TYPES OF THE STATE SPACE OF COMPLEX TECHNICAL SYSTEMS

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Abstract

Considered in the paper complex technical system consists of a set of technical objects. These objects are the elements of the system. An object is treated as an element of a system if it is characterized by a specified set of features. Technical object features can be divided into two groups: additive and constitutive. Additive features are independent from relations inside the system, but constitutive ones depend on it. System features resulted from additive features of its elements can be defined as a sum of features of particular elements of the system. Unfortunately, in case of constitutive features of the system this way of defining is not proper. So, to identify the system itself, it is necessary to determine the unique set of the system features. Considering complex technical systems, it was stated that a state of a system is defined by instantaneous values of cardinal features of the system. So, the state of a system can be expressed in their features' space. But the set of the cardinal features of the system depend on the considered issue. In the field of machines maintenance and operation the technical systems can be analysed for different points of view. Therefore, the state of the system can be described in different features' spaces. In the paper different types of the system features' spaces are introduced. Thanks to the defined spaces application it is possible to create coherent description of all types of processes which are executed in a technical system during operation and maintenance phase.

Keywords: *terotechnology, modelling, technical system, state of the system*

1. Introduction

The technical system is identified by a unique set of its features. These are the cardinal features of the system. Instantaneous values of the cardinal features unequivocally determine the state of the system [10]. Thus, this state is described by a vector of the cardinal features of the system. Therefore it can be interpreted as a point in the n-dimensional space of the technical system features. The number of dimensions n is equal to a cardinality of the set of the cardinal features of the system.

For each feature of the system, independently from its type, it is possible to define its domain as a range of possible values of the feature. The domain of the feature is limited by its minimum and maximum values. Inside the domain of the feature the minimum and maximum boundary values can be distinguished. These values determine the range of the acceptable values. The range of the suboptimal values is a subset of the range of the acceptable values. The suboptimal values are limited by the minimum and maximum suboptimal values.

The points of the n-dimensional space of the technical system features are the representation of the system states. So, the characteristic ranges of the features determine in the space n-dimensional fields of the system states. The ranges of acceptable values determine the field of acceptable states, the ranges of unacceptable values determine the field of unacceptable states and the ranges of suboptimal values determine the field of suboptimal states.

In the area of the machine maintenance and operation the technical system can be analysed in a context of diagnostics, safety, reliability, tribology and terotechnology. The contents of the set of the system cardinal features depend on the context of considerations. Different set of the system cardinal features formulates different space of the system features. Therefore the system state, as a point of the space, can belong to different groups of the system states. The group to which the system state belongs to depends on the space in which the state is expressed.

2. The space of the technical states of the system

If the set of the cardinal features consists of the physical features and if the characteristic values and ranges of these features are defined in a context of the system ability to realise the aims of its operation then, in the features' space, the fields of reliability are obtained [12]. Such space is called the space of the technical states of the system.

The domains of the features which are the dimensions of the considered space are divided into ranges described by following formulas (1-4).

$$X_{iZM} = \langle x_{i\min}, x_{i\max} \rangle, \tag{1}$$

$$X_{iND} = \langle x_{i\min}, x_{igr}), \tag{2}$$

$$X_{iD} = \langle x_{igr}, x_{i\max} \rangle, \tag{3}$$

$$X_{iSO} = \langle x_{iSO\min}, x_{i\max} \rangle, \tag{4}$$

where:

X_{iZM} - the domain of the system feature no. i,
x_{igr} - the boundary value of the system feature no. i,
x_{imin}, x_{imax} - the minimum and maximum values of the system feature no. i,
x_{iSOmin} - the suboptimal minimum value of the system feature no. i,
X_{iND} - the range of unacceptable values of the system feature no. i,
X_{iSO} - the range of suboptimal values of the system feature no. i,
X_{iD} - the range of acceptable values of the system feature no. i.

The partitioning of the feature domain, presented above, implies the creation of the fields of reliability states of the system in the space of its technical states. These are the field of the system ability, the field of the system inability and the intermediate field of the system limited ability [2, 13]. The exemplary position of the fields of the reliability states in R^2 space of two independent features is presented in the Fig. 1.

