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To cite this article: A S Kozlov et al 2018 J. Phys.: Conf. Ser. 1015 032080

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Development library of finite elements for computer-aided design system of reed sensors

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Abstract. The article is devoted to the development of a modern highly reliable element base of devices for security and fire alarm systems, in particular, to the improvement of the quality of contact cores (reed and membrane) of reed sensors. Modeling of elastic sensitive elements uses quadrangular elements of plates and shells, considered in the system of curvilinear orthogonal coordinates. The developed mathematical models and the formed finite element library are designed for systems of automated design of reed switch detectors to create competitive devices alarms. The finite element library is used for the automated system production of reed switch detectors both in series production and in the implementation of individual orders.

1. Introduction

The improvement of the existing automatics systems steadily leads to an increase of technical and metrological requirements for the main reliability indicators of the element base of switches, distributors and commuting relays, which, in turn, are an important part of automatic control systems. Such parameters of magnetically controlled contacts (reed switches) as contact’s speed, dynamic noise, rattling are provided due to the quality of the elastic elements (cores of magnetically controlled contacts) that are included in their composition [1, 2].

Reed sensors and relays (figure) by the combination of their characteristics and profitability in many respects surpass even semiconductor analogs, which making is widely used in automation devices.
Figure 1. Reed sensors: a – shorting contact; b – nonshorting contact; c – switch contact

Figure 1 (a, b, c) show shorting contact, nonshorting contact and switch contact respectively.

The main difference between reed relays and electromechanical relays is a large service life, which is caused by the absence of moving parts subject to wear and abrasion. Also, the intensity of controlled magnetic field and high contact’s speed make it possible to use this type of relay for switching chains of electronic blocks of high-sensitivity devices.

Another advantage of reed relays in front of other relay switching devices is the protection of the contact group from impacts moisture, dust and other unfavorable factors, which can lead to premature wear and failure of the relay.

A separate variety of high-voltage reed sensors is used in devices for relay protection of high-voltage lines. In this case in the design, there are arcing and damping devices that prevent the occurrence of vibration, and relay contacts bounce.

The increase in the requirements for reliability of alarm (fire and security) devices makes the issues of improving the quality of the contact cores of reed sensors relevant. The development of theoretical and experimental methods for analyzing new types of reed sensors for alarm devices has determined the relevance of the chosen topics.

2. Discussion and results

Today, it is absolutely obvious that the modern security system must meet the integral properties with respect to subsystems of members. In other words, it must have special technical and software means to implement interaction of the element base of the subsystems of the automatic control systems. This is possible through programming of logical chains: event - condition - action. The event, in particular, is the receipt of alarming information from security sensors and fire alarms. Possible ways to increase the efficiency of fire and alarm systems can be the development of methods for creating a new element base of sensors that are part of such systems.

In order to successfully solve the problem of designing a new element base of the reed sensors of the automatic control systems, it is necessary to conduct research in the development of mathematical models of statics and dynamics of sensitive elements of security and fire alarm devices [3].

The urgency of the development of a modern highly reliable element base of devices for security and fire alarm systems is particularly high when used in shipborne optical communication systems, as well as in specialized switching devices for automatics, in particular, at strategically important
facilities such as missile systems and atom stations. The possibility of using reed sensors in alarm devices on submarines and atomic reactors is due to insensitivity of reed switches to radiation.

At present, progress in the development of new switching devices of automatic control systems containing shell and plate elastic elements is connected with the use of the automated system of designing contact cores of reed sensors, based on modern machine-oriented calculation methods [4].

The reed sensors production of automatic control systems belongs to highly automated and precision technologies, which requires high qualification of working personnel and specialized technological equipment. Consequently, there is a need to create a computer-aided design reed plate and membrane element base [3, 5].

Obviously, the creation the library of finite elements in the annex to this element base of sensors and detectors of control systems will make it possible to apply it in the creation of highly reliable and competitive signaling systems.

Let us consider the elements of the first type, using a system of curvilinear orthogonal coordinates. In this case, in each node the vector of generalized nodal displacements will have 5 components - 3 components of the displacement vector and 2 angles of rotation, i.e.:

$$\{U\}^T = [u_1 u_2 u_3 \partial_1 \partial_2],$$

and the slewing nodes will take the form:

$$\partial_1 = \frac{1}{r} \frac{\partial u_3}{\partial \varphi} - \frac{u_2}{R_2}; \partial_2 = \frac{\partial u_3}{\partial s} + \frac{u_1}{R_1},$$

where $s, \varphi$ – meridional and circumferential curvilinear coordinates of the middle surface of the shell; $R_1, R_2$ – principal radius of curvature; $r$ – the radius of the shell in a section perpendicular to the axis of rotation.

