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Analysis of the Modernised Railway Vehicle Component with Regard to Reliability and Operational Safety

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ABSTRACT

This paper presents an analysis of the design of the bogie pivot of an electric multiple unit, which is cast in cast steel to replace the forged pivot used to date. The change in pivot manufacturing technology is justified for economic reasons, but may affect the reliability and operational safety of multiple units. The authors analysed to what extent the change in pivot manufacturing technology from forged to cast can affect the operational reliability of the upgraded structural component and what requirements should be met so that the introduced upgrade does not reduce the operational safety of the electric multiple unit. An important part of the analysis is the consideration of the effect of preventive replacements of the rubber element of the vibration damper on damage to the pivot and vibration damper system. The dependence of damage to the cooperating components of the pivot elements and vibration damper in the system is demonstrated. The lifespan of the rubber element of the damper is considerably less than that of the bogie pivot of the electric traction unit, and its damage increases the probability of damage to the cast steel pivot. This relationship is critical and, in order to ensure the required reliability of the traction unit, a strategy of preventive replacement of the rubber element of the damper was proposed and achieved in the simulation model developed. This issue is presented in this paper because it is fundamental to the safe operation of rail vehicles.

Keywords: rail vehicles, structural modernisation, reliability, operational safety

INTRODUCTION

Structural upgrades of technical objects are an inherent part of their construction processes. The improvement of structures by introducing newer solutions is clearly visible in the production of cars and electronic equipment, as well as in the manufacture of many other products. Modernisations are driven by advances in technology, changing customer requirements and economic considerations [1]. The analysis presented here is aimed at ensuring the reliability and operational safety [2] of the modernised design. In the case under consideration for the bogie pivot of a rail vehicle, the modernisation of the design involves the application of a different manufacturing technology than that used to date. Consideration is being given to manufacturing the pivot using a steel casting process instead of a forging process. Undoubtedly, for economic reasons, the use of the new technology is fully justified. However, in view of the responsible function that the pivot has in a rail vehicle it should meet the strength requirements, which are a necessary condition to guarantee operational safety [3].

The basic problem in casting technology is to ensure that the material structure is uniform throughout the volume of the cast component and to eliminate the possibility of defects in the form of voids and inclusions within the casting [4]. The occurrence of such defects promotes the initiation of fracture and the lack of a uniform internal material structure results primarily in the formation of areas of reduced impact strength [5]. The combination of these two phenomena is very dangerous as it can lead to the initiation and rapid propagation of cracks cf. [6], especially when variable external loads are present. This type of loading is characteristic of the operating conditions of rail vehicle pivots and creates favourable conditions for damage and an immediate safety risk. The risk is much greater when the rubber bushing of the vibration damper cooperating with the pivot is damaged, as the dynamics of the loads carried by the pivot increases.

The rubber element of the damper cf. [7], in comparison to the other components of the system, is characterised by a significantly lower durability and a rapid deformation process under harsh operating conditions [8, 9, 10]. The low durability of this element affects the reliability of the pivot function. One possible solution to the problem is to develop a replacement strategy for the rubber damper element correlated with the reliability of the pivot and the entire system [11, 12, 13].

The result of the analysis performed is the development of a procedure for planning the preventive renewal of the rubber damper element enabling the assumed reliability of the system to be achieved, as well as a procedure for properly planning and carrying out the process of upgrading objects of this type [14, 15].

Impact strength as an indicator of the resistance of cast steel to dynamic loads in terms of reliability

One of the important characteristics of cast steel, in terms of applicability, is impact strength. This is the material's resistance to brittle fracture under dynamic loading. The impact strength measure used is the ratio of the energy required to fracture the sample with a single impact to the cross-sectional area of the sample at the notch [16]:

$$KC = \frac{K}{S}\left[\frac{\mathrm{J}}{\mathrm{mm}^2}\right] \tag{1}$$

where: KC – impact strength [J/mm²], K – impact work [J], S – area of the initial cross-section of the sample at the notch [mm²].

According to [17], cast steels that are used in railway structures are divided into two groups: steels for highly stressed castings (C1) and steels for other castings (C2). C1 steel castings are used, among other things, for bogie pivots, bearing housings of wheel set axles, and buffer parts. The use of cast steel in the construction of railway vehicles, especially in group C1, is conditioned by the fulfilment of a number of requirements in order to ensure operational safety. The types of tests and requirements for the production process, chemical composition and the method and conditions of testing the finished products are defined by the relevant standards [18].

In the application for railway vehicle pivots, the impact strength of the material is a particularly important parameter that should be tested. This is due to the fact that these components transmit high forces and, in addition, may also be subjected to impacts on the vehicle's supporting structure. If the impact strength is too low, this can then lead to a fracture of the pivot and a direct threat to the safety of rail traffic and passengers. According to standard [18], minimum impact strength values are given for individual steel grades as impact work values. They are determined as an average of the three samples tested, where the value of a single measurement must not be less than 2/3 of the average value obtained.

