Application of the object model in the modelling process of locomotive drive units

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Abstract. The article deals with the problem of selecting the object model of technical solutions to the mechanical part of the locomotive traction drive. The basis of the accepted model is a concept that considers a technical object as a set of internal elements, external elements of the environment, as well as relations between their sets. The proposed model is adapted for use with modern CAD systems. Approbation of the model is carried out on the example of the synthesis of a rational design of the suspension of the locomotive traction drive, reducing the possibility of self-oscillations. As a result of the use of the proposed model, two patentable variants of the suspension of the locomotive traction drive were created, which solve the problem of reducing the likelihood of self-oscillations of the carriage.

1. Introduction
Modelling of creative activity in the process of creating inventions is constrained by the lack of a mathematically rigorous language for solving inventive problems. In common CAD systems the machine can not recognize the image of an arbitrary part if this part is not recognized in advance by a person, and can not pick up the known analogues and prototypes.

2. Theoretical information
The CAD introduction in the design process of locomotives has not yet led to a corresponding improvement in the quality of the design solutions to the traction drive. So there were failures of rubber-cord couplings and suspension units of the reducer [1–6] and the mounting units of the traction motor (TM) in the electrical locomotives EP1 and EP10. The electrical locomotive 2ES6 had a break in the leash of the TM and squeezing the rubber out of the suspension hinges. These results suggest that the weak point in the traction drives design at the moment is the modelling of their technical solutions.

The analysis of the existing design methodology showed that there are currently a number of design methods based on the design process models, which, according to the classification [7–11], can be attributed to the algorithmic models. There are two obstacles to the use of these models in CAD. Firstly, the methods are empirical in nature, so that to date, there were offered a variety of possible algorithms for finding a technical solution. Second, these algorithms were calculated for their use by man, so the problem of choice of the model type of technical solutions to creating communication procedures with the well-known CAD systems were not considered.
We will take the concept described in [12–17] as a general methodological basis for the modeling of technical solutions to the drive. According to this concept, any technical object can be represented by the five.

$$C = \left( \phi, R, A^{(i)}, A^{(R)}, A^{(SR)} \right)$$

where the set $\phi = \left( S_1, ..., S_p \right)$ is the composition of the system, where $S_1, ..., S_p$ are the internal elements $C$, the set $R = \left( R_1, ..., R_q \right)$ is the environment (the super–system), and $R_1, ..., R_q$ are the external elements $C$, the set $A^{(i)}$ is all the relations on the elements (the internal structure of the system $C$), and the sets $A^{(R)}$ and $A^{(SR)}$ are all the relations between the elements $\phi$ and $R$ (the structure of the system interaction with the environment).

Hence, the design model of a technical device is a system which has many descriptions. The mapping is considered to be a homomorphic mapping of the set of real objects to the set of their descriptions. $\phi = \left( S_1, ..., S_p \right)$ if $\phi$ has the same composition as the set $\phi'$. Accordingly, the display of the system $C = C \left( \phi, R, A^{(i)}, A^{(R)}, A^{(SR)} \right)$ on the system $C = C \left( \phi, R, A^{(i)}, A^{(R)}, A^{(SR)} \right)$ is considered to be specified if five mappings are given: $\alpha_1 : \phi \rightarrow \phi$; $\alpha_2 : R \rightarrow R$; $\alpha_3 : A^{(i)} \rightarrow A^{(i)}$; $\alpha_4 : A^{(R)} \rightarrow A^{(R)}$; $\alpha_5 : A^{(SR)} \rightarrow A^{(SR)}$.

3. An example of the technical solution

As an example, we formulate the original problem. You want to create a suspension design of the traction motor, reducing the possibility of self-oscillations.

Let us take the classification of technical systems as a basis for building an object model of a technical system, as a way to identify its typical structure.

It is most natural for technical devices to build the classification in the same sequence as to create the design itself. The most common features are a similar set of functional features of the technical system, as a way to identify its typical structure.

The classification of technical systems is considered to be homomorphic if the features of a particular technological base at the time of their manufacture.

