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EVALUATION OF THE RELIABILITY INDICATORS OF A CONVEYOR

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Abstract: *The objective of this paper is to evaluate the main indicators of operational reliability for an electromechanical system consisting of five belt conveyors on rollers arranged in series. Knowing the behavior of each conveyor determines the analytical expression of the reliability of the system. The functions of the density of probability of occurrence of defects, the intensity of failure, as well as the value of the average fault-free operating time of the strip relay are determined. The methodology allows the generalization of computational relations for technical systems with series structure.*
Keywords: *roller belt conveyor, failure, reliability indicators*

1. Introduction

The fundamental problem in calculating the reliability of the band relay is to establish the analytical expression of its reliability. [1, 2]

It is specified that all the assumptions that allow the statistical calculation of reliability are met:

− the transmission relay may be in working order or in a faulty state at any time;
− the system consists of five conveyors, coded B1, B2, B3, B4 and B5S, so that each conveyor can be in working or fault state at some point, the relay status being given only by the status of each carrier;
− each conveyor has a random service life;
− random variables, i.e. actual operating times, or times to the first failure, or times between failures, from the point of view of reliability are synonymous terms, which quantify the same effect;
− failure events are independent, i.e. the failure of one element does not influence the functionality of the other elements.

From the point of view of reliability, the belt relay is considered as a complex system consisting of five subsystems linked in series, namely conveyors B1, B2, B3, B4 and B5S, figure 1. [3]

Fig. 1. Strip Relay Reliability Logic Diagram

The reliability of the R-band relay $_{RB}(t)$ is the product of the reliability of the five conveyors,

$$R_{RB}(t) = \prod_1^5 R_i(t), \tag{1}$$

where i corresponds to B1, B2, B3, B4, B5S.

2. Characterization of conveyor functionality [2, 4]

Transporter B1. The reliability of the B1 conveyor is assimilated by the $R_C(t)$ reliability of the belt belt belt with textile inserts EP 250/5 (EP 1250). Reliability indicators can be equally evaluated using normal or triparametric Weibull distributions. The operating conditions are defined by the operation in an open atmosphere, under the open sky, over a short horizontal transport distance, about 100 *m*, with technological forces of medium values, the presence of an abrasive environment, favorable conditions for preventive and corrective maintenance.

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The B1 conveyor is considered as a reliable equipment characterized by an average time between failures, $MTBF_{B1}$, of about 6000 *hours*.

Transporter B2. The reliability of the B2 conveyor is assessed by assimilating the reliability of the conveyor belt subsystem consisting of serialized elements, belt belt and vulcanizations. The operating conditions of the conveyor belt are defined by underground operation, with upward transport on an inclined plane of 12°, a transport distance of 970 *m*, with technological forces of high values, the massive presence of abrasive media in a limited space with natural aeration, improper conditions of preventive and corrective maintenance.

The reliability of STM 3150 steel cord tape mat is evaluated with the three-parameter Weibull distribution. The average duration of operation of the belt belt is of the order of 18000 *hours*, expressed in *hours* of effective operation, under the operating conditions of the quarry.

The hot vulcanizations related to the conveyor belt are evaluated equally with the normal and triparametric Weibull distributions. It is worth noting the higher share of coatings restorations of vulcanizations with a much shorter execution time, with direct influences on the availability of the conveyor.

The very large gap between the reliability functions of the belt belt and the related vulcanizations indicates that the reliability of the conveyor belt subsystem is assimilated by the reliability of the vulcanizations, $R_V(t)$. Under these conditions, the reliability of the B2 conveyor is quantified by the reliability of the vulcanizations and is characterized by the $MTBF_{B2}$ indicator of about 900 *hours*. In the belt relay assembly, the B2 conveyor is the element with the lowest reliability.

Transporter B3. The operating conditions are defined by underground operation, upward transport on an inclined plane of 15°, a transport distance of 860 *m*, with technological forces of high values, the massive presence of abrasive media, improper conditions for preventive and corrective maintenance.

The reliability of the STM 3150 belt belt is evaluated with the three-parameter Weibull distribution. The belt belt is a reliable product characterized by an average use time until decommissioning, MTBF, of 18500 *hours*. The value is comparable to that highlighted on the belt belt of the B2 conveyor.

