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The reliability analysis for some subassemblies in the structure of 060-DA diesel-electric locomotive

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Abstract. The increasing complexity of technical systems, together with their increasingly important functions, determines the continuously growing importance of reliability studies. The working regime parameters are more and more intense, the operating conditions are more and more complex, leading to the need of a large scale automation of production processes, and also of their control, including the use of some powerful process computers. Industrial products, mechanical equipment and devices, various machine components, and so on, they can all be regarded as basic units with autonomous operation, embedded in complex aggregates or installations. The 060-DA diesel-electric locomotive is SUCH a complex set of components and subassemblies, working together, so that any accidental failure of a basic constituent could lead to a total or partial decommissioning of the locomotive, or to its incorrect operation. The subject of the present paper is a reliability analysis for the most important components and subassemblies from the structure of 060-DA diesel-electric locomotive.

1. Applying the concept of reliability to system diagnostics

The quantitative concept of reliability is defined as the probability that a system, product, component, or structure will fulfil the functions for which it is intended, at the required performance level, for a specified time, under pre-established operating conditions. The correct operation of any technical system is characterized by its performance parameters: good running ability, integrity of its components, lifetime duration, free operation, availability, capability, and ability to be repaired and restored.

In the physical approach, the ability to properly operate a mechanical component is modelled using a random variable S (strength); the component must support the load L, also defined as a random variable quantity. It is admitted that a component malfunction occurs as soon as the load becomes higher than the strength, so its reliability R is the probability for the strength to be greater than the load:

$$R = P_r(S>L) \tag{1}$$

where Pr(A) is the likelihood of a certain event A to occur.

The load is usually variable as a function of time, L(t), as well as the element's strength, S(t), because the component deteriorates over time, as a result of the action of failure mechanisms such as corrosion, erosion, wear, fatigue, and so on. Figure 1 illustrates a possible time dependence of both cited variable quantities, S(t) and L(t).

IOP Conf. Series: Materials Science and Engineering **444** (2018) 062013 doi:10.1088/1757-899X/444/6/062013

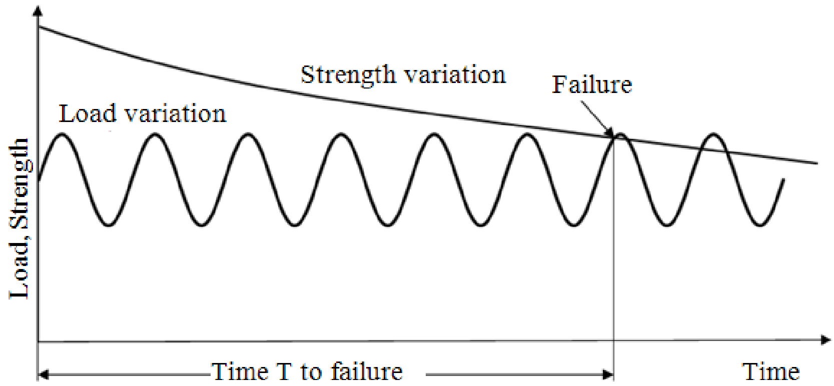


Figure 1. Load and strength variation for a mechanical component.

The time duration T up to failure, for the considered component, is (the shortest) time that passes until the condition S(t)<L(t) is reached, and it is given by the relationship:

$$T = min\{t;\ S(t)<L(t)\} \tag{2}$$

Under these circumstances, the component reliability R(t) could be defined as:

$$R(t) = p(t) = P_r(T>t) \tag{3}$$

where p(t) is the reliability function, expressing the probability of proper operation, and T is the time limit specified for proper functioning.

Any reliability study must always provide, as its main objective, the information that will form the basis for management decisions; before initiating the study, the decision maker must state the problem to be solved, specifying the objectives and terms of limitation in the study; as a consequence, the relevant information for decision-making could be available on time and in proper format.

2. Reliability indicators

The indicators (or features) of reliability are certain parameters that express, qualitatively and quantitatively, the fact that a technical component or structure can be considered as being reliable or not. These characteristics are usually referring to some repairable items or to some components (including complex systems) intended to be repaired. The following paragraphs are a brief description for some of these indicators, in order for them to be used in the content of this paper.

If the time duration to failure T is continuously distributed with the function f(t) of reliability density, then the failure function F(t), providing the probability of failure [the probability for that the component to fail within the time frame (0, t)], is given by the relationship:

$$F(t)=P_r(T\leq t)=\int_0^t f(u)du \quad for\ t>0 \tag{4}$$

As a result, the reliability function R(t) from Eq. (3) will have the following mathematical expression:

$$R(t)=1-F(t)=p(t)=P_r(t>T) \quad for\ t>0 \tag{5}$$

One can conclude that R(t) is the probability for the considered element to not failure or work inconsistently, for the (0, t) time period; in other words, R(t) is the probability for the element to survive a period of time (0, t) and to continue to operate at the t moment. Consequently, the component reliability R(t) is also known as its survival function.

