ratio of the normative and physical terms of equipment operation. The dispersion equality and the correctness of the equation are verified by the Fisher criterion.

Keywords: reliability; failure; failure rate; life cycle function of equipment operation; failure rate function; service life.

Introduction

At present, printing and packaging production uses the equipment based on flexible automated complexes and lines. Modern packaging lines are often equipped with printed blocks for marking. With the creation and implementation of such complex technical systems, the problem of ensuring their reliability, forming requirements for operating conditions becomes acute.

The operation of the equipment is accompanied by failures, which arise for many reasons. The need to investigate failures is dictated by the objective circumstance that technological equipment and operations performed on it do not have absolute reliability. Failures of equipment can lead to the need to re-execute technological operations, and this, in its turn, increases the consumption of materials and the cost of manufacturing products, reduces the economic efficiency of production.

The equipment of printing and packaging shops is, as a rule, expensive that makes up a significant part of fixed assets. It requires significant costs to upgrade it. Therefore, enterprises strive to preserve fixed assets and extend all the available equipment by using all available means. All this emphasizes the urgency of researching the stage of decommissioning of equipment, including using theoretical methods.

Methods

The reliability of printing and packaging production [1] is not studied so globally as the reliability of forest [2], agricultural [3], transport equipment [4], etc. The life cycle of equipment and its reliability in [5] are described in detail, however these sources do not give a general idea of operation of various technological equipment, and also there are no experimental examples at real enterprises.

In the literature there is no comprehensive approach to assessing the reliability of printing and packaging equipment, the mode of their operation, depending on a wide range of factors: consumer (circulation, product volume, quality requirements, design), operational (shift, repair system, nominal production), structural parameters of the system, dynamics of changes in performance and reliability during operation. In various industries there are solutions to individual problems, varying degrees of complexity, accuracy and complexity, but insufficiently effective, complete and generalized, simple and adapted to the systems of printing and packaging machines, taking into account their specific features, therefore, there is a great potential for their development and improvement.

The analysis of the main and most frequently used in the theory of reliability models of failure-free operation of equipment shows [6] that none of them describes all the periods of its operation. This, in its turn, does not give a complete picture of the operation of equipment throughout the life cycle.

The purpose of this article is a theoretical study of the failure of printing and packaging equipment at the stage of decommissioning, as well as the construction of an analytical reliability function that covers all stages of the life cycle of printing and packaging equipment.

Results

The total time of operation of the equipment, as a rule, is divided into 3 periods: 1) running-in and trial operation; 2) normal operation in accordance with the requirements of regulatory documentation; 3) physical aging, a period characterized by an increase in the failure rate, the manifestation of accumulation of various defects due to aging of the equipment elements.

In some cases, the fourth period is also introduced — the decommissioning of equipment. Since the equipment during this period is used less and less, the failure rate can decrease. The principal form of the dependence of the reliability function on the time of operation of equipment with 4 periods is shown schematically in Figure 1.

Quantitative analysis of information on failures makes it possible to identify the patterns of failure and on this basis to develop measures to eliminate their causes. To solve the problem of evaluating reliability characteristics, information obtained at the stage of actual equipment operation can be used first of all. The negative side of operational observations is a small amount of statistical data. The lack of such

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information for the 4th period, makes the theoretical study of faiures at the decommissioning stage relevant.

The analysis of the main and most frequently used in the theory of reliability models of failure-free operation of equipment shows that none of them describes all the periods of its operation. Therefore, the problem of constructing a model of non-failure operation that describes the total operational time of the equipment is topical. For the purpose of constructing this function, it was proposed in [6] to use the life-cycle of equipment operation (LCESL).

To describe the stage of decommissioning of equipment, it is necessary to use a more complicated function of the LCESL. In particular, for these purposes, it is possible to apply the LC function, which, after the saturation stage, goes into the decay stage [7]. The phase trajectory of a given function is an ellipse. The equation of a given function is a transcendental function with respect to y, therefore, in the further construction of the LC function, it is necessary to use numerical methods to determine the roots of the equation [8].

Let us consider a special case in which we can assume that the transcendental equation is simplified. The LC function can be represented in the form of a simple explicit function of time:

$$y(t) = a\left(1 - \cos\frac{bt}{a}\right), \quad (1)$$

where a, b — are the parameters of the function.

If we differentiate this equation, we get:

$$\frac{d}{dt}\left[a\left(1 - \cos\left(\frac{bt}{a}\right)\right)\right] = = b\sin\left(\frac{bt}{a}\right). \quad (2)$$

During the operation time of the equipment, a generalized power-law function of the failure rate can be introduced:

$$\lambda(t) = \frac{C}{\left|\frac{dl(t)}{dt}\right|^{n}}, \quad (3)$$

where n — is an exponent; C — is a coefficient of proportionality.