The hot vulcanizations related to the conveyor belt are evaluated equally with the normal and triparametric Weibull distributions. The average operating time until the restoration of a vulcanization or its complete performance, MTBF, is of the order of 1200 *hours*. The value is comparable to that shown on carrier B2. The difference can be explained by the different operating conditions of the two conveyor belts.

The very large gap between the reliability functions of the belt belt and the related vulcanizations indicates that the reliability of the conveyor belt subsystem is assimilated by the reliability of the vulcanizations. Under these conditions, the reliability of the B3 conveyor is characterized by the $_{MTBF\ B3}$ indicator of 1200 *hours*.

Transporter B4. The operating conditions are defined by underground operation, upward transport on an inclined plane of 9°, a transport distance of 520 *m*, with technological forces of high values, the massive presence of abrasive medium, improper conditions of preventive and corrective maintenance.

The reliability of the ST 3150 belt belt is evaluated with the three-parameter Weibull distribution. The belt belt is a reliable product characterized by an average time of use until decommissioning, MTBF, of about 19500 *hours*. The value is comparable to that of the B2 and B3 conveyors.

The hot vulcanizations related to the conveyor belt are evaluated equally with the normal and triparametric Weibull distributions. The average operating time until the restoration of a vulcanization or its complete performance, MTBF, is about 1800 *hours*. The very large gap between the reliability functions of the belt belt and the related vulcanizations indicates that the reliability of the conveyor belt subsystem is assimilated by the reliability of the vulcanizations. Under these conditions, the reliability of the B4 conveyor is assimilated by the reliability of vulcanizations and is characterized by the $MTBF_{B4}$ indicator of 1774 *hours*.

B5S transporter . The reliability of the B5S conveyor is assimilated by the reliability of the belt belt with EP 250/5 textile inserts. Reliability indicators are evaluated with the three-parameter Weibull distribution. The B5S conveyor is a reliable equipment characterized by $MTBF_{B5S}$ for about 1750 *hours*. The relatively low value of the belt belt life is noteworthy, compared to the B1 conveyor, being the same type of carpet with five textile inserts.

3. Evaluation of the operational reliability indicators of the band relay [5, 6, 7]

The reliability of the band relay, $R_{RB}(t)$, is calculated with the relationship

$$R_{RB}(t) = \prod_{i=1}^{5} R_i(t) = R_{B1}(t) \times R_{B2}(t) \times R_{B3}(t) \times R_{B4}(t) \times R_{B5S}(t) \qquad (2)$$

In this relationship, $R_i(t)$, with *i* identified by *B1*, *B2*, *B3*, *B4*, *B5S*, are the reliability functions of the relay component carriers, built on the basis of the three-parameter Weibull distribution:

− $R_{B1}(t) = R_{CB1}(t) = e^{-\left(\frac{t-2,732E\text{-}04}{6469,334}\right)^{3,674}}$,the reliability of the conveyor being given by the reliability of the belt belt with textile inserts with a width of 1400 *mm*, EP 250/5 (EP 1250), characterized by the average time between failures $MTBF_{B1}$ = 5836 *hours*;

− $R_{B2}(t) = R_{VB2}(t) = e^{-\left(\frac{t-2,474E\text{-}07}{995,517}\right)^{2,773}}$,the reliability of vulcanizations of STM 3150 metal cord belt mats, characterized by $MTBF_{B2}$ = 886 *hours*;

− $R_{B3}(t) = R_{VB3}(t) = e^{-\left(\frac{t+1,049E\text{-}06}{1283,129}\right)^{2,349}}$,the reliability of vulcanizations of STM 3150 metal cord belt belts, characterized by $MTBF_{B3}$ = 1137 *hours*;

− $R_{B4}(t) = R_{VB4}(t) = e^{-\left(\frac{t+2,454E\text{-}06}{1933,904}\right)^{3,644}}$,the reliability of vulcanizations of ST 3150 metal cord belt belts, characterized by $MTBF_{B4}$ = 1744 *hours*;

− $R_{B5S}(t) = R_{CB5S}(t) = e^{-\left(\frac{t+4,904E\text{-}06}{1857,042}\right)^{6,965}}$,the reliability of the tape mat with textile inserts with a width of 1600 *mm*, EP 250/5 (EP 1250), characterized by the average time between failures $MTBF_{B5S}$ = 1737 *hours*.