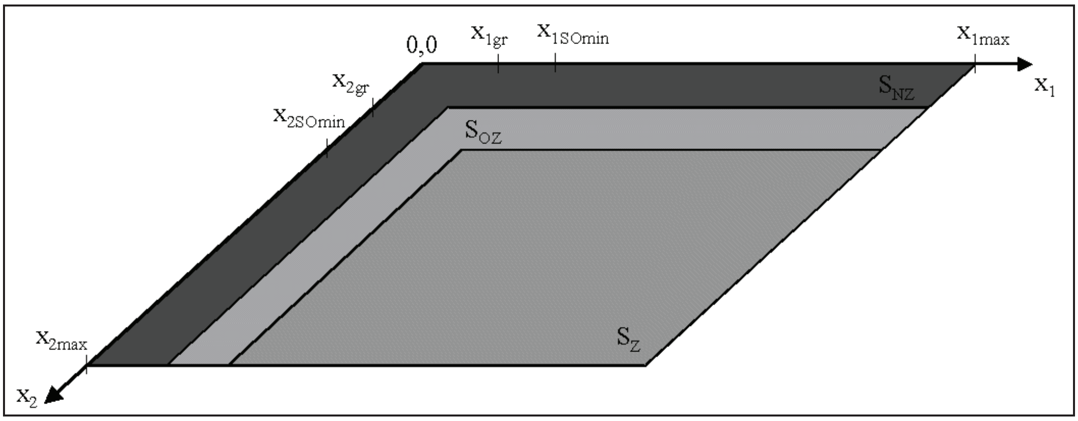

Fig. 1. The fields of reliability states of the system expressed in the R^2 space of two independent features: S_{nz} – the field of inability states; S_z – the field of ability states; S_{oz} – the field of limited ability states

The system is in the ability state when the values of all its cardinal features – the dimensions of the space of the technical states are in the range of suboptimal values (5).

$$s_R(x_1, x_2, \cdots, x_n) \in S_Z \Leftrightarrow \forall x_i \in X \wedge i = 1,2,\cdots,n : x_i \in X_{iSO}, \tag{5}$$

where:

s_R - the real state of the system,
x_i - the cardinal feature of the system no. i,
S_Z - the field of ability states of the system.

The system is in inability state when the value of at least one cardinal feature – the dimension of the space of the technical states is in the range of unacceptable values (6).

$$s_R(x_1, x_2, \cdots, x_n) \in S_{NZ} \Leftrightarrow \exists X_k \subset X : card(X_k) \geq 1 \wedge \forall x_i \in X_k : x_i \in X_{iND}, \tag{6}$$

where S_{NZ} is the field of inability states of the system.

The system is in the limited ability state when the values of all its cardinal features – the dimensions of the space of the technical states are in the range of acceptable values and the value of at least one of them is in the range of suboptimal values (7).

$$s_R(x_1, x_2, \cdots, x_n) \in S_{OZ} \Leftrightarrow \forall x_i \in X : x_i \in X_{iD} \wedge \exists X_k \subset X : card(X_k) \geq 1 \wedge \forall x_i \in X_k : x_i \notin X_{iSO}, \tag{7}$$

where: S_{OZ} is the field of limited ability states of the system.

3. The space of the operation states of the system

If the set of the cardinal features consists of the parameters of the operation process executed in the concerned technical system then the state of the system, expressed as a point of the defined space is an operation state of the system [4, 9]. Such space is called the space of the operation states of the system.

The domain of the features – the dimensions of the space is partitioned according to the formulas (8-11) (Fig. 2).