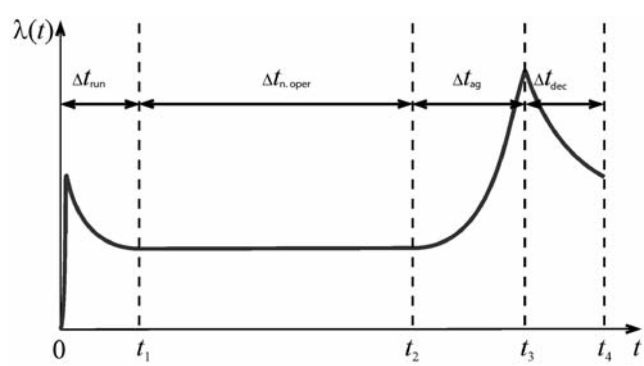

Figure 1. Principal view of the dependency of the reliability function on the time of operation of the equipment

The coefficient of proportionality c and the parameters of the functions a, b and n are determined from the experimental statistical data on the failure rate using the least squares (OLS) method. The condition for a minimum of the function depending on several parameters is the vanishing of all partial derivatives (C, a, b and n).

$$\begin{cases} \frac{\partial}{\partial C}\sum_{k=1}^{n}\left(\frac{C}{\left|b\sin\left(\frac{bt_k}{a}\right)\right|^n}-y_k\right)^2=0 \\ \frac{\partial}{\partial a}\sum_{k=1}^{n}\left(\frac{C}{\left|b\sin\left(\frac{bt_k}{a}\right)\right|^n}-y_k\right)^2=0 \\ \frac{\partial}{\partial b}\sum_{k=1}^{n}\left(\frac{C}{\left|b\sin\left(\frac{bt_k}{a}\right)\right|^n}-y_k\right)^2=0 \\ \frac{\partial}{\partial n}\sum_{k=1}^{n}\left(\frac{C}{\left|b\sin\left(\frac{bt_k}{a}\right)\right|^n}-y_k\right)^2=0 \end{cases}. \quad (4)$$

The coefficient of proportionality C and the parameters of the functions a, b and n were determined in the mathematical package MathCAD. The partial derivative with respect to the proportionality coefficient c has the form:

$$2C\sum_{k=1}^{m}\frac{1}{\left[\left|b\left(-\frac{e^{\frac{bt_k i}{a}}i}{2}+\frac{e^{-\frac{bt_k i}{a}}i}{2}\right)\right|\right]^{2n}}-2\sum_{k=1}^{m}\left[\left[\frac{1}{\left|b\left(-\frac{e^{\frac{bt_k i}{a}}i}{2}+\frac{e^{-\frac{bt_k i}{a}}i}{2}\right)\right|}\right]^{n}y_k\right]=0. \quad (5)$$

The partial derivatives with respect to a, b and n have a more complex form and are not given in this paper.

The advantage of the constructed generalized analytical function of the failure rate is that it describes the nuances of the change in the failure rate of real printing equipment.

Table 1

Data parameters for constructing a generalized analytical failure function for printing and packaging equipment

Type of equipment	C	a	b	n
ROLAND 207 LV	0,120	1,100	0,200	0,700
BOBST SP 102 E II	0,060	1,600	0,200	0,760
YAWA TYM 1050S	0,075	0,650	0,123	0,454
Ball mill UNICON	0,038	1,100	0,200	0,850
The packer of sweets ‘Linepack’	0,347	1,120	0,213	0,400
Chocolate production line	0,347	1,120	0,200	0,340

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Table 1 shows the proportionality coefficient C and the parameters of the functions a, b and n for printing and packaging equipment.

Further, according to the data in table 1, the failure rate functions were constructed. These failure rate functions are shown in figure 2. It should be noted that the ROLAND 207 LV printing machine was installed in 2006, the BOBST SP 102 E II die-cutting press was installed in 2008, and the model was manufactured in 1997, the YAWA TYM 1050S in 2008, the UNICON ball mill was installed in 2002,