If the thickness of the casting exceeds 28 [mm], additional requirements specified in [19] must also be taken into account, which mainly concern the method of taking the sample and test ingot for testing. The impact strength values given in [18], depending on the steel grade, have a range of 20–45 J and are determined at an ambient temperature of 23 ± 5 °C. However, it must be remembered and constructors should bear in mind that some steel grades have significantly lower impact strength values at reduced temperatures, where rail vehicles are also operated. According to studies presented in [20, 21], the impact strength of cast steel, depending on the heat treatment applied and the chemical composition (admixture content), can be almost twice as low at -30 °C compared to that tested at 20 °C. One way to reduce this difference is to use a suitable heat treatment on cast steel [20]. An additional problem in the use of cast steels for the pivots is the need for the cast steel to meet several strength requirements at the same time. Due to the transfer of high loads, the material for the pivot should have high values of yield strength Re and ultimate strength Rm, and due to the resistance to fracture, high impact strength. In the case of cast steel, however, the values of impact strength decrease as the values of Re and Rm increase [18, 21].

The bogie pivot is an essential element of the connection between the bogie and the body of the railway vehicle (Figure 1). The function of the bogie pivot is to transmit the forces between the bodywork and the bogie, and to enable the bogie to turn in a horizontal plane relative to the bodywork of the vehicle. Depending on the forces involved, there are three types of loading on the bogie pivot: a bogie pivot carrying only the horizontal tractive and braking forces, a bogie pivot carrying only the vertical forces from the weight of the bodywork, and a bogie pivot carrying both horizontal and vertical forces Consideration of the possibility of assessing the reliability of a railway vehicle bogie pivot design began with a search for design features whose limits, if reached, could lead to failure. Since the forged pivots in service to date showed high reliability, attention was therefore directed to the changes introduced in manufacturing technology and the resulting changes in the properties of the structure, including above all the strength properties of the pivot material.

The analysis of the reliability of the pivot in question must be carried out comprehensively, across the entire design of the system of components that cooperate during the transmission of the driving force from the bogie to the wagon body structure. There are three factors involved in the pivot failure process. The initial factor initiating the process is the failure of the metal-rubber bushing (of the vibration damper) of the pivot connector to the bogie. The next phase of damage is initiated by increased freedom of movement in the through-port of the bogie cross member and contact in the form of impacts of the pivot on the edge of the through-port of the cross member. The impact resistance of the pivot depends on the local impact strength of the pivot material.

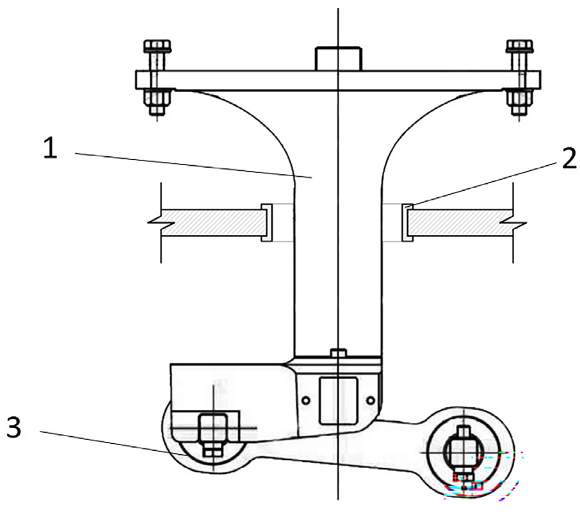

Figure 1. Schematic diagram of the construction of the analysed rail vehicle bogie pivot system, 1 – rail vehicle bogie pivot, 2 – through-port of the rail vehicle bogie frame cross member, 3 – tractive force vibration damper (metal-rubber bushing)

To assess the material properties of the pivot, samples must be taken randomly from several locations on the same pivot and from different pivots belonging to the random sample. The first test is the evaluation of the tensile properties. The static tensile test is carried out according to standard [22]. The literature data and tensile diagrams, as well as the nature of the fractures, confirm that the cast steel is characterised by low ductility. Specimen fractures without plastic deformation (constrictions) in the fracture area suggest brittleness of the material and the need for an impact test of the pivot material.

A detailed analysis of the interaction of the components and the occurring damage to the components for the transmission of force from the drive train to the pivot may indicate that there are impacts of the pivot on the edge of the through-port of the cross-member. During impacts, the structure transmits momentary dynamic loads of significant magnitude, which can lead to cracks and damage to the pivot. For impact forcing factors, the impact indices of the structural material can be of leading importance in assessing the reliability of the structure. Comparing the impact strength of cast steels with the limiting permissible value defined in the standard [16] enables the assessment and prediction of the limit state of resistance to impact forcing factors of a rail vehicle pivot.

The impact strength that characterises the susceptibility of cast pivots to brittle fracture compared to forged pivots significantly reduces their reliability. In subsection 3, the probability of correct pivot operation, i.e. the reliability characteristics that may be appropriate for cast pivots, was assumed. Taking into account that damage to the metal-rubber bushing (of the vibration damper) cooperating with the cast pivot significantly reduces its operating time to failure, it was analysed how preventive bushing replacement affects the reliability of these bogie components. Using a simulation method, the reliability of the system was checked for various cases occurring in the operation of the interacting pivot and rubber bushing.