In the general case, this element is an arbitrary quadrilateral on the middle surface of the shell. It uses normalized coordinate system $\xi, \eta$, on which the quadrangle is mapped. For this system, it gets:

$$s = \sum_{i=1}^{4} L_i(\xi, \eta)s_i;$$

$$r = \sum_{i=1}^{4} H_i(\xi, \eta)r_i + \sum_{i=1}^{4} H_{1i}(\xi, \eta)\frac{\partial r}{\partial \xi} + \sum_{i=1}^{4} H_{2i}(\xi, \eta)\frac{\partial r}{\partial \eta};$$

$$z = \sum_{i=1}^{4} H_i(\xi, \eta)z_i + \sum_{i=1}^{4} H_{1i}(\xi, \eta)\frac{\partial z}{\partial \xi} + \sum_{i=1}^{4} H_{2i}(\xi, \eta)\frac{\partial z}{\partial \eta},$$

where $L_i(\xi, \eta)$ - bilinear Lagrange polynomials; $H_i(\xi, \eta), H_{1i}(\xi, \eta), H_{2i}(\xi, \eta)$ - Hermitian cubic functions; $s_i, r_i, z_i$ - node values of the approximated functions.

Then the approximating functions take the form:
\[ L_i = \frac{1}{4} (1 + \xi_i^2)(1 + \eta_1); \]
\[ H_1 = \Phi_1(\xi)\Phi_1(\eta); \quad H_{ij} = \Phi_1(\eta)\Phi_2(\xi); \quad H_{2i} = \Phi_1(\xi)\Phi_2(\eta); \]
\[ \Phi_1(\lambda) = \frac{1}{4} (2 + 3\lambda_0 - \lambda_{30}); \Phi_2(\lambda) = \frac{1}{4} (\lambda_{30} + \lambda_{20} - \lambda_0 - 1); \]
\[ \lambda_0 \to \xi_0, \eta_0; \quad \eta_0 = \xi_0; \quad \lambda_0 \to \xi, \eta, \]

where \( \xi_i, \eta_i \) - the nodal values of the normalized coordinates.

To model the shells that have an arbitrary form of the meridian, their principal radii of curvature \( R_1, R_2 \) are determined by the formulas:
\[ r = r(s), z = z(s), \frac{dr}{ds} = \cos \theta, \frac{dz}{ds} = \sin \theta, \]
where \( \theta \) - the angle between the axis of rotation \( z \) and the normal to the middle surface of the shell.

In this case, the derivatives with respect to the normalized coordinates at the node points have the form:
\[ \left( \frac{\partial q}{\partial \lambda} \right)_i = \left( \frac{\partial q}{\partial S} \right)_i \left( \frac{\partial S}{\partial \lambda} \right)_i, \lambda \to \xi, \eta \]

(\( i = 1, ..., 4 \)).

When modeling shells of the canonical form, the radii of curvature and their derivatives are determined from known dependences.

There is a need to bring the common stiffness matrix to the same dimension with the coordinate transformation matrix, which requires the introduction of the sixth nodal displacement - rotation angle \( \psi \). Then stiffness matrix \([K_0] \) takes the form:
\[ k_{ij}^1 = \begin{cases} \gamma Eh \Delta, i = j; \\ - \frac{1}{3} \gamma Eh \Delta, i \neq j, \end{cases} \]

where \( E \) - the modulus of elasticity of the material, \( h \) - the thickness of the shell layer. In this case, the change in coefficient \( \gamma \) in the interval of \( 3 \times 10^{-3} \leq \gamma \leq 3 \times 10^{-1} \) practically does not affect the final result.

The disadvantages of the described element include the necessity of using the fictitious angle of rotation \( \psi \) and the low order of approximation of the tangential displacements.

Therefore, it is more promising to use a finite element of isoparametric type of a curvilinear quadrangle with nine axes in nodes. Then:
\[ \{U\}^T = [u_1 \frac{\partial u_1}{\partial \alpha_1} u_2 \frac{\partial u_1}{\partial \alpha_2} u_3 \frac{\partial u_2}{\partial \alpha_1} u_4 \frac{\partial u_2}{\partial \alpha_2} u_5 \frac{\partial u_3}{\partial \alpha_1} u_6 \frac{\partial u_3}{\partial \alpha_2}], \]

where \( u_i, i = 1, 2, 3 \) are the components of the displacement vector in the local coordinate system associated with the coordinate lines; \( \alpha_i, i = 1, 2, 3 \) - coordinate lines.

When assembling an ensemble, the components of the displacement vector of one of the elements are selected as basic. For an adjacent shell, the components of the node vector of displacement vectors are expressed through the basic ones taking into account conjugation of shells.

This approach makes it possible to improve the accuracy of the approximation of the geometry of the shell.
3. Conclusion

Thus, the formed library of finite elements of reed and membrane sensitive elements is designed for computer-aided design systems of reed switches and reed power contacts. It is established that when using the moment scheme of finite elements, it is possible to achieve the accuracy of calculations of deformations and voltage of sensitive elements of reed switches for 5–7% that is a good result.

Derived mathematically models can be used for computer-aided design systems in batch production and when implementing an individual order.

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