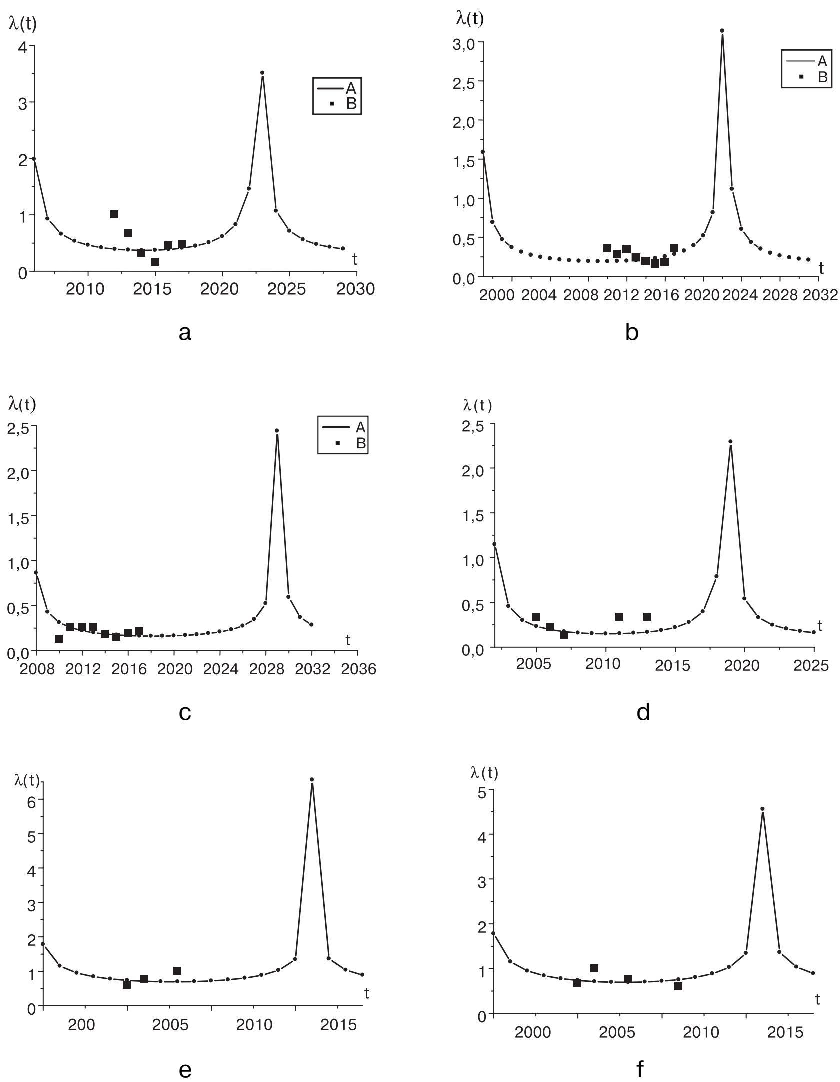

Figure 2. Failure Rate Functions: a — ROLAND 207 LV; b — BOBST SP 102 E II; c — YAWA TYM 1050 S; d — ball mill UNICON; e — the packer of sweets ‘Linepack’; f — chocolate production line: A — theoretical dependence; B — experimental data

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the 'Linepack' sweets packer and the chocolate production line in 2000.

From the graphs we can conclude that all printing equipment is suitable for work. The machine YAWA TYM 1050S is in the normal operation phase. The packer of 'Linepack' sweets and the chocolate production line are not suitable for work, since they are already at the stage of decommissioning. This indicates the need to replace these packaging units with new ones. The UNICON ball mill is still workable, but its service life is also coming to an end and needs to be replaced.

An important factor is the comparison of the normative and physical life of the equipment. The standard operating life of the equipment is established in accordance with the standard duration of depreciation of equipment. For printing equipment, it is: sheet machines — 812 years, rolls — 25 years, finishing equipment 1015 years. For packaging lines it is: 1012 years; individual machines and units — 78 years. At the same time, the analysis of the practice of the real packaging shops at the confectionery enterprises shows that the physical lifetime covers the normative by 1,52 times (table 2).

Thus, if we proceed only from the depreciation of the equipment, then the picture of the change in the failures can turn out to be distorted. Expected at the end of the period of amortization, the increase in the intensity of failures in reality can not be traced. Moreover, the failure rate is affected by the system of preventive maintenance and other measures. At the first stage of the research it is necessary to determine the duration of the physical life of the equipment. In this situation, the significance of the failure rate model is repeatedly increased.

The dispersion equality and the correctness of the equation are verified by Fisher's criterion. In the analysis of variance Fisher's criterion makes it possible to evaluate the significance of factors and their interactions. Fisher's criterion is based on additional assumptions about the independence and normality of data samples. Before applying it, it is recommended that you perform a normalization check.

Table 2

Ratio of normative and physical terms of equipment operation

Type of equipment	Physical life	Statutory period
ROLAND 207 LV	18	8–12
BOBST SP 102 E II	25	10–15
YAWA TYM 1050S	21	10–15
Ball mill UNICON	18	7–8
The packer of sweets 'Linepack'	17	7–8
Chocolate production line	17	10–12

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The variance of the relative mean value from the experimental data of D_{ym}:

$$D_{ym} = \frac{\sum_{jj=1}^{No} \left(ym - ys_{jj}\right)^2}{No}, \qquad (6)$$

where — number of experimental data (points).