Reliability assessment of the pivot - rubber damper system, including consideration of preventive replacements

A simulation method was used to assess the reliability of the system. The system under analysis has a specific and unusual reliability case. The system consists of a pivot and a rubber damper element, the way they work together having been characterised earlier. The system only fails when the pivot fails. Damage to the rubber damper element does not prevent the system from working properly, but causes a very large change in the operating conditions of the pivot. This change involves a significant increase in shock loads resulting from impacts of the pivot against the edge of the cross member through-port. This situation results in the possibility of a much more rapid failure of the pivot through breakage.

The problem is particularly related to pivots made using the casting technique, which are prone to brittle fracture. As it is impossible in practice to manufacture a rubber element for the damper with a lifespan close to that of the pivot [8, 9, 10, 13], hence, in order to ensure the reliability and operational safety of the system, the damper can be preventively replaced, thus avoiding the change in operating conditions of the pivot and its damage. An assessment of the reliability of the system operated in this way and the effect of damper damage on the reliability of the system, as well as an evaluation of the effects of preventive damper renewal, is possible using a simulation experiment [23, 24, 25]. The following assumptions were made in the simulation model developed:

1. In the considered operation horizon (T_h), the system failure may occur as a result of a pivot failure that has operated under normal conditions (the rubber element of the damper has not been damaged) or as a result of a pivot failure that has developed under changed conditions of its operation after a previous failure of the rubber element of the damper.
2. The value of the random variable of the such determined working time to system failure (t_f), in each of the i-th simulations, will be taken as the smaller of the values of the two random variables determined according to the relation:

$$t_f(i) = \min\{t_Y(i)\,;\ t_X(i) + t_Z(i)\} \tag{2}$$

where: t_f – value of the random variable operating time to system failure, i – simulation number, t_Y – value of the random variable operating time to failure of the pivot working without damaging the rubber element of the damper, t_X – value of the random variable of operating time to failure of the rubber element of the damper, t_Z – value of the random variable of operating time to failure of the pivot operating under conditions with a damaged damper rubber element.

A graphical representation of the determination of the values of the random variables of operating time to system failure (t_f) and an example of two possible cases in the simulation is shown in Figure 2. The simulation experiment was realised using the Matlab package. The probability distributions of the random variables Y, X and Z were assumed on the basis of observations and operational experiments. The types of distributions were adopted on the basis of information provided by the operator, and to determine them more precisely, planned operational tests should be carried out. The types of distributions and their parameters are shown in Table 1. After carrying out 10^5 repetitions of the simulation for $T_h = 5 \cdot 10^6$ km, the courses of changes in the reliability of the pivot-rubber element of the damper were estimated and are shown in Figure 3. For comparison, the same figure shows the course of the reliability of the system if the rubber element of the damper did not fail. The reliability courses obtained clearly show the very large impact of damage to the

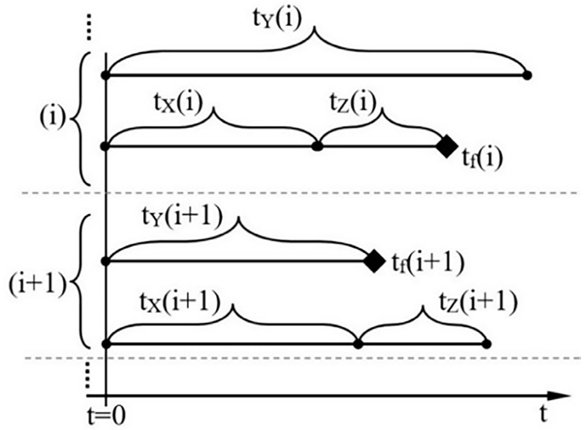

Figure 2. Determination of operating time to system failure (t_f) in simulations

Table 1. Distributions and parameters for random variables of operating times to failure

Random variable	Distribution	Distribution parameters
Y	Normal	average value, m = $4 \cdot 10^6$ km standard deviation, σ = $0.4 \cdot 10^6$ km
X	Normal	average value, m = $5 \cdot 10^5$ km standard deviation, σ = $0.6 \cdot 10^5$ km
Z	Weibull	scale parameter, β = $7 \cdot 10^3$ km shape parameter, ν = 2.5

