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AUTOMATED APPARATUS-PROGRAM SYSTEM FOR EVALUATING THE STRENGTH OF A REDUCER SHAFT

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ABSTRACT

The paper deals with a design of automated system for studying the strength of a reducer shaft according to the probabilistic evaluation method concerning the examination of machine elements. The apparatus-program system is Windows-based with an opportunity for connection with program packages about a numerical study of objects and details according to the finite element method. The data about the studied objects are obtained by means of two ways, namely: directly from an integrated system for measuring parameters of details, which is worked in the mode of real time, or from files containing data about studied objects, that are received as a result of other examinations. The automated apparatus-program system is open for development in the following directions: addition of methods for evaluating various machine elements; expansion of control-measurable system with regard to different methods and systems for measuring the studied quantities.

KEYWORDS: reducer shaft, probabilistic evaluation method, automated control-measurable systems, analysis according to the finite element method

1. Introduction

In the process of operation many machine elements experience the action of alternating stresses in the time. Furthermore, the known methods for calculating the operational strength of machine elements allow to account for only the force loading with a constant character without accounting for its probabilistic variation. The stressed-and-strained state of shaft and of assembly is determined by physical-mechanical characteristics of their material by the values of external forces and moments, by the contact conditions of separate elements, by the distribution character of loading, etc.

All these indices have a probabilistic character and therefore the stresses provoked by them will also possess a probabilistic character.

In connection with the statements mentioned above, it is imposed the necessity for determining the fracture probability of shaft in the process of assembly operation to be specified as a criterion for assessment of the stress in the critical section of shaft.

2. Model and Design of Automated System

The construction of real input shaft from the reducer about rope electric hoist is shown in Fig.1.

Fig. 1. *Construction of real input shaft from the reducer about rope electric hoist.*

The paper deals with the reducer shaft tested by means of laboratory stand according to the joint project between Central Mechanical Engineering Institute-Sofia and BRV-TESMA-Gabrovo as the loading of tested shaft is given in Fig.2 [1].

On the basis of obtained data from the testing a numerical parametric model of this shaft has been developed by means of the finite element method, which allows the simulation of process and the transmission of torque. The model is made in the medium of COSMOSWorks – specialized application towards SolidWorks [2, 3], destined for solving tasks from mechanics of solid deformable body according to the finite element method as the solved task is from linear statics (Fig.3).

On the units of external cylindrical surfaces of splines, which are in contact with the left radial-axial bearing support (immovable), the following kinematical constraints are imposed: radial and axial zero displacements. On the surface of splines, which are in contact with the splines of central gear, zero angular displacements are imposed. On the surface of contact with the right radial bearing support, zero radial displacement is imposed.

On the external cylindrical surfaces of splines towards the clutch, zero radial displacement is imposed as this corresponds to the radial bearing support. On this surfaces of shaft splines, which are in contact with the splines of clutch, the torque M_{yc}=85 Nm is set.

The external cylindrical surfaces of splines (upper ones – according to the scheme), which are in contact with the central gear, are six in number and are loaded by the force P_1=1800 N that is parallel to the Y-axis. The surface of eventual contact of the shaft with the planet carrier is loaded by the force P_2=4200 N that is also parallel to the Y-axis.