For simplification we use a measure of similarity in the form of a non-negative real function

$$C(R_i, R_j) = \frac{2m(R_i \cap R_j)}{m(R_i) + m(R_j)}$$

where $m(R_i \cap R_j)$ is the number of common species in the descriptions $R_i$ and $R_j$, $m(R_i)$ and $m(R_j)$ are the number of species in the descriptions $R_i$ and $R_j$.

Let’s consider an example of finding a prototype in the object library. Let $R_i$ be the description of the designed suspension, $R_2 - R_5$ be the description of the prototypes, $S_1 - S_{12}$ be the features of the objects (table 1). On the basis of table 1 we make the species lists (table 2 a).

Let sets $m(R_i), m(R_j)$ be the number of features of the $i$-th and $j$-th variants in the species lists, the set $m(R_i \cap R_j)$ be the number of features simultaneously available in the $i$-th and $j$-th variants.

Then the measure of inclusion of the set of features of the $i$-th variant in the $j$-th:

$$W(R_i, R_j) = \frac{m(R_i \cap R_j)}{m(R_j)}.$$
Table 1. Signs of the TM suspension options.

|   | \(R_1\) | \(R_2\) | \(R_3\) | \(R_4\) | \(R_5\) |
|---|---|---|---|---|---|
| \(S_1\) | One-piece pull | One-piece pull | One-piece pull | – | One-piece pull |
| \(S_2\) | – | – | – | – | – |
| \(S_3\) | Bracket | Bracket | Bracket | Bracket | Bracket |
| \(S_4\) | – | – | – | – | – |
| \(S_5\) | Detachable crown of TM | Detachable crown of TM | Detachable crown of TM | – | Detachable crown of TM |
| \(S_6\) | – | Leash | – | – | – |
| \(S_7\) | – | Rubber blocks | – | – | Rubber blocks |
| \(S_8\) | – | – | – | – | – |
| \(S_9\) | – | – | – | – | – |
| \(S_{10}\) | – | – | – | Guide rods | – |
| \(S_{11}\) | – | – | – | – | Disks |
| \(S_{12}\) | – | – | – | – | – |

Table 2. Species lists and measure matrices: a – species lists, b – matrix of inclusion measures, c – matrix of intersection measures, d – similarity measures matrix.

(a) \(R_1\) \(R_2\) \(R_3\) \(R_4\) \(R_5\)

|   | \(R_1\) | \(R_2\) | \(R_3\) | \(R_4\) |
|---|---|---|---|---|
| \(S_1\) | 1 | 1 | 0 | 1 |
| \(S_2\) | 0 | 1 | 0 | 0 | 1 |
| \(S_3\) | 1 | 1 | 1 | 1 | 1 |
| \(S_4\) | 0 | 0 | 0 | 1 | 0 |
| \(S_5\) | 1 | 1 | 1 | 0 | 1 |
| \(S_6\) | 0 | 1 | 0 | 0 | 0 |
| \(S_7\) | 0 | 1 | 0 | 0 | 1 |
| \(S_8\) | 1 | 0 | 1 | 0 | 0 |
| \(S_9\) | 0 | 0 | 0 | 1 | 0 |
| \(S_{10}\) | 0 | 0 | 0 | 1 | 0 |
| \(S_{11}\) | 0 | 0 | 0 | 1 | 0 |
| \(S_{12}\) | 1 | 0 | 0 | 0 | 0 |

(b) \(R_1\) \(R_2\) \(R_3\) \(R_4\) \(R_5\)

|   | \(R_1\) | \(R_2\) | \(R_3\) | \(R_4\) | \(R_5\) |
|---|---|---|---|---|---|
| \(R_1\) | 50 | 100 | 25 | 50 |
| \(R_2\) | 60 | 75 | 25 | 83 |
| \(R_3\) | 80 | 50 | 25 | 50 |
| \(R_4\) | 20 | 17 | 25 | 17 |
| \(R_5\) | 60 | 83 | 75 | 25 |

(c) \(R_1\) \(R_2\) \(R_3\) \(R_4\) \(R_5\)

|   | \(R_1\) | \(R_2\) | \(R_3\) | \(R_4\) | \(R_5\) |
|---|---|---|---|---|---|
| \(R_2\) | 0 | 1 | 0 | 0 |
| \(R_3\) | 1 | 1 | 1 | 1 |
| \(R_4\) | 0 | 0 | 0 | 1 |
| \(R_5\) | 1 | 1 | 1 | 0 |

\[
W(R_i, R_j) = \frac{m(R_i \cap R_j)}{m(R_i)}
\] (4)

variant in the \(i\)-th:

\[
W(R_i, R_j) = \frac{m(R_i \cap R_j)}{m(R_i)}
\]

(4)
On the basis of (3) and (4) we calculate the values of the elements of the matrix of inclusion measures (table 2 b) as a percentage, rounding the values to integers.