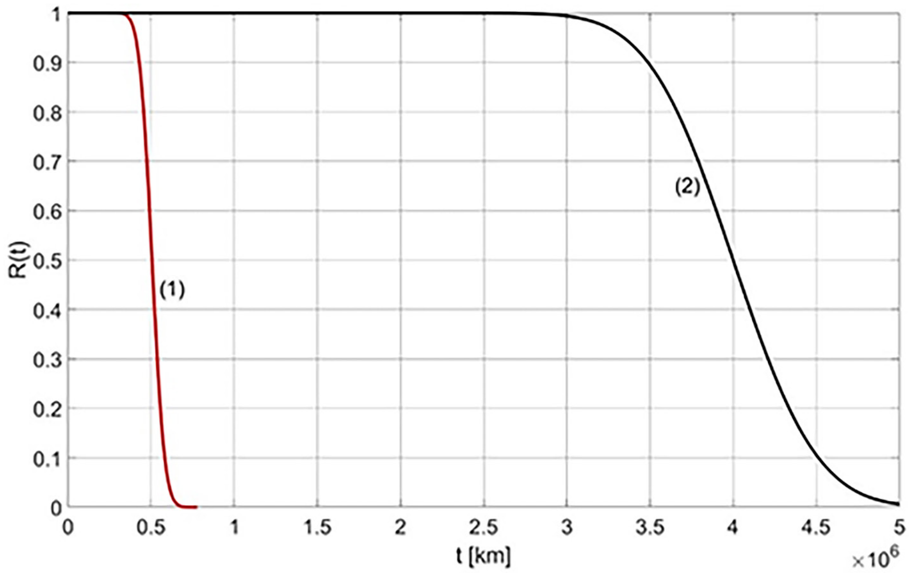

Figure 3. Reliability of the pivot-rubber element of the damper (1) and the course of the reliability of the system if the rubber element of the damper did not fail (2)

rubber element of the damper on the reliability of the system under consideration. Such a significant reduction in the reliability of the system cannot be accepted in practice for operational safety reasons. This impact can be reduced by preventive replacement of the rubber damper element in this system, which will have an effect depending on the assumed replacement period (t_{pr}) [23, 25, 26].

The simulation model developed to assess the impact of the preventive replacement of a rubber damper element on reliability is based on the one previously presented, except that the assumed period of preventive replacement of the rubber damper element (t_{pr}) is taken into account when determining the value of the random variable (t_f). The preventive renewal of a rubber damper element means replacing it with a new one. After drawing the value $t_Y(i)$, the value $t_{Xj}(i)$ is drawn and compared with the value t_{pr}. If $t_{Xj}(i)$ is greater than t_{pr} then the value of t_{pr} is stored as the value of t. The next value of $t_{Xj+1}(i)$ is then drawn and compared with the value of t_{pr}. If, for example, $t_{Xj+1}(i)$ is again greater than t_{pr} then t_{pr} is added to the t value. However, if $t_{Xj+1}(i)$ would be less than t_{pr}, it means that the damage to the rubber element occurred before its preventive replacement. Then $t_{Xj+1}(i)$ and the drawn $t_Z(i)$ are added to the current t-value and this t-value is compared to $t_Y(i)$. The smaller of the two is the value of the operating time to system failure in this simulation ($t_f(i)$). If, by the time the value of t reaches the value of T_h, no subsequent $t_{Xj}(i)$ happens to be less than t_{pr} then there is no failure of the pivot in this simulation by a change in its operating conditions through failure of the rubber element of the damper. The determination of the reliability value is made on the basis of the operating times to system failure ($t_f(i)$), stored in the simulations, according to the relationship [23, 24]:

$$R(t) = 1 - \frac{n_{t_f}(t)}{n} \tag{3}$$

where: $n_{tf}(t)$ – number of values of t_f less than t, collected in simulations, n – number of simulation repetitions.

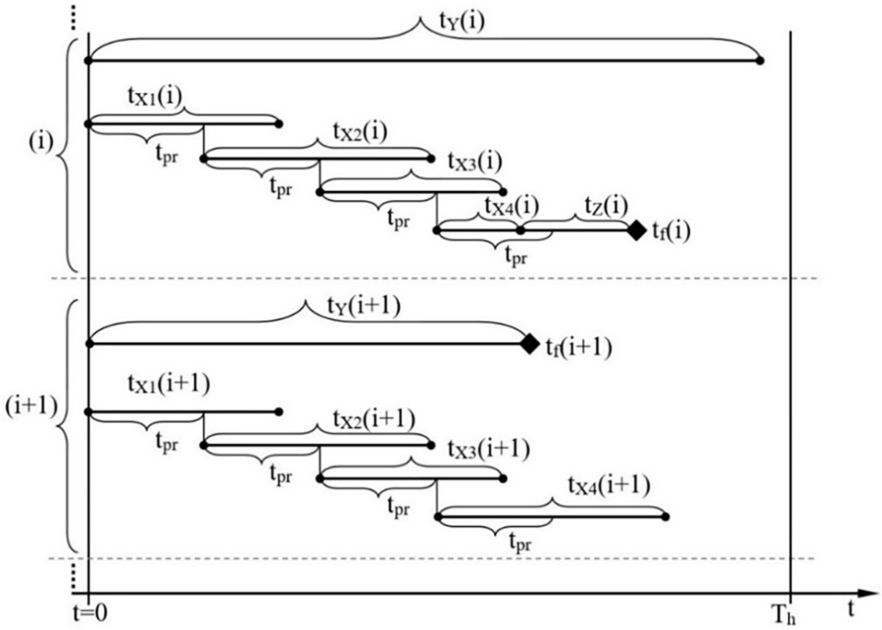

Figure 4. Determination of the operating time to system failure (t_f) in simulations when the rubber element of the damper is renewed preventively at intervals t_{pr}