The average correct operation time represents the arithmetic average of the correct operation durations for the considered statistical sample, and it is calculated as:

$$TMBF = \frac{\sum_{i=1}^{N} t_{Fi}}{N} \tag{6}$$

where t_{Fi} is the correct operation duration for each of the N considered components.

Considering the number N_f of failures during the total time T, another reliability indicator, namely the failure rate λ, could be established as:

$$\lambda = \frac{N_f}{T} \tag{7}$$

In connection with the reliability and the maintenance of the mechanical, electrical, and mechatronic systems, the rate of repairs is also regarded as an important parameter that is calculated as:

$$\mu = \frac{N_r}{T} \tag{8}$$

where the notation Nr represents the number of repairs on the respective component, during the considered time interval T.

The failure rate can be usually express as a mathematical function l(u), or it can be constant, on the time interval (0, t), such that the reliability function is given by the relationship:

$$R(t) = e^{\left(-\int_0^t \lambda(u)du\right)} = e^{(-\lambda t)} \tag{9}$$

The unavailability Q(t) of a component at the t moment, or the failure probability at the end of the (0, t) time interval, can be established, in dependence with the failure rate and the rate of repairs , for the respective component, as follows:

$$Q(t) = \frac{\lambda}{\lambda + \mu}[1 - e^{-(\lambda+\mu)t}] \tag{10}$$

On that basis, another reliability indicator is defined, namely the frequency of failure w(t) on the time interval (0, t), having the following mathematical expression:

$$w(t) = (1 - Q(t)) \cdot \lambda \tag{11}$$

3. An analysis of equipment failures over a 5-year period, for the modernized 060-DA diesel-electric locomotive

In order to discuss on some reliability problems concerning the diesel-electric locomotives, some statistical data are presented herein after, with respect to the failures of various equipments from the locomotive structure. The partially modernized (using made in Romania equipment) 060-DA diesel-electric locomotive was considered, as a specific case, corresponding to the years 2006-2010, and only the equipment failures which have disrupted the passenger train traffic were taken into account.

The equipment of a diesel-electric locomotive is divided into several categories, as follows:

- mechanical equipment - bogies and driving axles, locomotive case, clash and binding apparatus;
- pneumatic equipment - compressed air production unit and braking installation;
- thermal equipment - diesel engine and its auxiliary plants;
- electrical equipment - electrical power system (including power-electrical machines), auxiliary services electrical system.

The numbers of failures, from each of the above cited categories, are summarized in Table 1 from below. The diagram in Figure 2 illustrates, for the considered time-duration, the time dependence of the number of failures, corresponding to each of the four equipments categories (including, for the electrical equipment, the auxiliary services system).

One can establish that the electrical defects prevail, for the 060-DA diesel-electric locomotive, while the pneumatic defects are the fewest. On the other hand, one can observe that the number of failures does not vary greatly from one year to the next, for each of the four equipment categories.

Table 1. Failures of various equipments.

Equipment type	Number of failure/Years				
	2006	**2007**	**2008**	**2009**	**2010**
Mechanical	6	5	5	5	3
Pneumatically	3	1	3	2	2
Thermal	12	6	7	7	7
Electrical	25	25	30	23	32

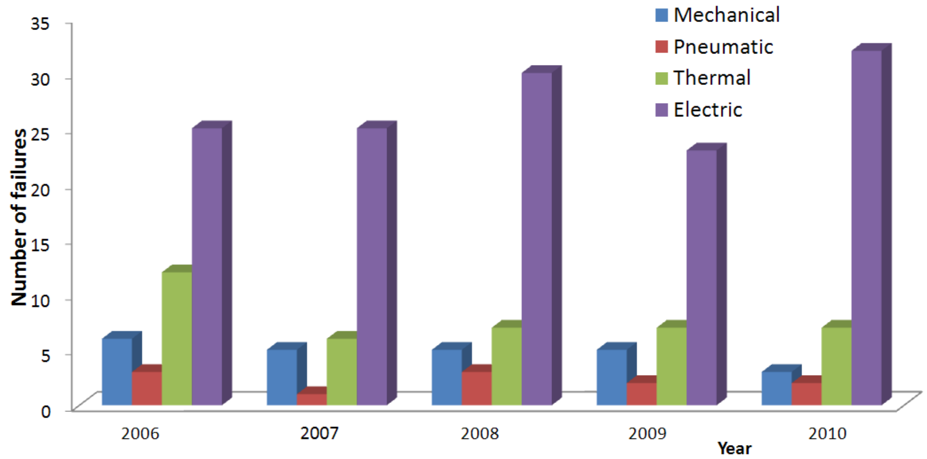


Figure 2. Time-dependence for various equipments failures.