The relationship (2) becomes,

$$R_{RB}(t) = e^{-\left(\frac{t-2,732E\text{-}04}{6469,334}\right)^{3,674}} \times e^{-\left(\frac{t-2,474E\text{-}07}{995,517}\right)^{2,773}} \times e^{-\left(\frac{t+1,049E\text{-}06}{1283,129}\right)^{2,349}} \times e^{-\left(\frac{t+2,454E\text{-}06}{1933,904}\right)^{3,644}} \times e^{-\left(\frac{t+4,904E\text{-}06}{1857,042}\right)^{6,965}} \quad (3)$$

Each factor represents a triparametric Weibull distribution of the form $R(t)=e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$, where β is the dimensionless shape parameter, η the real scale parameter, quantified in *hours*, and γ the initialization parameter, expressed in *hours*.

The initialization parameter γ has a very small value, compared to the effective operating time *t* which is of the order of 10^3, which is why it can be neglected. Relationship (3) becomes

$$R_{RB}(t) = e^{-\left(\frac{t}{6469,334}\right)^{3,674}} \times e^{-\left(\frac{t}{995,517}\right)^{2,773}} \times e^{-\left(\frac{t}{1283,129}\right)^{2,349}} \times e^{-\left(\frac{t}{1933,904}\right)^{3,644}} \times e^{-\left(\frac{t}{1857,042}\right)^{6,965}}, \quad (4)$$

which is a product of five biparametric Weibull distributions of the form $R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$.

The analytical expression of the reliability of the band relay becomes

$R_{RB}(t)$ = [1−WEIBULL.DIST(*t*;3,674;6469,334;TRUE)]×
×[1−WEIBULL.DIST(*t*;2,773;995,517;TRUE)]×
×[1−WEIBULL.DIST(*t*;2,349;1283,129;TRUE)]× (5)
×[1−WEIBULL.DIST(*t*;3,644;1933,904;TRUE)]×
×[1−WEIBULL.DIST(*t*;6,965;1857,042;TRUE)],

with the representation in figure 2.

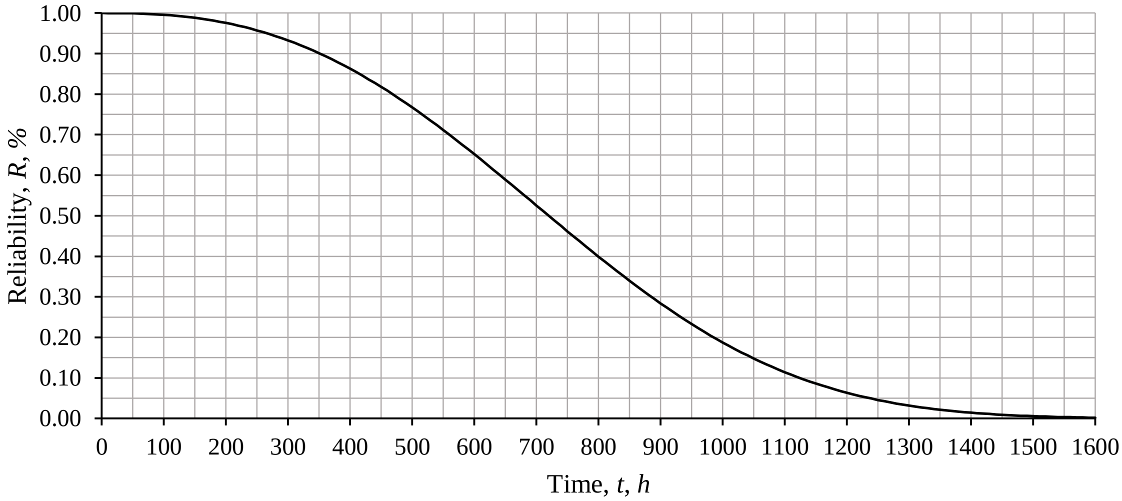

Fig. 2. $R_{RB}(t)$ function of the reliability of the conveyor relay

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Relation (4) can also be written in the form of

$$R_{RB}(t) = e^{-[\left(\frac{t}{6469,334}\right)^{3,674} + \left(\frac{t}{995,517}\right)^{2,773} + \left(\frac{t}{1283,129}\right)^{2,349} + \left(\frac{t}{1933,904}\right)^{3,644} + \left(\frac{t}{1857,042}\right)^{6,965}]}. \quad (6)$$

After performing the calculations, it results

$$R_{RB}(t) = e^{-(9,975E\text{-}15\, t^{3,674} + 4,857E\text{-}09\, t^{2,773} + 4,997E\text{-}08\, t^{2,349} + 1,057E\text{-}12\, t^{3,644} + 1,709E\text{-}23\, t^{6,965})}, \quad (7)$$

relationship that is equivalent to (4) and (5), including the graphical representation in Figure 2.