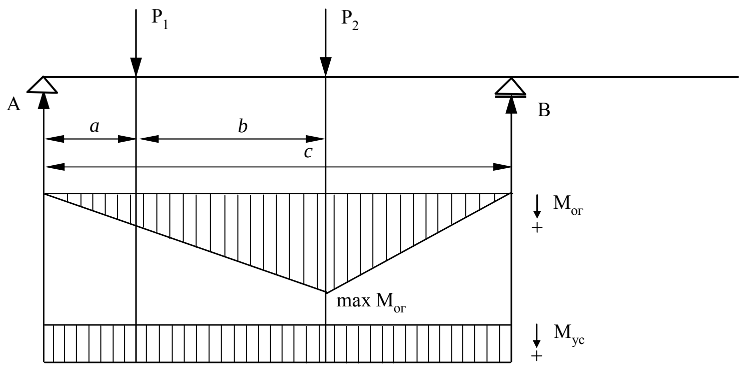
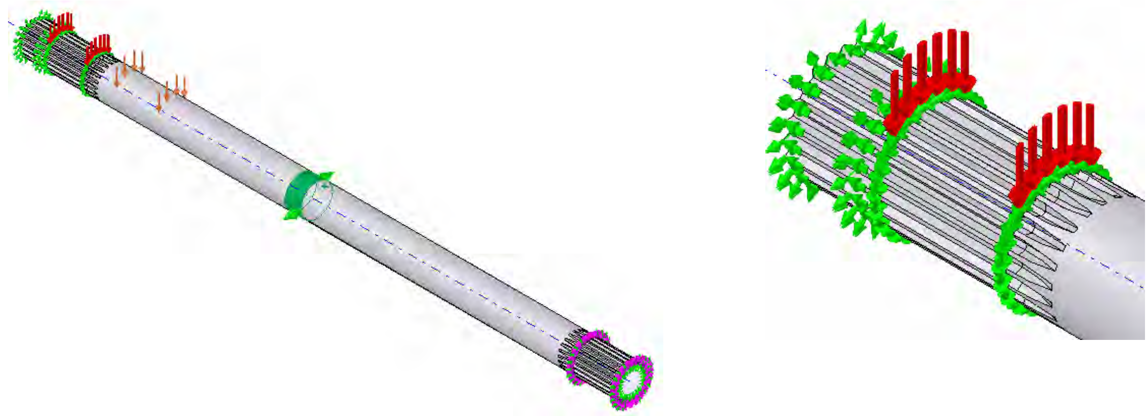


Fig. 2. *Loading of reducer shaft tested on laboratory stand.*

The developed finite-element model of reducer shaft affords an opportunity to determine the following stresses: the equivalent stresses as well the tangential stresses τ_{yc}, the bending stresses σ_{or}, the shearing stresses τ_{xz} and τ_{xy}, respectively [6].

The data obtained by the testing of shaft enter an automated system for studying the strength of reducer shaft according to the probabilistic evaluation method concerning the examination of machine elements [4].



a) b)

Fig. 3. *Model of the reducer shaft: a) loading and constraints of shaft; b) spline part of shaft that is in contact with the central gear.*

The apparatus-program system is Windows-based with an opportunity for connection with program packages about a numerical study of objects and details according to the finite element method (Fig.4). The data about the studied objects are obtained by means of two ways (Fig.5), namely: directly from an integrated system for measuring parameters of details, which is worked in the mode of real time, or from files containing data about studied objects, that are received as a result of other examinations.

For evaluating the mutual influence between acting forces as well the originated internal stresses, a program module about statistic and variance analysis is used.

