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Determination of reliability of working position with rigid inter-aggregate relation

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Abstract. Machine-building enterprises implement the methods of operative transition from one nomenclature of production to another for preservation of competitiveness. The strategy of scientific and technological development of Russian Federation reflects this aspect in the form of one of the priorities: digitalization. One of the most time-consuming processes is the reconfiguration of automatic mass production lines. These lines consist of a number of working positions. The relation between units in mass production is rigid and inter-operational reserves are absent. Stopping one unit is equivalent to stopping the whole line. Therefore, the task of the time estimation of line’s operability of this type is relevant. The task is complex and requires consideration of many factors. This article presents a constructive scheme for reliability. The calculation of work and reliability indicators are carried out. The calculation of the reliability of positions with rigid inter-aggregate relation made it possible to obtain reliability indicators for the second line of development of recomposed work positions with automatic change of nodes. In this case, the rigid relation is not violated. In this calculation the probability of failure due to the simplicity the proposed nodes design was not taken into account.

It is known that reliability is a property of an object to continuously maintain an operational state for some time or throughout operation period [1-4]. Reliability depends on various factors, such as surface topography of load-bearing of machine parts, it’s hardness and strength and also surface roughness [5-7].

The probability of the work position reliability with a rigid inter-aggregate relation WPR (P(t)WPR) depends on the probability of aggregate nodes reliability for all stages of the composition of the work position [8-10]. To determine the influence of aggregate nodes on P(t)WPR and to derivate the general formula for calculating P(t)WPR we use the structural reliability scheme (SRS) [11-14].

When constructing a SRS each aggregate node of the WPR is indicated by a separate structural unit. The building blocks are placed in series or in parallel depending on the failure effect of the aggregate node (Figure 1, a). If the failure of the aggregate node leads to the failure of the entire work position, the structural unit of the aggregate unit is placed in series. The probability of the work station reliability with a SRS consisted of series-connected structural units of aggregate nodes is derived as a product of the probabilities of the components reliability of the aggregate nodes [15-17].
\[ P(t) = P(t)_{e1} \cdot P(t)_{e2} \cdot \ldots \cdot P(t)_{en} = \prod_{i=1}^{n} P(t)_{ei}, \]  \hspace{1cm} (1) 

where \( n \) - the number of aggregate nodes in the set of the work position; 
\( P(t)_{ei} \) - probability of the i-th aggregate node’s reliability.

Structural blocks which are positioned in parallel (Figure 1, b) describe a SRS with a group of aggregate nodes producing WP failure only in case of the entire group failure. The probability of the SRS reliability with parallel structural blocks derives in equation [18-20]:

\[ P(t) = 1 - \prod_{i=1}^{n} (1 - P(t)_{ei}), \]  \hspace{1cm} (2) 

where \( n \) - the number of aggregate nodes; 
\( P(t)_{ei} \) - probability of the i-th aggregate node’s reliability.

Figure 1. Structural Reliability Scheme (SRS) for series (a) and parallel (b) elements positioning.

To calculate the probability of work position reliability of the production system with a rigid inter-aggregate relation (\( P(t)_{WPR} \)), it is necessary to differentiate (to split) the WPR composition into composite aggregate units and, in accordance with the SRS, to derive a general formula for the probability of the WPR reliability (\( P(t)_{WPR} \)).

The WPR consists of \( n \) sets, the failure of each set leads to the failure of the entire WP; therefore, the calculation formula of \( P(t)_{WPR} \) is:

\[ P(t)_{WPR} = P(t)_{k1} \cdot \ldots \cdot P(t)_{kn} = \prod_{i=1}^{n} P(t)_{ki}, \]  \hspace{1cm} (3) 

where \( P(t)_{ki} \) - the probability of the k-th WPR aggregate node’s reliability; 
i - ordinal number of the WPR set; 
\( n \) - number of sets included in work position.

Every the k-th set is composed with groups of aggregate nodes. The probability of the k-set reliability is determined by the probability of aggregate nodes of group reliability [21]. Considering the regardless of the set the failure of any group leads to the failure of the entire WPR, the equation for probability of k-th set reliability of WPR (\( P(t)_{ki} \)) is:

\[ P(t)_{ki} = P(t)_{g1} \cdot \ldots \cdot P(t)_{gn} = \prod_{j=1}^{m} P(t)_{gj}, \]  \hspace{1cm} (4) 

where \( P(t)_{gj} \) - probability of the j-th reliability group of the WPR; 
j - index number of the WPR group; 
m - the number of groups of the k-th set of WPR.

The probability of the group reliability of WPR is determined by the probability of the nodes reliability installed in this group. Since the groups of the WPR always consist of one aggregate node, the probability of the group reliability will be equal to the probability of the aggregate node reliability operating on this group (\( P(t)_{nj} \)).

According to the analysis, the structural diagram construction of the work position with a rigid inter-aggregate relation reliability is presented on Figure 2 (SRS of the WPR):
Figure 2. Structural diagram of the work position reliability with rigid inter-aggregate relation (SRS of the WPR), where: \( P(t)_{n1}, P(t)_{n4}, P(t)_{n6} \) - the probability of the housing’s reliability; \( P(t)_{n2}, P(t)_{n7} \) – the probability of powered plates reliability; \( P(t)_{n3}, P(t)_{n1}, P(t)_{n8} \) - the probability of spindle assembly reliability.

Using SRS the general formula for the probability of the work position reliability \( P(t)_{WPR} \):

\[
P(t)_{WPR} = \prod_{i=1}^{n} \left( \prod_{j=1}^{m} P(t)_{kj} \right) = \prod_{i=1}^{n} \left( \prod_{j=1}^{m} P(t)_{nj} \right) = \prod_{i=1}^{q} P(t)_{nj}
\]

where \( q \) - the number of aggregate nodes of the rigid WPR; \( n \) - the number of sets in the working position of the WPR; \( m \) – the number of groups of the i-th set of WPR; \( P(t)_{gj} \) is the probability of the j-th group reliability of the WPR.

When calculating by equation 5, it should be taken into account that the probability of failure \( F(t) \) of aggregate nodes of the housing type due to the simplicity of the design, the rigid relation and the absence of kinematic pairs is close to zero \( F(t) \to 0; P(t) \to 1 \). Thereafter, it should be noticed from the equation 5 that the reliability is equal to 1, does not affect \( P(t)_{WPR} \), therefore, the probability of the housing reliability \( P(t)_{n1}, P(t)_{n4}, P(t)_{n6} \) in the formula 5 can be omitted.

Thus, the calculation of the performance indicators and reliability of the work position with a rigid inter-aggregate relation allows to calculate the reliability indexes for the second direction of development of recomposed work positions with automatic change of nodes without failure of rigid inter-aggregate relation of basic nodes. The use of WPR in industry 4.0 is promising, including those using additive technologies [22] and adaptive algorithms for maintain manufacturing processes in production [23, 24].

After the general equation for the probability of a work position with a rigid inter-aggregate relation reliability was determined, one can proceed to determine the probability of the elements reliability of a work position with a rigid inter-aggregate relation (aggregate nodes).

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