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Optimisation and Analysis of Microswitch Mechanical Structure

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Abstract: The text discusses the failure issues of the YBLXW-5 series micro switch concerning mechanical, electrical, and heating aspects, thoroughly investigating the contact bounce phenomenon and its structural optimization methods. By establishing statics and dynamics models, the dynamic characteristics of bounce were analyzed, and finite element simulation along with genetic algorithms was used to optimize structural parameters. The research results indicate that the optimized micro switch's bounce time decreased by 32.04%, and the maximum bounce amplitude reduced by 55.97%, significantly enhancing dynamic performance and contact reliability. This study provides a theoretical basis and practical guidance for the structural optimization and performance improvement of micro switches, which is of great significance for their stability, reliability, and safety in actual applications, while also promoting the development and application of micro switch technology.

Keywords: Micro Switch, Structural Optimization, Finite Element Simulation Analysis.

1. Introduction

The micro switch, as a key electrical control component, is widely used in fields such as industrial automation, household appliances, and aerospace. However, in practical applications, the micro switch often suffers from mechanical and electrical failures due to contact bounce phenomena, adversely affecting its reliability and service life. Contact bounce not only induces instantaneous overcurrent in circuits but also leads to issues such as contact wear and arc ablation, which, in severe cases, may even trigger equipment malfunctions. Therefore, researching the bounce phenomenon of micro switches and optimizing their structural design is of significant importance for enhancing their performance and reliability.

In existing studies, scholars have established mathematical models and dynamic simulation models for the bouncing process of micro switches to analyze the dynamic characteristics of bounce and propose various optimization methods. For example, optimizing spring design and material selection can effectively reduce contact bounce and improve the performance stability and lifespan of micro switches. Additionally, research has focused on optimizing contact materials and contact resistance, suggesting methods to enhance contact performance, such as using suitable contact materials and altering contact shapes to lower contact resistance and reduce contact wear[1]. However, existing studies still exhibit deficiencies in model accuracy, optimization algorithm efficiency, and the application of new materials, necessitating further exploration and improvement.

This paper takes the YBLXW-5 series micro switch as the research object, conducts an in-depth analysis of its bounce phenomenon, and proposes a structural optimization method based on finite element simulation and genetic algorithms[2]. First, by establishing the static and dynamic models of the micro switch, the dynamic characteristics of contact bounce are analyzed in detail. Second, utilizing ABAQUS and SIMPACK for combined simulation, a rigid-flexible coupling dynamic model is developed, verifying the accuracy of the model and deriving dynamic characteristic curves related to contact bounce. On this basis, aimed at reducing bounce time and minimizing bounce amplitude, an improved genetic algorithm is employed to optimize the main structural parameters of the micro switch. The research results indicate that the optimized micro switch shows a 32.04% reduction in bounce time and a 55.97% decrease in maximum bounce amplitude, significantly enhancing dynamic performance and contact reliability. This study provides a theoretical basis and practical guidance for the structural optimization and performance enhancement of micro switches, while also laying the foundation for future research in multi-physical field coupling simulation, new material applications, and intelligent design.The physical diagram and internal structure diagram of YBLXW-5 series micro switch are shown in Figures 1 and 2.

Figure 1. Actual Image of YBLXW-5 Series Micro Switch

Figure 2. Internal Physical Diagram of YBLXW-5 Series Micro Switch

2. The Establishment and Analysis of The Micro-switch Model

2.1. The structure of the micro switch

In this paper, the YBLXW-5 series micro switch is taken as the research object, and its theoretical model and simulation analysis are studied. The micro switch is suitable for 380/220V voltage, 0.79/0.14A current, operating temperature range from -5°C to 40°C, humidity not exceeding 50%. It is mainly composed of an operating mechanism, a shell and a contact, the operating mechanism is driven by a spring and a push rod, and the contact is a single breakpoint conversion element, which has the characteristics of small size, high sensitivity and strong reliability. The working principle consists of three stages: initial separation, operational contact, and release disconnection. The core component shrapnel is made of highly elastic metal materials, commonly used beryllium bronze, phosphor bronze and other copper alloys, relying on elastic deformation to achieve on-off, due to thin thickness and small stroke, it is easy to produce nonlinear characteristics[3].Therefore, when conducting dynamic analysis of micro switches, the elastic deformation of components cannot be neglected, and the dynamic analysis calculations should not be performed using a rigid contact system directly.A schematic diagram of the shrapnel structure is shown in Figure 3.