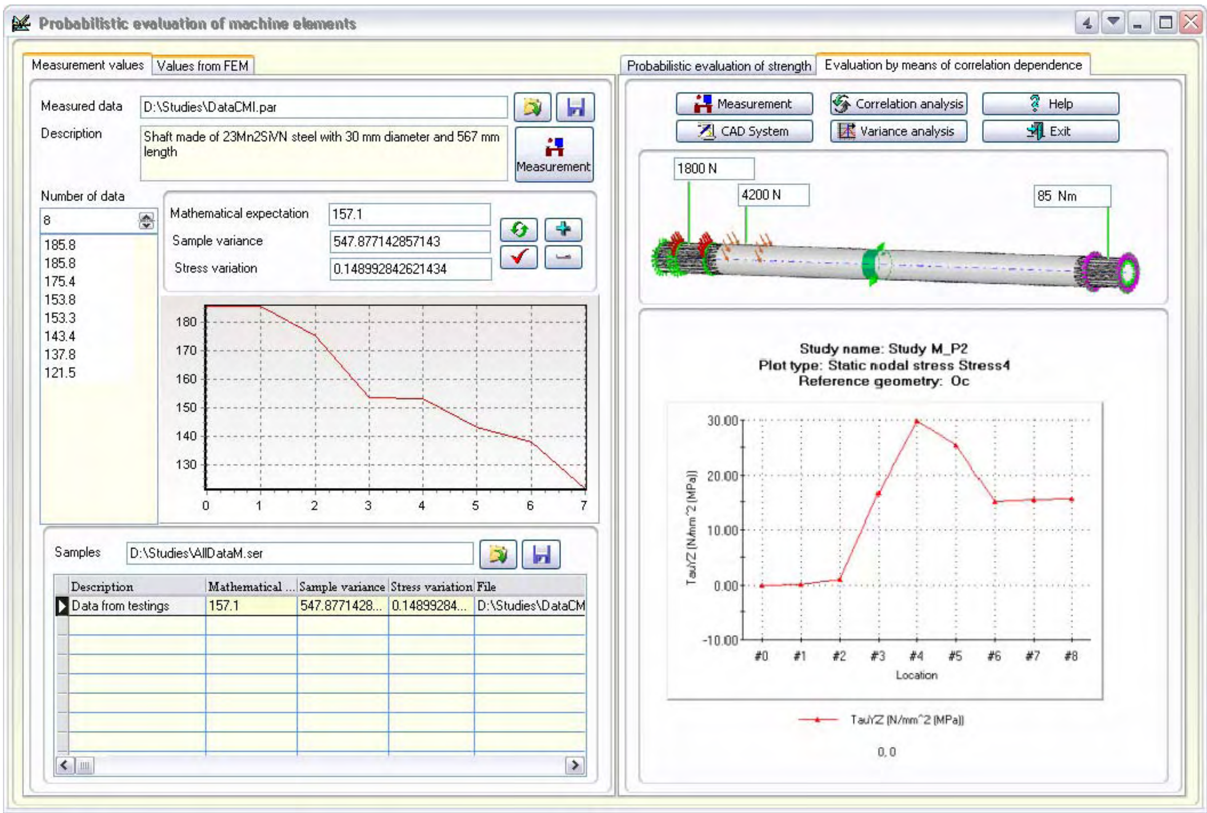


__Fig. 4.__ System for probabilistic evaluation of forces, moments and stresses originated in machine elements.

In the developed software product, two methodologies destined for evaluating the fracture probability of detail have been used.

By an application of the first methodology it is aimed to evaluate the machine element according to the following indices: coefficient of reserve over strength and probability of failure by means of the preliminarily accepted criterion for assessment, i.e. a stress in the critical section [7].

Since a series of loadings acts on the shaft, then the mathematical expectation of a stress in the critical section $M(\tilde{\sigma}_p)$ will be equal to the sum of mathematical expectations of stresses from each loading as follows:

$$M(\tilde{\sigma}_p) = \frac{\sum_{i=1}^{n} M(\tilde{\sigma}_{pi})}{n} \quad (1)$$

where: i is a set serial number of the acting force loadings on the element; n is a quantity (number) of these loadings; $M(\tilde{\sigma}_{pi})$ is mathematical expectation of the i-th sample.

Analogically it can be written:

$$M(\tilde{\sigma}_m) = \frac{\sum_{j=1}^{m} M(\tilde{\sigma}_{mj})}{m} \quad (2)$$

where: $\tilde{\sigma}_m$ and $\tilde{\sigma}_p$ are strength experimental and calculated characteristics of the machine element (the reducer shaft), respectively.

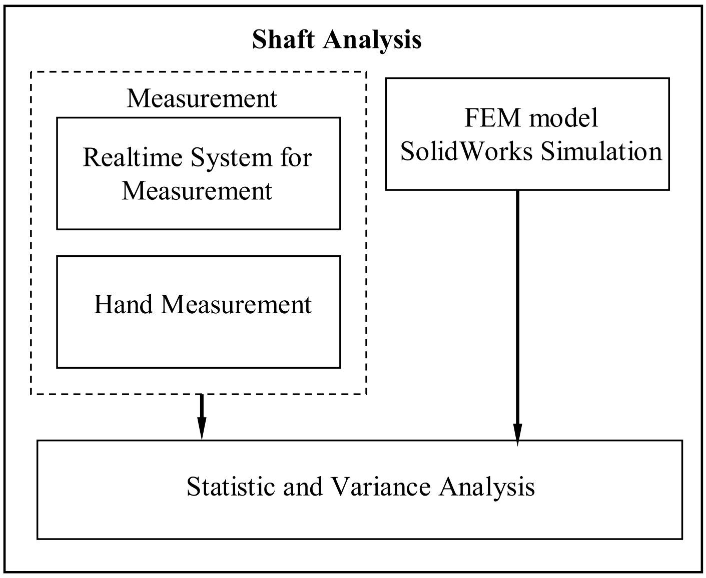


Fig. 5. *Organization of the system for shaft analysis.*

The variance of resultant stress is determined according to the following dependence:

$$D(\sigma_m)=\frac{\sum_{j=1}^{m}\left(\tilde{\sigma}_{mj}-M(\sigma_m)\right)^2}{m} \quad (3)$$

where: $\tilde{\sigma}_{mj}$ is the magnitude of j-th loading; m is a number of loadings; j is a set serial number of loading.