4. The reliability calculus for some components and subassemblies of 060-DA diesel-electric locomotive

A typical example of reliability calculation is presented below, referring to the mechanical equipment consisting of: driving axle bearings, driving axle gear, suspension elements, and braking wheelhouse. In this regard, the failures number and the number of repairs are presented in Table 2, for each of the cited mechanical components, together with the failure rate, and respectively the repair rate that will be useful for the components reliability calculus.

Table 2. Failures of mechanical equipment.

Type of mechanical equipment	Number of failures/Year					Total time = 43824 hours			
	2006	**2007**	**2008**	**2009**	**2010**	**Total Fail**	**λ total**	**μ total**	**Total repairs**
Engine axle	2	3	4	2	3	14	0.0003194	0.000570464	25
Drive engine axle	3	1	1	1	-	6	0.0001369	0.000273823	12
Suspension elements	1	1	-	1	-	3	6.8455E-05	0.000228185	10
Brake linings	-	-	-	1	-	1	2.2818E-05	9.12742E-05	4

It can be seen that most failures are reported for the driving axle bearings, and the fewest - for the brake linings.

Using the data from Table 2, and assuming some approximately constant values (on the considered time duration) for the failure rate and the rate of repairs, the values from Table 3 were obtained for the reliability and respectively the failure functions, referring to the above cited mechanical equipment elements.

Table 3. Reliability calculus for mechanical components.

Mechanical equipment	***Engine axle***	***Drive engine axle***	***Suspension elements***	***Brake linings***
λ=no. failures/total time	0.00031946	0.000136911	6.84556E-05	2.28185E-05
discrete time	R(t)=e^(-λt)			
0	1	1	1	1
4382.4	0.248937733	0.551038244	0.742319503	0.905448229
8764.8	0.061969995	0.303643146	0.551038244	0.819836495
13147.2	0.01542667	0.167318986	0.409046435	0.742319503
17529.6	0.00384028	0.09219916	0.303643146	0.672131879
21912	0.000955991	0.050805263	0.225400229	0.608580619
26294.4	0.000237982	0.027995643	0.167318986	0.551038244
30676.8	5.92427E-05	0.01542667	0.124204147	0.498936602
35059.2	1.47478E-05	0.008500685	0.09219916	0.451761263
39441.6	3.67127E-06	0.004684203	0.068441235	0.409046435
43824	9.13918E-07	0.002581175	0.050805263	0.37037037
$Q(t)=\frac{\lambda}{\lambda+\mu}[1-e^{-(\lambda+\mu)t}]$	**0.000317164**	**0.00013594**	**6.79721E-05**	**2.26579E-05**
$w(t)=(1-Q(t))\cdot\lambda$	**0.000319358**	**0.000136893**	**6.8451E-05**	**2.2818E-05**
Q_{total}=	**0.000543733**			
W_{total}=	**0.00054752**			

The data from Table 3 were afterwards be used for obtaining the time-dependence curves (Figure 3), for the reliability indicator of the cited mechanical equipment components, for the 060-DA diesel-electric locomotive.

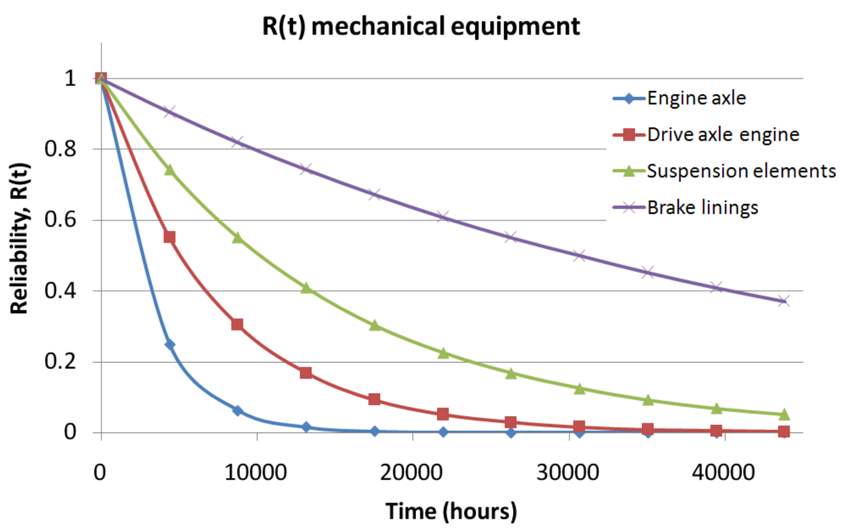
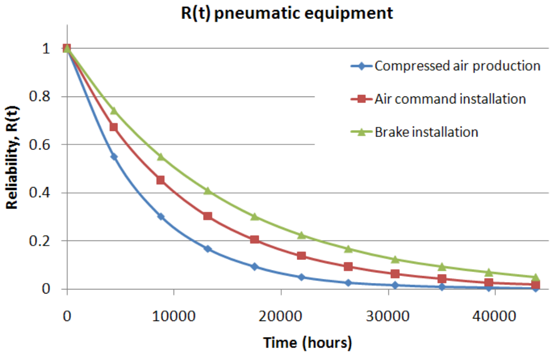