Dispersion of the relative average value from the calculated data D_{Lm}:

$$D_{Lm} = \frac{\sum_{jj=1}^{No} \left(Lm - Ls_{jj}\right)^2}{No}. \qquad (7)$$

Fisher's criteria is according to the following formula:

$$F = \frac{D_m}{D_l}, \qquad (8)$$

where D_m — a large dispersion obtained; D_l — a smaller dispersion obtained.

Since, according to the criterion condition, the numerator must be greater than or equal to the denominator, the empirical value will always be greater than or equal to one.

The calculated values of the Fisher test are given in table 3.

Since the calculated values are less than the tabulated values, it can be concluded that the equations are compiled, correctly. The proposed function of the failure rate of printing and packaging equipment allows us to take into account the factors of moral and physical deterioration.

Conclusions

The developed failure rate functions allowed to simulate the change in the failure rate at the decommissioning stage for printing and packaging equipment put into operation in different years. The change in the intensity of failures, despite the different regimes of discounts, is associated with different technical conditions of the equipment and shops.

The analysis of operational information and functions of failure rates shows that the printing equipment is suitable for work. Packaging equipment is obsolete and requires replacement. When decommissioning, the failure rate of the 'Linepack'

Table 3

Values of the Fisher Criterion

Type of equipment	$F_{calcul. fail.}$	$\nu_{1,2}$	$F_{tabl.}$
ROLAND 207 LV	4,433	5	5,050
BOBST SP 102 E II	2,095	7	3,790
YAWA TYM 1050S	3,482	7	3,790
Ball mill UNICON	4,198	4	6,390
The packer of sweets 'Linepack'	3,596	2	19,000
Chocolate production line	2,179	3	9,280

sweets packer with one-shift operation mode and the chocolate line with a two-shift operating mode decreases almost equally. Such a change in the intensity of failure, despite the different modes of operation, is associated with various technical conditions and the loading of equipment.

The constructed functions of failure rates for printing and packaging equipment made it possible to show the difference in the physical and normative life of the equipment.

The constructed analytical function of reliability of printing and packaging equipment allows to conduct analysis, estimation and prediction of reliability, clarification of failures, standardization of reliability indicators. On the basis of the proposed methodology, an information base on the reliability of equipment can be created, and the task of synthesizing printing, packaging machines and systems can be solved on the basis. The failure rate function allows you to analyze statistics and causes of failures, develop measures to eliminate them, and evaluate the effectiveness of measures to ensure reliability.

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Статья рассматривает методику статистического моделирования надежности печатного и упаковочного оборудования. Приведен принципиальный вид зависимости функции надежности от времени эксплуатации оборудования с 4 периодами. Для целей построения функции, описывающей все периоды эксплуатации, в статье предложено использовать функцию жизненного цикла эксплуатации оборудования (ЖЦЭО).

Построена обобщенная аналитическая функция интенсивности отказов, которая описывает нюансы изменения интенсивности отказов реального печатного и упаковочного оборудования. Разработанные в статье функции интенсивности отказов позволили промоделировать изменение интенсивности отказов на стадии выведения из эксплуатации для печатного и упаковочного оборудования, введенных в эксплуатацию в разные года. В статье приводится соотношение нормативного и физического сроков эксплуатации оборудования. Равенство дисперсий и правильность уравнения проверяется по критерию Фишера.

Ключевые слова: надежность; отказ; интенсивность отказов; функция жизненного цикла эксплуатации оборудования; функция интенсивности отказов; срок эксплуатации.

Стаття розглядає методику статистичного моделювання надійності друкарського і пакувального обладнання. Наведено принциповий вид залежності функції надійності

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від часу експлуатації обладнання з 4-а періодами. З метою побудови функції, яка описує всі періоди експлуатації, в статті запропоновано використовувати функцію життєвого циклу експлуатації обладнання (ЖЦЕО). Побудовано узагальнену аналітичну функцію інтенсивності відмов, яка описує нюанси зміни інтенсивності відмов реального друкарського і пакувального обладнання. Розроблені в статті функції інтенсивності відмов дозволили промоделювати зміну інтенсивності відмов на стадії виведення з експлуатації для друкарського та пакувального обладнання, введених у експлуатацію в різні роки. У статті наводиться співвідношення нормативного та фізичного термінів експлуатації обладнання. Рівність дисперсій і правильність рівняння перевіряється за критерієм Фішера.

Ключові слова: надійність; відмова; інтенсивність відмов; функція життєвого циклу експлуатації обладнання; функція інтенсивності відмов; термін експлуатації.

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