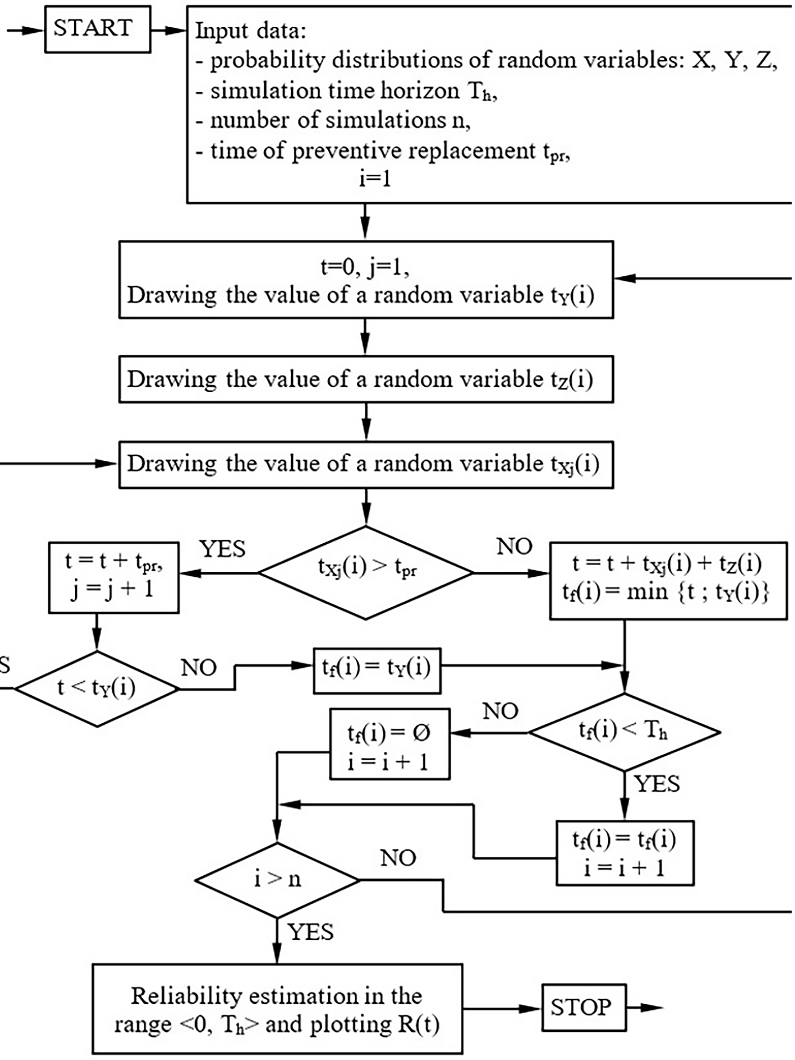

Figure 5. Block diagram of a simulation with a preventively renewed rubber damper element

Graphically, examples of two cases of the simulation courses are shown schematically in Figure 4 and a diagram showing how the entire simulation experiment is implemented is shown in Figure 5. For the chosen simulation model, using the Matlab package, the reliability courses of the system were determined for different values of the preventive replacement time (t_{pr}) of the rubber element of the damper and are included in Figure 6, together with the reliabilities obtained previously when the rubber element of the damper was not renewed preventively.

From the results obtained, it can be seen that preventive replacements of the rubber element of the damper have a clear effect on the reliability of the system. The more frequent the preventive replacements of the rubber element are carried out (lower t_{pr} values), the closer the reliability of the system approaches that which could be achieved if the rubber element of the damper were not damaged (2). Since preventive replacement requires stopping the vehicle and incurring the cost of this replacement, it is up to the decision of the operator how much he/she is willing to reduce the preventive replacement period (t_{pr}), thus increasing the number of downtimes and the cost of preventive operations to achieve greater system reliability. For this reason, the simulation also additionally estimated the average values of the number of preventive renewals (n_{pr}) of the rubber damper element in the assumed vehicle operation horizon $T_h = 4{\cdot}10^6$ [km] mileage and the average numbers of pivot failures (n_f) in the same period, depending on the time of preventive replacement of the rubber damper element (t_{pr}). The results are shown in Table 2. It can be noticed that there is a clear reduction in the number of failures (n_f) of the pivot when the preventive replacement period (t_{pr}) of the rubber element of the damper is decreased, with a corresponding increase in the number of replacements over the service life