Analogically it can be written:

$$D(\sigma_p)=\frac{\sum_{i=1}^{n}\left(\tilde{\sigma}_{pi}-M(\sigma_p)\right)^2}{n} \quad (4)$$

Knowing the variance and the mathematical expectation, the variation coefficient of stresses can be determined as their relative characteristic in the following type:

$$\nu(\sigma_m)=\frac{\sqrt{D(\sigma_m)}}{M(\sigma_m)} \quad (5)$$

Analogically it can be written:

$$\nu(\sigma_p)=\frac{\sqrt{D(\sigma_p)}}{M(\sigma_p)} \quad (6)$$

The condition for non-fracture of element is worked on the following dependence [7]:

$$\tilde{u}=\tilde{\sigma}_m-\tilde{\sigma}_p>0 \quad (7)$$

where: $\tilde{u}$ is a function of strength; $\tilde{\sigma}_m$, $\tilde{\sigma}_p$ are strength experimental and calculated characteristics of the element.

From where it follows, that: $M(\tilde{\sigma}_m)>M(\tilde{\sigma}_p)$.

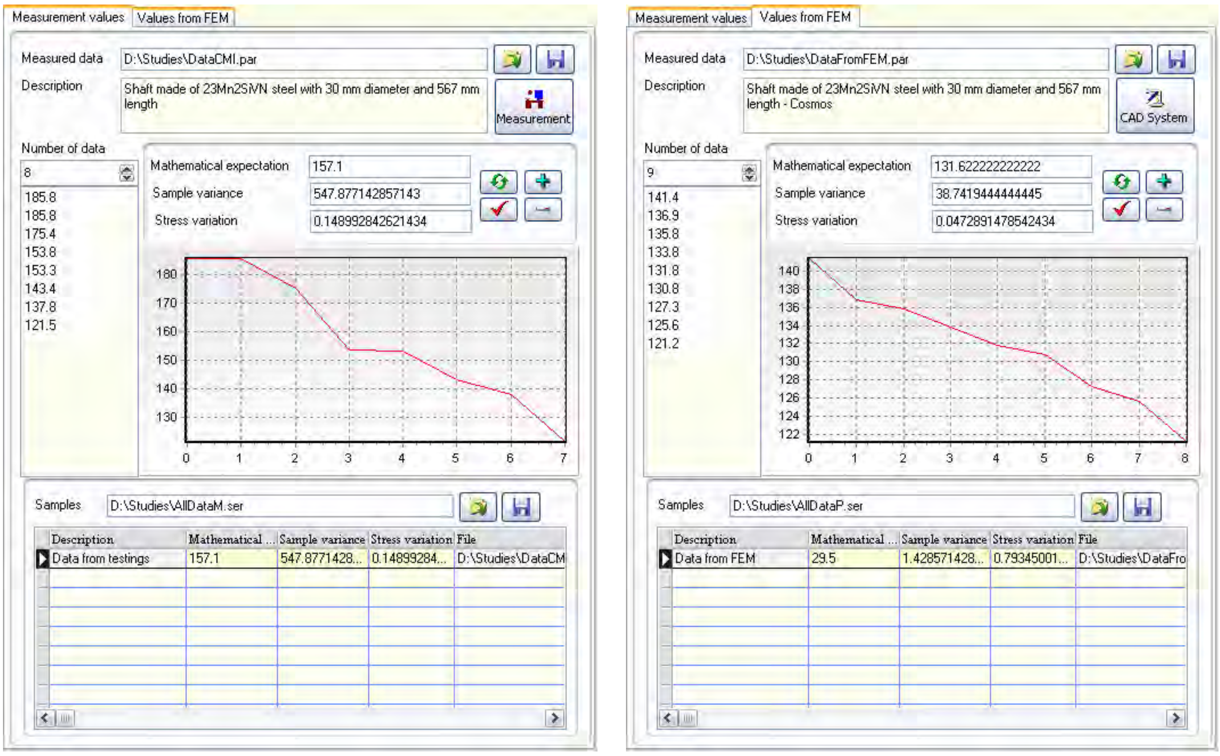
Therefore the coefficient of reserve over strength ξ can be determined by the following ratio and it has to possess a value, which is larger than unity:

$$\xi=\frac{M(\tilde{\sigma}_m)}{M(\tilde{\sigma}_p)} \quad (8)$$

Since the values of stresses obtained by experiment and calculations in the critical section have probabilistic character with normal law of distribution, then the fracture probability can be presented in the following type:

$$P(\tilde{u})=\frac{1}{\sqrt{2\pi\left[D(\sigma_p)+D(\sigma_m)\right]}}\cdot \int_0^{\infty} exp\left[-\frac{1}{2}\left[\frac{\left(u-M(\sigma_p)+M(\sigma_m)\right)}{D(\sigma_p)+D(\sigma_m)}\right]\right]du \quad (9)$$