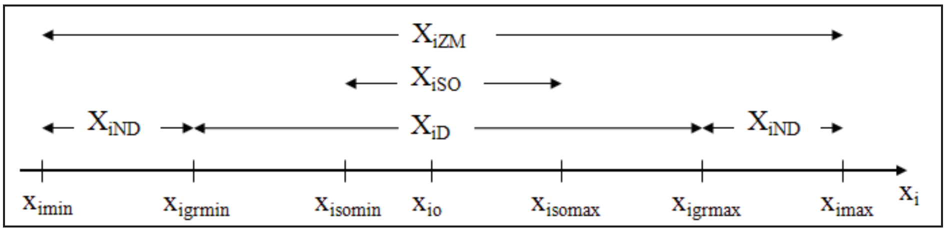

Fig. 2. The domain of the feature – the dimension of the space of the operation states of the system

$$X_{iZM} = \langle x_{i\min}, x_{i\max} \rangle, \tag{8}$$

$$X_{iND} = \langle x_{i\min}, x_{igr\min}) \cup (x_{igr\max}, x_{i\max} \rangle, \tag{9}$$

$$X_{iD} = \langle x_{igr\min}, x_{igr\max} \rangle, \tag{10}$$

$$X_{iSO} = \langle x_{iso\min}, x_{iso\max} \rangle, \tag{11}$$

where:

x_{igrmin}, x_{igrmax} - the minimum and maximum boundary values of the system feature no. i,

x_{iSOmin}, s_{iSOmax} - the minimum and maximum suboptimal values of the system feature no. i.

The partitioning of the feature domain, presented above, implies the creation in the space the field of optimal operation of the system, the field of stable operation of the system and the field of the system failure [3, 8]. Below, the exemplary position of the fields of the operation states in R^2 space of two independent features is presented (Fig. 3).

In the considered space, it was stated, that the system is in the optimal operation state when the values of all its features – the dimensions of the space of the operation states of the system are in the range of suboptimal values (12)

$$s_R(x_1, x_2, \cdots, x_n) \in S_O \Leftrightarrow \forall x_i \in X \wedge i = 1,2,\cdots,n; x_i \in X_{iSO}, \tag{12}$$

where S_O is the field of optimal operation of the system.

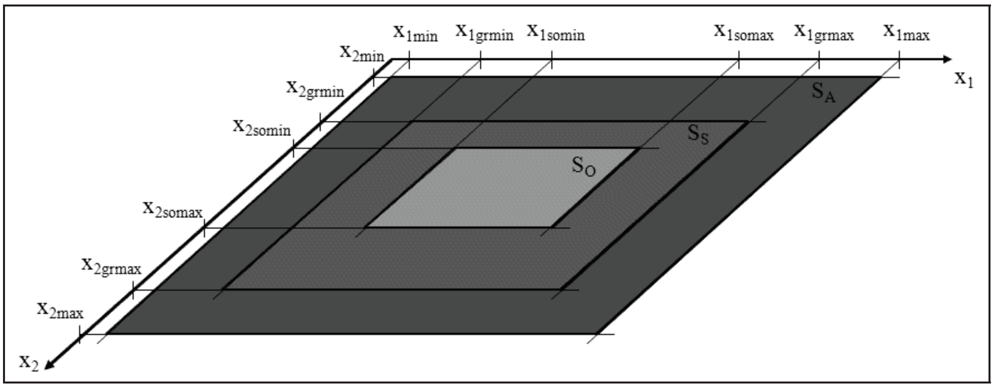

Fig.3. The fields of operation states of the system expressed in the R2 space of two independent features: SO – the field of optimal operation; SS – the field of stable operation; SA – the field of the system failure

The system is in the stable operation state when the value of at least one cardinal feature – the dimension of the space of the operation states is in the range of acceptable values and is not in the range of suboptimal values and the values of all remaining cardinal features are in the range of suboptimal values (13).

$$s_R(x_1, x_2, \cdots, x_n) \in S_S \Leftrightarrow \exists X_k \subset X : \begin{cases} card(X) \geq card(X_k) \geq 1, \\ \forall x_i \in X_k : x_i \in X_{iD} \wedge x \notin X_{iSO,} \\ \forall x_j \in X \setminus X_k : x_j \in X_{iSO,} \end{cases} \tag{13}$$

where S_S is the field of stable operation of the system.