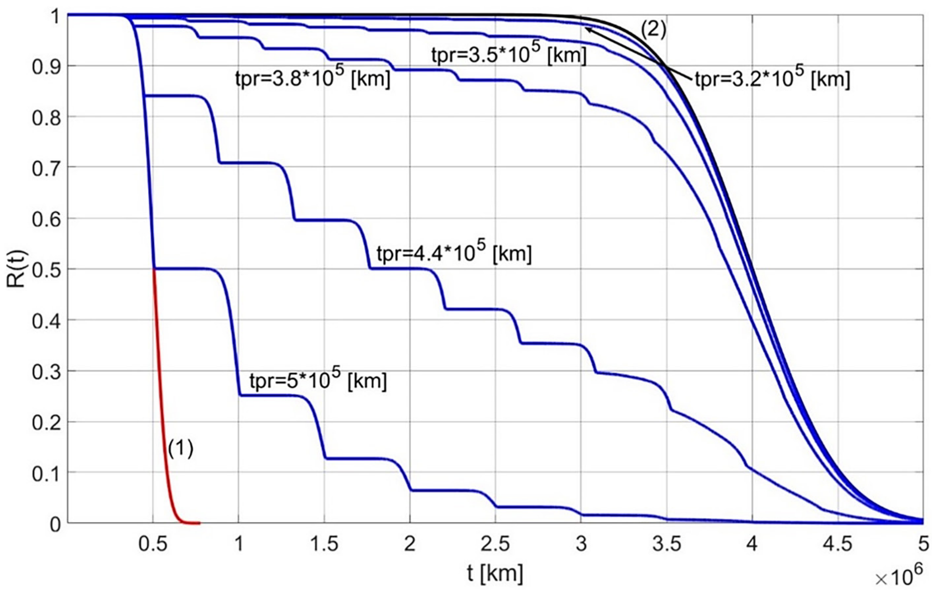

Figure 6. Reliability of the pivot-damper system with preventive renewal of the damper rubber element

Table 2. Average values for the number of preventive renewals of the rubber element of the damper and the number of pivot failures depending on t_{pr} at $T_h = 4{\cdot}10^6$ km

Preventive exchange period t_{pr} [km]	Average number of preventive rubber component replacements n_{pr}	Average number of pivot failures n_f
–	0	7.5
$5{\cdot}10^5$	4.0	4.0
$4.4{\cdot}10^5$	7.57	1.43
$3.8{\cdot}10^5$	9.77	0.22
$3.5{\cdot}10^5$	10.93	0.07
$3.2{\cdot}10^5$	11.98	0.02

considered. These results provide further guideline for deciding on the preventive replacement period (t_{pr}) of the rubber damper element to be used in practice.

Once the required reliability of the system has been assumed for the service life under consideration, it is possible to estimate what the time for preventive replacement of a rubber element should be to achieve the expected reliability value [23]. On the basis of the results obtained in the case under study, it can be pointed out that in order to maintain, for example, a system reliability of not less than 0.95 for $2.5 \cdot 10^6$ km of mileage, a preventive replacement of the rubber element of the damper should take place every $3.5 \cdot 10^5$ km of travel. Almost 11 preventive damper replacements should then be expected, but the average number of pivot failures will then be close to 0 (only 0.07). In the case of rail vehicles, the most important criterion when making decisions regarding maintenance dates and preventive replacements is the operational risk and related safety. The obtained results make it possible to determine the R_Z risk related to the operation of the analysed system. The value of the estimated risk can be taken as the product of the probability of failure of the system at a given time and the appropriately expressed consequences of this event (e.g. in the form of costs incurred). Then, for the selected mileage, e.g. $t = 2.5 \cdot 10^6$ km, the reliability values $R(t_{pr})$ for various t_{pr} should be read from the charts in Figure 6 and then the risk $R_Z(t_{pr})$ can be determined as:

$$R_Z(t_{pr}) = \left(1 - R(t_{pr})\right) \cdot C \text{ [u.]} \tag{4}$$

It can be seen that with a constant value of costs C, the risk values will be lower the smaller the t_{pr} values are. For example, for the mileage $t = 2.5 \cdot 10^6$ km, the risk value $R_Z(t_{pr} = 3.2 \cdot 10^5$ km) will be about 60 times smaller than $R_Z(t_{pr} = 4.4 \cdot 10^5$ km) and about 4.5 times smaller than $R_Z(t_{pr} = 3.5 \cdot 10^5$ km).

The importance of the design process in the modernisation of technical objects to ensure safety at the operational stage

Ensuring the safe operation of technical objects in all areas of human activity is a priority. Functional safety takes on particular importance in the field of transport and the vehicles used in transport [3]. The development of systems to ensure the reliable construction of vehicles and their safe operation is of fundamental importance and concerns all phases of a vehicle's existence, including the renewal and upgrade phase. These processes can be comprehensively covered in RAMS (Reliability, Availability, Maintenance and Safety) procedures [27, 28] as in the diagram (Figure 7).

