

# Prognosis of Survivability of Deformable Elements as Problem of Inductive Modeling

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**Abstract.** *The task of the prognosis of survivability of deformable bodies with defects that appear and develop in them is stated as the problem of inductive modeling. The way of formalization of knowledge about a system and its defects, and identification of parameters of defects over time using the Gauss - Newton method is shown. Forecasting is realized by application of the fuzzy logical deduction on the knowledge base reflecting criterion of survivability adopted in mechanics of deformable rigid body.*

## Keywords

Survivability, prognosis, identification, damage, destruction, deformable system.

## 1 Introduction

The prognosis of survivability of deformable bodies based on the historical system behavior information obtained by means of monitoring and subsequent identification of defects, and also cause-effect relations circumscribed by the knowledge bases, is rather actual problem in space engineering and aircraft industry. Such formulation of problem requires creation of the approach combining inverse models of mechanics of deformable rigid body, knowledge about cause-effect relationships between behavior of defects in elements and survivability of entire system and methods of fuzzy deduction.

## 2 Theoretical Part

The inductive model of the prognosis of survivability of deformable systems consists of three consecutive tasks - formalization of knowledge about object, identification of defects according to results of observations and forecasting of survivability using the knowledge base and identified parameters of defects. The formalization of knowledge about object includes:

1. Creation of a vector  $W^* = \{w_i^*\}$ ,  $i = \overline{1, N}$ , which components are values measured in fixed points of object's surface (displacements, deformations).
2. Selection of the algorithm for resolution of primal deformation problem for the said system (finite element method). Solution of this task will allow creation of the vector  $W = \{w_j\}$  components of which are calculated values of the measured physical parameters in nodes  $j = \overline{1, M}$ .
3. Selection of the vector  $H = \{H_k\}$ , which consists of characteristics of damages in points on object's surface  $(x_k, y_k)$ ,  $k = \overline{1, K}$  (value of modulus of elasticity, thicknesses, yield stress, ultimate strength, coordinates of the nodes located at the damage boundaries).
4. Selection of the set of linguistic variables describing concept "survivability". Those variables can be one of the following: duration till destruction, level of residual durability defined (on loads, deformations etc.) by terms, membership functions and suitable scales.

The identification of defect's parameters  $H_k$  includes:

a) selection of criterion for definition of vector  $H$  as  $\Delta^2(H, t) = \frac{1}{N} \sum_{t=1}^N (W(t, H) - W^*(t, H))^T \cdot (W(t, H) - W^*(t, H)) \Rightarrow \min$ , where  $t$  – number of discrete sample;

b) creation of the sensitivity matrix of the object  $A_r(t, H) = \left\{ \frac{\partial w_j(t, H)}{\partial H_k} \right\} = \{ \overline{a_{jk}} \}$ ;

c) application of a Gauss-Newton algorithm [1] for identification of the vector's  $H$  components:  $H^{(i+1)} = H^{(i)} - [\Gamma(H^{(i)})]^{-1} \cdot B(H^{(i)})$ , where  $B(H^{(i)})$ ,  $\Gamma(H^{(i)})$  – gradient and Hessian accordingly,

$$B(H^{(i)}) = \frac{1}{N} \sum_{t=1}^N A(t, H^{(i)}) \cdot (W(t, H^{(i)}) - W^*(t)),$$

$$\Gamma(H^{(i)}) = \frac{1}{N} \sum_{t=1}^N A(t, H^{(i)}) \cdot A^T(t, H^{(i)}), \quad A(t, H^{(i)}) = \{ a_{ij} \}, \quad i = \overline{1, P}, \quad j = \overline{1, P}. \quad \text{The elements } a_{ij} \text{ are selected}$$

from  $\tilde{a}_{jk}$ , so that matrix  $A$  is both nonsingular and most informative [2]. The selected sets determine a choice  $\{x_i, y_i\}, \{x_k, y_k\}$  of coordinates of most informative measuring points and discretization nodes of defects distribution function. The information about parameters of defect obtained as a result of identification is converted to the linguistic fuzzy descriptive form.

The prognosis of survivability is performed:

1) by selecting algorithms of manipulation of the formalized initial knowledge and the knowledge obtained as a result of identification; creation of the knowledge base in the form implicative and functional laws (algorithms of the primal problem solution, destruction criterion, limitations on properties of defects),

2) by creation of the fuzzy knowledge base in the form of fuzzy linguistic rules, similarly to demonstrated in [3]. The formalized generalized variable “survivability” is used as an output variable. Identified parameters of defects or function from them are used as input variables.

The prognosis is performed using the fuzzy knowledge base, information about the defect, which is obtained from its observations during given time  $\Delta\tau \cdot N$  and by application of the algorithm of identification. The knowledge base look-up for obtaining a conclusion about the current state of the object is possible at the specific discrete time intervals  $\tau_l = l \cdot \Delta\tau \cdot N$ .

### 3 Conclusion

Examples of adaptation of the developed method for the prognosis of time till destruction of plates and shells with breaches occurred during exploitation are presented. Results of primal computations for preset damage dynamics are used as the input information. Relative inaccuracy of the prognosis of time of achievement of critical size of damage was determined as 0,1.

### References

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