The system is in the failure state when the value of at least one cardinal feature – the dimension of the space of the operation states is in the range of unacceptable values (14).

$$s_R(x_1, x_2, \cdots, x_n) \in S_A \Leftrightarrow \exists x_i \in X \wedge i = 1,2,\cdots,n; x_i \in X_{iND}, \tag{14}$$

where S_A is the field of the failure state of the system.

4. The space of the quality states of the system

If the set of the cardinal features comprises the quality features of the system [5, 19], then the space defined by them consists of the R^n points which are the representation of the quality states of the system. Such space is called the space of the quality states of the system.

For each feature the conditions of proper quality of the system operation are defined. It should be possible to unequivocally identify if the condition is fulfilled or not by a specified feature [6, 11, 14]. Fixed boundary values divide the domain of the feature into the range of values corresponding to desirable quality of the system operation and the range of values corresponding to undesirable quality of the system operation (15 - 17) (Fig. 4)

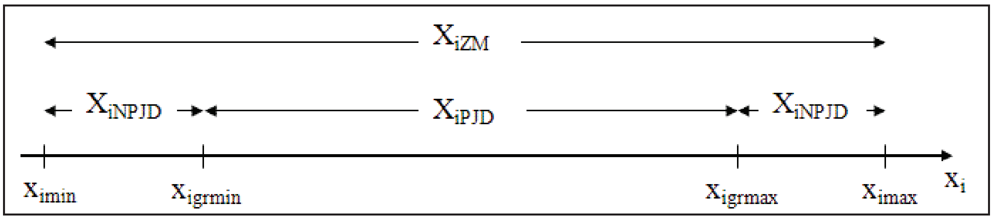

Fig. 4. The domain of the feature – the dimension of the space of the quality states of the system

$$X_{iZM} = \langle x_{i\min}, x_{i\max} \rangle, \tag{15}$$

$$X_{iNPJD} = \langle x_{i\min}, x_{igr\min}) \cup (x_{igr\max}, x_{i\max} \rangle = X_{iND}, \tag{16}$$

$$X_{iPJD} = \langle x_{igr\min}, x_{igr\max} \rangle = X_{iD}, \tag{17}$$

where:
X_{iNPJD} - the range of the values corresponding to desirable quality of the system operation,
X_{iPJD} - the range of the values corresponding to undesirable quality of the system operation.

Introduced partitioning of the domains of the quality features determines in the features' space the field of the states of desirable quality of the system operation and the field of the states of undesirable quality of the system operation [7, 15]. The system is in the state of desirable quality of operation when the values of all its cardinal features – the dimensions of the space of the quality states are in the range of acceptable values (18).

$$s_R(x_1, x_2, \cdots, x_n) \in S_{PJD} \Leftrightarrow \forall x_i \in X \wedge i = 1,2,\cdots,n; x_i \in X_{iD}, \tag{18}$$

where S_{PJD} is the field of the states of desirable quality of the system operation.

The system is in the state of undesirable quality of operation when the value of at least one cardinal feature – the dimension of the space of the quality states is in the range of unacceptable values (19).

$$s_R(x_1, x_2, \cdots, x_n) \in S_{NPJD} \Leftrightarrow \exists x_i \in X \wedge i = 1,2,\cdots,n; x_i \in X_{iND}, \tag{19}$$

where S_{NPJD} is the field of the states of undesirable quality of the system operation.