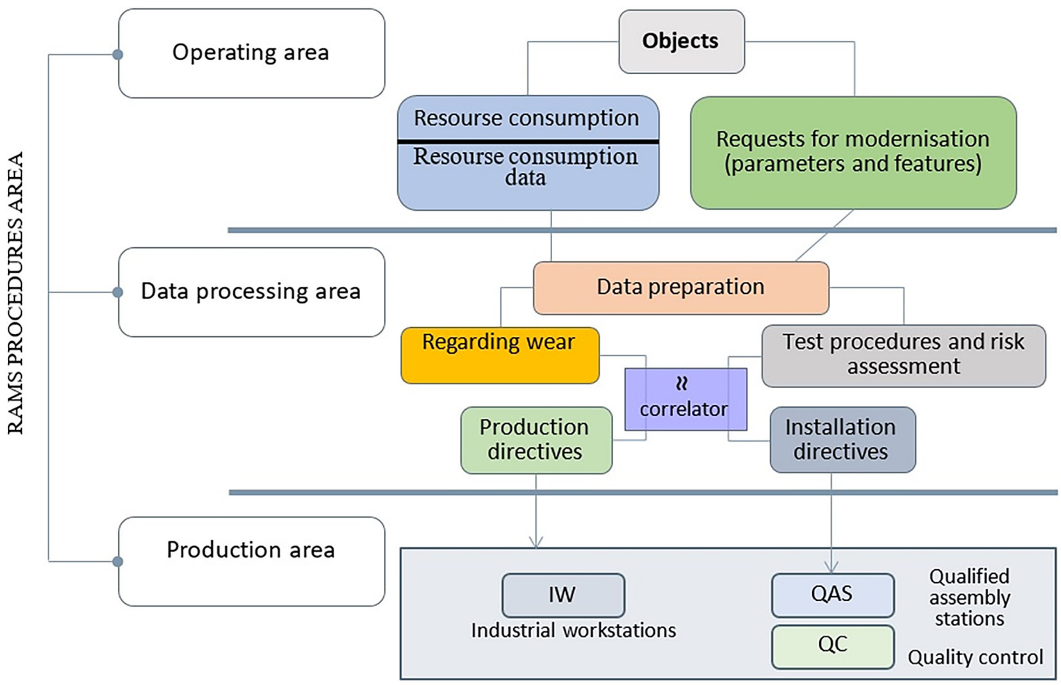

Figure 7. Elements of the RAMS procedure in operation and production for safe operation

The use of methods such as fault tree methods [29] and simulation methods in RAMS processes requires prior conceptualisation and preparation of actions to identify structural elements that may contribute to safety risks now and in the future. Conceptual action preparation [30] or conceptual relevance change preparation [31] by its nature involves creative activity [32, 33]) and decision-making [1, 35, 36]. With any technical project (especially in engineering), there is uncertainty associated with the upcoming future, i.e. concerning bringing about desired events (achieving the desired situation) and avoiding undesired events as a result of implementing the developed solution [35].

In technical activities, decisions taken at the design stage are then associated with the production of products with specific design and manufacturing characteristics. A technical product with these characteristics is then put into operation under specific conditions. The effects of its use are directly dependent on its characteristics and the aforementioned operating conditions. The actual course of the exploitation process and its effects are traditionally described by means of a variety of indicators concerning, among other things, the durability, reliability or readiness of the technical object, as well as the economics and safety of its exploitation [34]. There can therefore be no doubt that the possible effects of implementing a new technical solution should be analysed already at the design stage, as the course and effects of the process of the machine's (future) operation depend on the decisions of the machine designer [1]. Due to the cause-and-effect relationship presented, information is of major importance for design [1, 35]. The validity of the decisions made by the designer depends, in particular, on access to high-quality data. Hence, design activity remains closely linked to experimental research activity (and sometimes even research-design processes are considered [35] in the evaluation of the performance of a product in operation.

One of the most important assessments of a technical object and its exploitation process is the reliability assessment, which refers to the correct functioning of that object (when technical reliability is considered) [34], the proper execution of operations in relation to its use (when operation reliability is considered) [37] or the overall impact of its use on society (when socio-technical reliability is considered) [35].

The study [38] presents a concept of the research and design process, which is a proposal for the application of selected methods and tools for the development of reliability even before the final approval of the machine design (and in the context of its subsequent operation tests and upgrades). The presented concept is primarily aimed at ensuring acceptable technical reliability of the designed object. It demonstrates the extensive possibilities for testing, evaluating and ensuring reliability prior to series production. The referenced research and design process concept applies to the design of complex technical objects (in the reliability sense) that will be mass-produced, and is a sequential-iterative method of solving a design task [38]. It comprises activities from acceptance of the design task to final design acceptance and consists of five basic stages [38]:

1) task analysis, solution concept development and preliminary design;
2) detailed design combined with laboratory and simulation studies;
3) construction and testing of a prototype and making changes to the design;
4) testing and evaluation of the information series of the products and introducing changes to the design;
5) planning of future activities related to operational testing, evaluating commercial series, upgrading of the solution, and final acceptance of the design.