In the developed programme (Fig.6) the data obtained during measurements from the testing of reducer shaft according to Fig. 2 have been introduced (Fig. 6.a) as well the data obtained by the finite-element model according to Fig. 3 (Fig. 6.b).



a) b)

***Fig. 6.** Data obtained during measurements from testing of reducer shaft (a) and data obtained by the finite-element model (b).*

After performing the calculations, the probabilistic evaluation of the machine element strength, i.e. the reducer shaft has been obtained (Fig.7), which yields a conclusion about the strength of detail in the corresponding studied ranges.

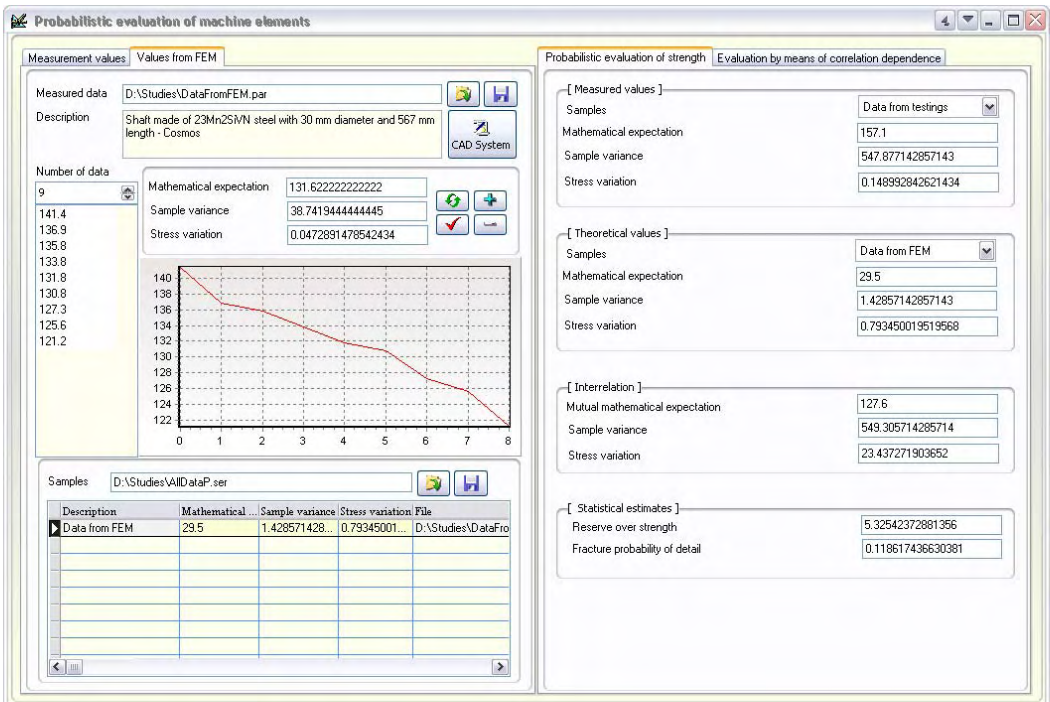


***Fig. 7.** Probabilistic evaluation of the strength of reducer shaft.*

The second methodology is based on synthesized mutual correlation dependence between the stresses and their originating forces as some constraints are accounted for.

The correlation function is generated by virtue of some type models whose parameters are adjusted depending on the properties of studied detail. The coefficients of correlation function are adjusted automatically by means of specialized software about adjustment of models, which works on the basis of heuristic algorithm for global optimization with accelerated convergence [5].

3. Conclusions

The developed apparatus-program system affords an opportunity for studying the strength of reducer shaft according to the probabilistic evaluation method concerning the examination of machine elements. The automated apparatus-program system is open for development in the following directions: addition of methods for evaluating various machine elements, expansion of control-measurable system with regard to different methods and systems for measuring the studied quantities.

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