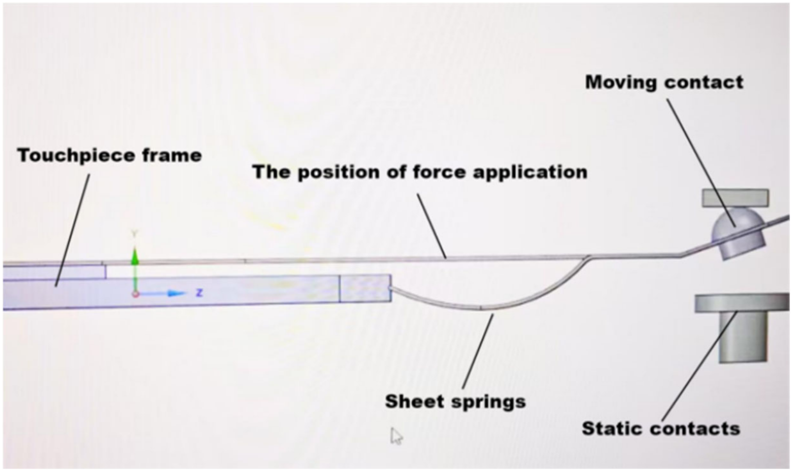

Figure 3. Schematic Diagram of the Spring Structure

2.2. Static Analysis of Micro Switches

Before studying the dynamic process of the system, it is also necessary to ensure that the static strength of the system meets the design requirements. For the micro switch in this paper, the compliance and bending stress in the static equilibrium state can be analyzed and calculated according to the cantilever thin beam model[4].

The leaf spring is divided into n segments starting from the fixed end, and each segment is a ds. Then the deformation energy of the micro segment is:

$$dU = \frac{M^2}{2EI} ds \tag{1}$$

The total deformation energy over the full length of the reed is:

$$U = \frac{1}{2EI}\int_s M^2 ds = \frac{1}{2EI}\left(\int_s M_1^2 ds + \int_{s'} M_2^2 ds + \int_{s'} M_1 M_2 ds\right) \tag{2}$$

where I—the moment of inertia of the reed section;

E – modulus of elasticity of the material;

M_1 - the cross-sectional moment when p_1 acts alone;

M_2 - the cross-sectional moment when p_2 acts alone;

$M = M_1 + M_2$ - the cross-sectional moment when p_1 and p_2 act at the same time

According to the model in this paper, p_1 is the contact force and p_1 is the operating force, when only the force p_1 is considered, the deflection generated at this time is d, the work done by the external force W_1 is by the conservation theorem of energy, the work done by the external force is equal to the deformation energy generated:

$$W_1 = \frac{1}{2EI}\int_s M_1^2 ds = \frac{1}{2} p_1 d = \frac{1}{2} c_1 p_1^2 \tag{3}$$

Under the action of external force, the compliance under the action of P_1 is:

$$c_1 = \frac{1}{EI}\int_s \frac{M_1}{P_1} ds \tag{4}$$

The cantilever of the reed can be divided into four parts, and the superposition principle can be obtained:

$$c_1 = \frac{1}{EI}\int_{l_1+l_2+l_3+l_4} \frac{M_1^2}{p_1} ds$$
$$= \frac{1}{EI}\left(\int_{l_1} \frac{M_1^2}{p_1} ds + \int_{l_2} \frac{M_1^2}{p_1} ds + \int_{l_3} \frac{M_1^2}{p_1} ds + \int_{l_4} \frac{M_1^2}{p_1} ds\right) \tag{5}$$
$$= c_{l1} + c_{l2} + c_{l3} + c_{l4}$$

Then the deflection of the free end of the reed under the action of P_1:

$$d = P_1\left(c_{l_1} + c_{l_2} + c_{l_3} + c_{l_4}\right) \tag{6}$$

The expression for P_1 is:

$$P_1 = \frac{d}{c_1} = \frac{d}{c_{l_1} + c_{l_2} + c_{l_3} + c_{l_4}} \tag{7}$$

According to the integral theorem of the curve, the expression of compliance can be obtained, and then the magnitude of P_1 can be obtained, and the magnitude of the external force P_2 can be obtained, the bending stress of the leaf spring is the maximum at the fixed end, and when the load is at the end of the free end, its maximum stress is:

$$\delta_{max} = \frac{Pl}{Z_m} \tag{8}$$

Z_m - the bending cross-section coefficient of the fixed end

According to the strength theory, in order to avoid the yield failure of the reed, the maximum stress of the system should be within the allowable stress of the sheet material. The sheet spring in this paper is beryllium bronze, and the tensile strength of the sheet is 940MPa after hot treatment, in order to ensure the working life of the system, it is designed according to the fatigue strength criterion, and the allowable fatigue stress should be:

$$[\sigma] \le 2/3\,\sigma_b = 626\text{MPa} \tag{9}$$

2.3. The dynamic model of the micro switch bounce

The contact spring structure of micro switch can be approximately regarded as the cantilever thin beam with a fixed total length of L at one end, wherein the free end has a concentrated mass m_1, and the structure is shown in Figure 4.