The essential stages of the method are shown in Figure 8, which also indicates the location within the research and design process, of the planned and undertaken research activities related to the reliability development of the designed object. The concept is discussed in detail in the referenced work [38] and, in the context of the considerations carried out in this article, it is noteworthy that it shows that there are ample opportunities to verify the reliability of the still-designed object. In the referenced concept [38], these are defined as follows:

- reliability assessment based on laboratory tests of structural materials, parts and subsystems as well as on failure rate estimates and computer simulation of object operation;
- reliability assessment based on testing of a prototype (or a prototype after a further design change);
- reliability assessment based on operational testing of an information series (i.e.

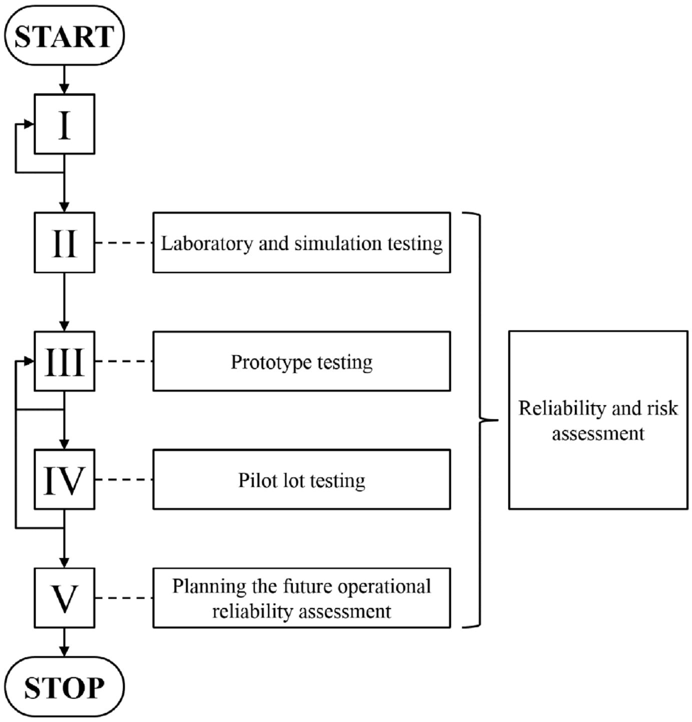

Figure 8. Schematic of the main stages of the characterised research and design method

products used under target operating conditions to meet needs, but subjected to detailed observation).

In addition, a future assessment of the reliability of the object based on commercial series performance tests (after the design has already been approved and implemented) is taken into account [38]. Such an assessment may enable a rational structural upgrade of the developed solution in the future, for which preparations should be made already at the design stage [38].

It is worth noting that the concept presented distinguishes between design reliability and operational reliability. Design reliability refers primarily to the failure rate of an object estimated on the basis of calculations (including simulations) based on data from laboratory tests, observations of other objects, etc. Operational reliability refers to the correctness of functioning of the products of the information series and commercial series and is determined on the basis of empirical statements concerning real objects used to satisfy needs. In addition, prototype reliability can be determined, which has the character of design reliability, based on the observation of a technical asset produced (based on a design not yet finally approved) and working exclusively for research purposes, under deliberately arranged conditions.

As shown, there are many possibilities to estimate the reliability of a technical object already at the design stage. It is also important to verify the design in practice through operational testing of commercial series and subsequent quality control of modernised and manufactured objects. These activities are costly, labour-intensive and time-consuming, but they provide the data necessary to make rational decisions in the design process. The earlier errors are detected in the design process, the lower the cost of correcting them should be. Verification of the correctness of the system and design of an object, its manufacturing technology and technology of its operation facilitates the avoidance of failures and their consequences, which may be, e.g. unexpected stoppages, incorrectly executed production and service processes or a threat to life, health, the environment and property. It can therefore be seen that the funding of reliability research is an investment with a chance of return, the absence of which can lead to serious losses. The considerations presented in this subsection are intended to emphasise that the commissioning of modernised components should be addressed comprehensively, taking into account the design processes of the technical object, and complements the issue presented in the article.

CONCLUSIONS

The introduction of new technologies in the production of objects that are particularly responsible in terms of operational safety should always be preceded by an analysis of the consequences resulting from the proposed changes and an assessment of possible hazards and risks.

The economic effect in the modernisation process cannot be the only criterion for deciding on changes to structural elements, but it is necessary to use the control of the manufacturing process and the quality of the final product to assess whether it meets the requirements for acceptance into service. Specifying assessment criteria and setting their limit values is one of the essential conditions for safe operation. The paper presents:

- an analysis of the suitability of cast steels as a material to be used for the casting of pivots,
- a characteristic of the operating conditions of selected pivots and the external factors affecting their use,
- the impact criterion as a primary element in the assessment of the functional reliability of the cast pivot,
- the effect of preventive replacements of the rubber damper element on the failure rate of the system,
- simulation model for estimating the reliability of the pivot-rubber damper element system with taking into account the timing of preventive replacements of the damper,
- the effect of the replacement intervals of the rubber element of the damper on the reliability of the system and the average numbers of preventive replacements and pivot failures over the analysed service life,
- the component upgrade process as an important part of the design process of the technical object.

Reducing production costs cannot be done without taking additional evaluation criteria into account, especially when operational safety is a priority issue in the use of technical objects.

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