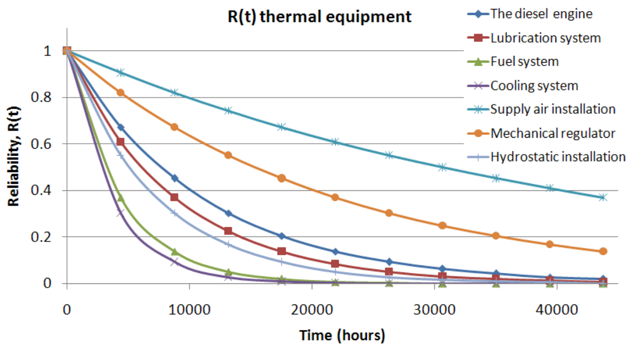
Figure 3. Reliability variation for the mechanical components.

IOP Conf. Series: Materials Science and Engineering **444** (2018) 062013 doi:10.1088/1757-899X/444/6/062013

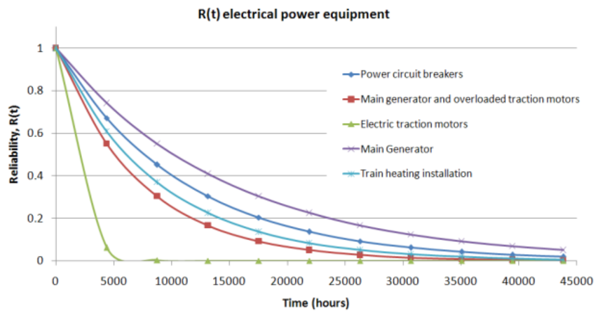
The same principles were followed for obtaining the time-dependence reliability curves (see Figure 4) for the other considered systems of the locomotive: pneumatic, thermal, electrical power, and respectively auxiliary electrical equipments.



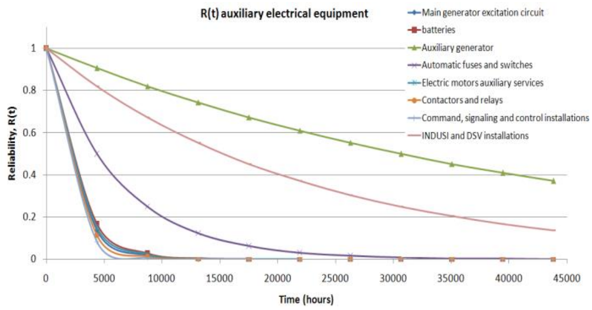
a) Pneumatic equipment



b) Thermal equipment



c) Electrical power equipment



d) Auxiliary electrical equipment

Figure 4. Reliability variation for auxiliary components.

Some findings can be made, by analyzing the above presented graphs:

- the failure of electrical auxiliary equipment are prevailing, for the considered locomotive;
- for the power equipment, most defects occur at drive engines, mainly disruptions of wire coils for their main or auxiliary poles; they are primarily caused by the big vibrations of two-stroke diesel-engine, leading to a loosening of mounting screws for the main or auxiliary poles;
- a small number of failures was registered for auxiliary equipment, which can be explained by the presence of a small number of mechanical dealings, for the auxiliary control systems; it is important to observe the use of a small number of switches, breakers, or automatic circuit-breakers for the operation of this type of locomotive.

5. Conclusions

The characteristics of reliability are established using the data referring to the reported components failures, for a certain statistical sample. From the above presented facts one can observe that a reliability analysis for technical systems uses information from various fields: detailed knowledge of the system technical design is required, and also of the physical mechanisms that can lead to failure or non-conforming operation of the respective system.

The knowledge of mathematical concepts and statistical methods is a necessary but not sufficient condition in order to make such analysis. The approach presented in the paper allows the analysis of the failure types, but especially it contributes to the identification of components that are prone to failure in the shortest time. The conclusions of such an analysis can lead to taking some additional measures on repair and maintenance intervention, in conjunction with the failure probability for any

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component of a technical system. In this regard, it was observed, for the considered diesel-electric locomotive, that more frequent maintenance interventions are necessary for some components of the electrical auxiliary equipment (see Figure 4d from above), and also for the driving electrical engines (Figure 4c).

6. References

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