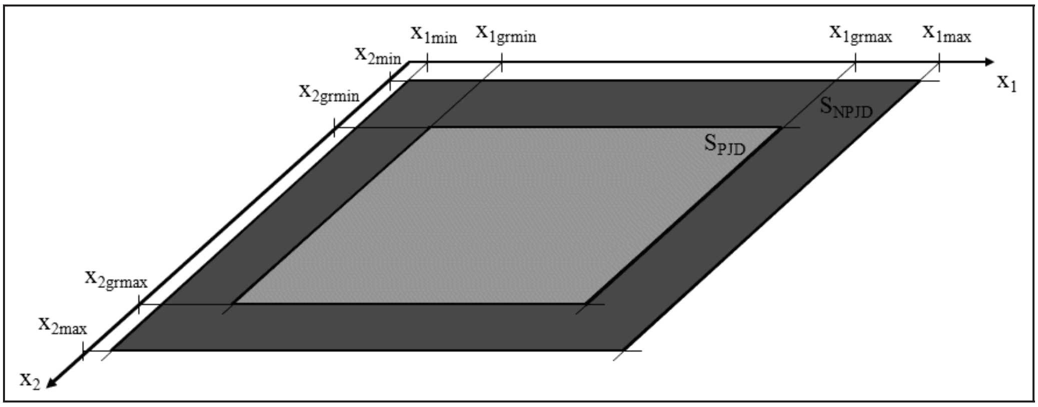

Fig. 5. The fields of the quality states of the system expressed in the R2 space of two independent features: SPJD – the field of the states of desirable quality of the system operation; SNPJD – the field of the states of undesirable quality of the system operation

For two independent features the exemplary position of the fields of the quality states of the system is presented in the Fig. 5.

5. The space of the safety states of the system

If the set of the cardinal features comprises the features which describe the state of safety of the system then it is possible to define, in R^n space of the system features, the field of secured states of the system, the field of emergency states of the system and the field of the states of unreliability of safety of the system. This R^n space is called the space of the safety states of the system.

It is said that the system is in the secured state when the values of the specified features of the system are between fixed boundary values in the specified period of time $t \subset [t_0,\ t_k]$ during the influence the definite levels of the forcing factors [16]. In the emergency state of the system the reliability of several system elements is decreased and the values of the features of these elements are outside the definite ranges [20]. The system is in the state of unreliability of safety when the value of one of the critical features, significant for the system, exceeds the fixed value [1].

The fields of defined above safety states of the system are obtained by introduction the partitioning of the feature domain according to the Fig. 6.

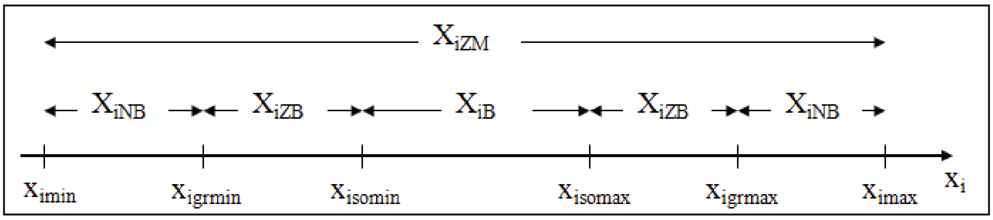

Fig. 6. The domain of the feature – the dimension of the space of the safety states of the system

The range of suboptimal values is corresponding to the secured states of the system, remaining part of the acceptable values is corresponding to the emergency states of the system and the range of unacceptable values is corresponding to the states of unreliability of safety of the system (20-22):

$$X_{iNB} = \langle x_{i\min}, x_{igr\min}) \cup (x_{igr\max}, x_{i\max} \rangle = X_{iND}, \tag{20}$$

$$X_{iZB} = \langle x_{igr\min}, x_{iso\min}) \cup (x_{iso\max}, x_{igr\max} \rangle = X_{iD} \setminus X_{iSO}, \tag{21}$$

$$X_{iB} = \langle x_{iso\min}, x_{iso\max} \rangle = X_{iSO}, \tag{22}$$

where:

X_{iNB} - the range of the values corresponding to the states of unreliability of safety of the system,
X_{iZB} - the range of the values corresponding to the emergency states of the system,
X_{iB} - the range of the values corresponding to the secured states of the system.

For two independent features the exemplary position of the fields of the safety states of the system is presented in the Fig. 7.

As a result of the analysis of the definitions of safety states of the system presented in different publications [17, 18] the expression of these states in the features space of the system was proposed.