The probability density of defects in the band relay, $f_{RB}(t)$, is expressed by the relation

$$f_{RB}(t) = -\frac{d(R_{RB}(t))}{dt} =$$
$$= (3,665E\text{-}14\, t^{2,674} + 1,347E\text{-}8\, t^{1,773} + 1,174E\text{-}7\, t^{1,349} + 3,853E\text{-}12\, t^{2,644} + 1,19E\text{-}22\, t^{5,965}) \times$$
$$\times e^{-(9,975E\text{-}15\, t^{3,674} + 4,857E\text{-}9\, t^{2,773} + 4,997E\text{-}8\, t^{2,349} + 1,057E\text{-}12\, t^{3,644} + 1,709E\text{-}23\, t^{6,965})}, \quad (8)$$

and the graphical representation in Figure 3.

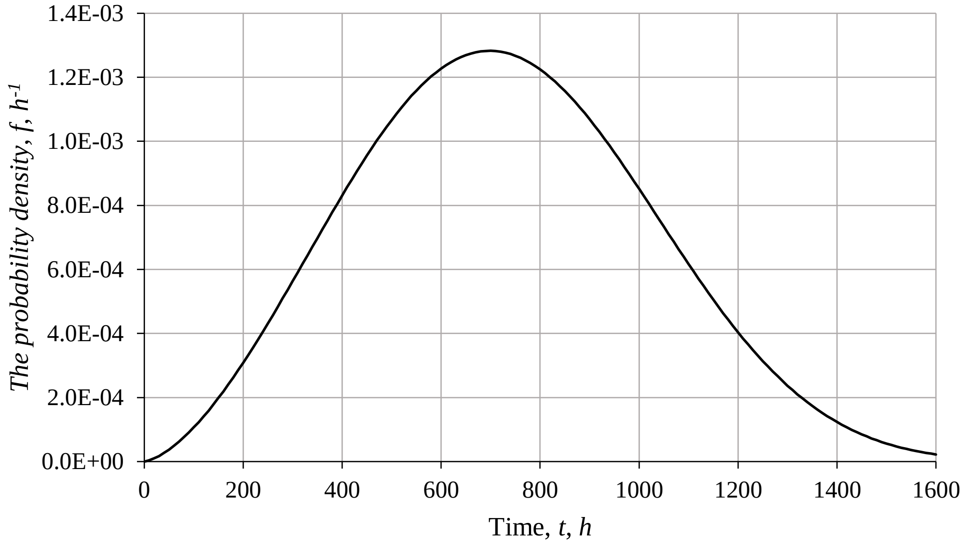

Fig. 3. The $f_{RB}(t)$ function of the probability density of defects in the conveyor relay

The intensity or failure rate of the band relay, $z_{RB}(t)$, shall be quantified with the

$$z_{RB}(t) = \frac{f_{RB}(t)}{R_{RB}(t)} = 3,665E\text{-}14\, t^{2,674} + 1,347E\text{-}8\, t^{1,773} + 1,174E\text{-}7\, t^{1,349} + 3,853E\text{-}12\, t^{2,644} + 1,19E\text{-}22\, t^{5,965} \quad (9)$$

and the representation in Figure 4.