The element of the matrix of intersection measures (table 2 c) in the \( i \)-th row and \( j \)-th column is \( m(R_i \cap R_j) \), hence \( m(R_i \cap R_j) = m(R_i) \). Elements of the matrix of similarity measures (table 2 d) are calculated by the formula (2).

For options \( R_1 \) and \( R_2 \) the number of species in the descriptions of the signs is \( m(R_1) = 5 \), \( m(R_2) = 6 \), \( m(R_1 \cap R_2) = 3 \). Then

\[
W(R_2,R_1) = \frac{m(R_1 \cap R_2)}{m(R_1)} = \frac{3}{5} = 60\%
\]

(the second row, the first column of the table 2b)

\[
W(R_1,R_2) = \frac{m(R_1 \cap R_2)}{m(R_2)} = \frac{3}{6} = 50\%
\]

(the first row, the second column of the table 2b). Accordingly, in table 2b the first row is \( m(R_1) = 5 \), the second row, the first column is \( m(R_1 \cap R_2) = 3 \), the second row, the second column is \( m(R_2) = 6 \), but in the table 2d

\[
C(R_1,R_2) = \frac{2m(R_1 \cap R_2)}{m(R_1) + m(R_2)} = \frac{2 \cdot 3}{5 + 6} = 55\%
\]

(the first row, the first column of the table 2d).

As it can be seen from the matrix of similarity measures (table 2d), the largest value of 89 in the prototype column \( R_1 \) is for the row \( R_3 \). Therefore, the TD suspension [18–20] is close to the designed object (figure 1), which is used as a prototype.

**Figure 1.** TD suspension: 1 – rubber-metal elements; 2 – motor; 3 – wheel; 4 – rail; 5 – carriage frame.

**Figure 2.** TM suspension with a high-speed controller: 1 – thrust; 2 – rubber-metal elements; 3 – non-selfbreaking thread; 4 – nut; 5 – speed controller; 6 – truck frame; 7 – rubber elements.

It is known that the lack of this suspension unit of the traction motor is due to the fact that the dissipative properties of elastic rubber elements are determined only by the internal friction in the rubber of the elements, which limits the possibility of reducing their stiffness due to the possibility of resonance phenomena from the impact of periodically repeated track irregularities, and also creates an opportunity for the development of friction self-oscillations of the traction motor frame on rubber elements when the locomotive is towed.
Let us consider how to obtain new patentable solutions based on the found prototype. The contradiction between the needs and possibilities here is quite obvious and lies in the fact that we need to exclude the possibility for the development of self-oscillations of the traction motor frame on rubber elements, but we cannot achieve it in the existing design due to the limited possibility for reducing the stiffness of the rubber elements.

Thus, the contradiction of the requirements for the suspension parts is that the rubber elements should be sufficiently rigid to transmit the reaction from the traction motor to the trolley frame, and should reduce the stiffness to eliminate the possibility of self-oscillations.

We will not synthesize the suspension from scratch, but use the techniques of resolving contradictions. We can include a speed controller in the design, which will reduce the amplitude of the oscillations in the case of resonance or self-oscillations during boxing by increasing the energy dissipation in the speed controller, thus preventing the occurrence of large loads in the parts (figure 2).

Thus, in the considered example, the search for prototypes using the object model in combination with the methods of programming of the design activity allowed to patent the design of the suspension 7 parts (figure 2).

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Thus, in the considered example, the search for prototypes using the object model in combination with the methods of programming of the design activity allowed to patent the design of the suspension of the traction motor [21]. Similarly, it was possible to patent another design of the suspension of the traction motor [22].

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