Thus, it is said that the system is in the secured state when the values of all its features – the dimensions of the space of the safety states of the system are in the range of suboptimal values (23).

$$s_R(x_1, x_2, \cdots, x_n) \in S_B \Leftrightarrow \forall x_i \in X \wedge i = 1,2,\cdots,n; x_i \in X_{iSO}, \tag{23}$$

where S_B is the field of the secured states of the system.

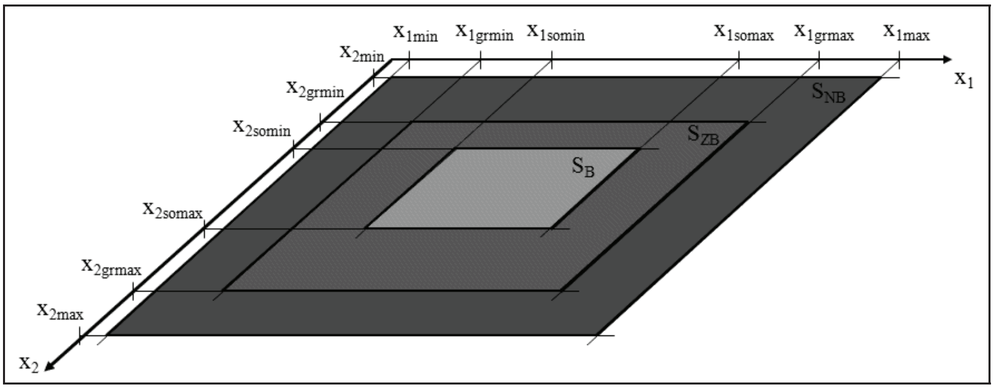

Fig.7. The fields of the safety states of the system expressed in the R2 space of two independent features: SB – the field of the secured states of the system; SZB – the field of the emergency states of the system; SNB – the field of the states of unreliability of safety of the system

The system is in the emergency state when the value of at least one cardinal feature – the dimension of the space of the safety states is in the range of acceptable values and is not in the range of suboptimal values and the values of all remaining cardinal features are in the range of suboptimal values (24):

$$s_R\left(x_1,x_2,\cdots,x_n\right)\in S_{ZB} \Leftrightarrow \exists X_k \subset X:\begin{cases} card(X)\geq card(X_k)\geq 1, \\ \forall x_i \in X_k : x_i \in X_{iD} \wedge x_i \notin X_{iSO,} \\ \forall x_j \in X \setminus X_k : x_j \in X_{iSO,} \end{cases} \tag{24}$$

where S_{ZB} is the field of the emergency states of the system.

The system is in the state of unreliability of safety when the value of at least one cardinal feature – the dimension of the space of the safety states is in the range of unacceptable values (25):

$$s_R\left(x_1,x_2,\cdots,x_n\right)\in S_{NB} \Leftrightarrow \exists x_i \in X \wedge i=1,2,\cdots,n; x_i \in X_{iND}\,, \tag{25}$$

where S_{NB} is the field of the states of unreliability of safety of the system.

6. Conclusions

On the basis of the considerations presented in the paper the following conclusions were formulated:

- the system state, as a point of the space of the system features, can belong to different groups of the system states depending on the type of space in which the state is expressed,
- on the basis of introduced characteristic values and ranges of features – the dimensions of the space of the technical states of the system the field of ability of the system, the field of inability of the system and the field of limited ability of the system were formulated,
- on the basis of introduced characteristic values and ranges of features – the dimensions of the space of the operation states of the system the field of optimal operation of the system, the field of stable operation of the system and the field of the system failure were formulated,
- on the basis of introduced characteristic values and ranges of features – the dimensions of the space of the quality states of the system the field of desirable quality of the system operation and the field of undesirable quality of the system operation were formulated,
- on the basis of introduced characteristic values and ranges of features – the dimensions of the space of the safety states of the system the field of secured states of the system, the field of emergency states of the system and the field of the state of unreliability of the safety of the system were formulated,
- thanks to the implementation of the defined spaces it is possible to uniformly describe the processes executed during the phase of operation and maintenance of the technical system.

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