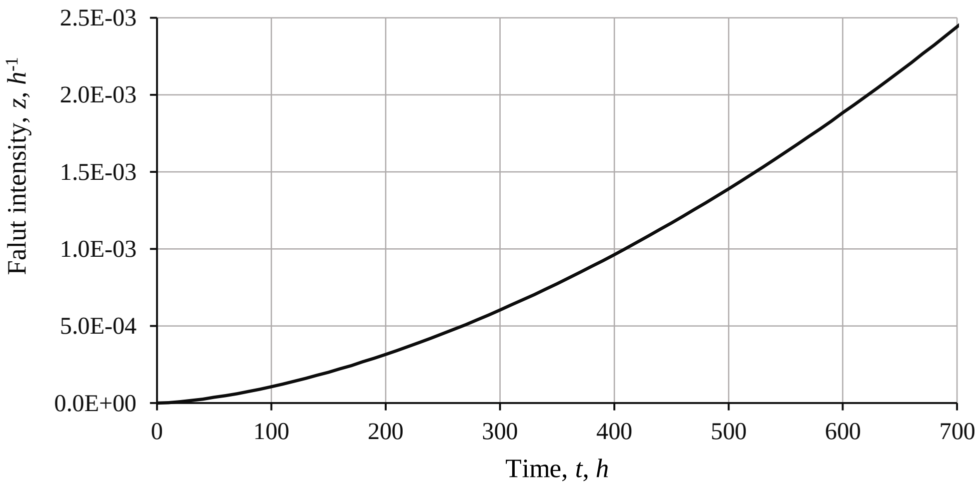

Fig. 4. The $z_{RB}(t)$ function of the fault current of the conveyor relay

The mean or mathematical expectation of relay operating times, $E(T)_{RB}$, is determined with the relationship

$$E(T)_{RB} = \int_0^\infty R_{RB}(t)\, dt =$$
$$= \int_0^\infty [e^{-(9{,}975E\text{-}15\, t^{3{,}674} + 4{,}857E\text{-}09\, t^{2{,}773} + 4{,}997E\text{-}08\, t^{2{,}349} + 1{,}057E\text{-}12\, t^{3{,}644} + 1{,}709E\text{-}23\, t^{6{,}965})}]\, dt = 731 \text{ hours} \quad (10)$$

The strip relay is a system with renewal. The system is brought into working condition, but its condition, after renewal, is different from the initial state by changing the initial parameters. These parameters must be updated after each renewal. In this case, the average E(T) must be interpreted as the average of the time between successive failures, noted in the literature with MTBF (Mean Time Between Failures). [8, 9]

The complete evaluation of the functionality of the band relay can be done based on its availability. Availability is determined on the basis of operational reliability indicators, determined in this paper, and maintainability indicators, which quantify maintenance actions.

4. Generalization of relations for a series system

The calculation relationships of the reliability indicators for a system with a series structure can be generalized depending on the type of distribution. [10]

For a series structure with n elements characterized by the biparametric Weibull distribution:

− reliability function, $R_S(t)$,

$$R_S(t) = e^{-\left(\sum_{i=1}^{n} \eta_i^{-\beta_i}\, t^{\beta_i}\right)} \quad (11)$$

− the function of the probability density of failures, $f_S(t)$,

$$f_S(t) = -\frac{d(R_S(t))}{dt} = \left(\sum_{i=1}^{n} \beta_i\, \eta_i^{-\beta_i}\, t^{\beta_i - 1}\right) \times R_S(t) = \left(\sum_{i=1}^{n} \beta_i\, \eta_i^{-\beta_i}\, t^{\beta_i - 1}\right) \times e^{-\left(\sum_{i=1}^{n} \eta_i^{-\beta_i}\, t^{\beta_i}\right)} \quad (12)$$

− the function of the intensity or failure rate, $z_S(t)$,

$$z_S(t) = \frac{f_S(t)}{R_S(t)} = \sum_{i=1}^{n} \beta_i\, \eta_i^{-\beta_i}\, t^{\beta_i - 1}\ ; \quad (13)$$

− average time between successive failures, MTBSS,

$$MTBS_S = \int_0^\infty R_{RB}(t)\, dt = \int_0^\infty e^{-\left(\sum_{i=1}^{n} \eta_i^{-\beta_i}\, t^{\beta_i}\right)}\, dt \quad (14)$$

5. Conclusions

The belt relay is a reliable conveyor system. The probability that the system will not fail after 400 *hours* of operation is 85%, which is very good. The low values of the fault speed and the fault intensity, in the order of $^{10-4}$ *faults/hour*, confirm the good reliability of the analyzed system. The average time between $MTBF_{RB}$ belt relay failures of 731 *hours* is sufficient to ensure the time required for ore transport. The reliability of the belt relay is lower than that of the B2 conveyor.

The belt relay must ensure the daily transport of at least 12000 *tons* of ore to ensure the continuity of the operation of the two preparation lines. For a maximum transported flow rate of 1000 *t/h*, limited by the functionality of the crusher, the operation of the feeder, the restrictions of the technical condition of each conveyor, results in a required daily operating time of 12 *hours* [2].

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