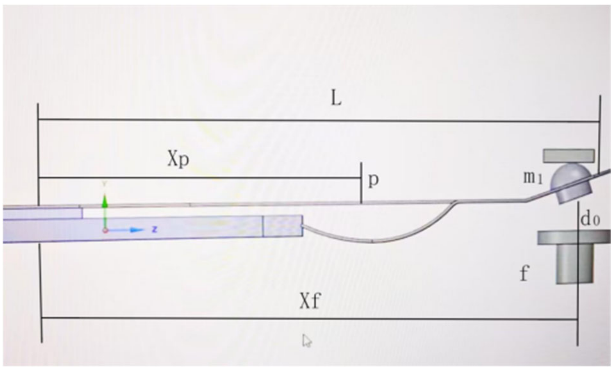

Figure 4. Mechanical model of the bounce of the microswitch

The cross-section of the spring of the micro switch is taken from the fixed end, and a section of micro element dx is taken at the horizontal direction x, and its mass is denoted as $\rho S dx$, under the condition that the push rod force P is acted on and the mass of the moving contact is considered, according to the theory of elastic mechanics, the dynamic equation of the micro switch is:

$$\begin{aligned}&[\rho S + m_1\delta(x - X_f)]\frac{\partial^2 y_1}{\partial t^2} + c_1\frac{\partial y_1}{\partial t} + EI\frac{\partial^4 y_1}{\partial x^4} \\ &= P\delta(x - X_p) - f\delta(x - X_f)\end{aligned} \tag{10}$$

where ρS —— the mass per unit length;

C_1 —— viscous damping coefficient of leaf spring;

f —— the collision contact force of the dynamic and static contacts;

$y_1(x,t)$ — the vertical displacement of the leaf spring at any time;

X_p —— position of the force;

X_m —— moving contact position;

$\delta(x)$—— the unit pulse function

The modal equations obtained by modal analysis are as follows:

$$M\ddot{q}_j + C_1\dot{q}_j + K_1 q_j = H_1 \tag{11}$$

In order to avoid the computational complexity of the higher-order partial derivative equation, the coefficients of the modal equation are brought into the spring mode shape to be simplified, and the collision contact force of the dynamic and static contacts is analyzed by the generalized Hertz contact theory, and the dynamic and static contacts in this paper are made of the same material, so the contact force can be expressed as:

$$f = \begin{cases} 0 & d_1 < 0 \\ K_H d_1^{\frac{3}{2}} + \lambda d_1 \left(\frac{\partial d_1}{\partial t}\right)^{\frac{3}{2}} & d_1 \ge 0 \\ K_H = \frac{2E}{3(1-\varepsilon)}\left(\frac{r_1 r_2}{r_1 + r_2}\right)^{\frac{1}{2}} & \end{cases} \tag{12}$$

Combined with the above and considering the boundary conditions and the initial conditions, the dynamic response of the micro switch under the action of the actuator force can be obtained [5-6]. Since the boundary conditions involve the initial values of partial differential equations, the finite difference method (FDM) can be used.

The partial differential equation is converted into a polynomial equation with a finite number of terms and solved, and the space step is Δx . then the differential representation of the system of partial differential equations with respect to the displacement boundary condition:

$$\begin{cases} |y_1|_{x=0} = 0 \\ \left|\frac{\partial y_1}{\partial x}\right|_{x=0} = \frac{y_1(x+\Delta x) - y_1(x)}{\Delta x} = 0 \\ \left|\frac{\partial^2 y_1}{\partial x^2}\right|_{x=L} = \frac{y_1(x+\Delta x) - 2y_1(x) + y_1(x-\Delta x)}{\Delta x^2} = 0 \\ \left|\frac{\partial^4 y_1}{\partial x^4}\right|_{x=L} = \frac{y_1(x+2\Delta x) - 4y_1(x+\Delta x) + 6y_1(x) - 4y_1(x-\Delta x) + y_1(x-2\Delta x)}{\Delta x^4} = 0 \end{cases} \tag{13}$$

In MATLAB, a function is written incorporating the initial conditions. Specifically, X_p =9.1mm, L =30.58mm, d_0 =1.1mm; m_1 =0.165g, m_2 =0.461g; P =5N; the density ρ =8250kg/m³ of the material used for the leaf spring, with an elasticity model of E =1.25e11N/m², and the elasticity model of the contact material being E =7.9e10N/m², Poisson's ratio c =0.37, contact stiffness k_1 =108N/m, contact damping c_3 =4.2×10³, spatial step size Δx =10-3mm, time step size Δt =10-4s, with a termination calculation precision of 10-6. The final result obtained shows that the displacement of the moving contact in the vertical direction varies with time, and the fitting curve of the solved results indicates that the position of the contact after the collision approximates a decaying sine function, which differs to some extent from the actual situation and requires further simulation analysis and calculation.

3. The Dynamic Analysis of The Soft and Hard Coupling of The Micro-movement Stroke Switch

3.1. Introduction to ABAQUS and SIMPACK co-simulation software

This article introduces the ABAQUS and SIMPACK co-simulation software. ABAQUS is a powerful finite element analysis software that supports multiple material models and multiphysics coupling analysis, and automation functions simplify the solution of complex problems, which is widely used in industry and research. SIMPACK is a kinematics and dynamics simulation software for electromechanical systems, which uses recursive algorithms and relative coordinate system modeling to analyze the performance of complex mechanical systems, and achieves efficient, stable and accurate rigid-flexible coupling analysis with ABAQUS co-simulation. Both belong to Dassault, with high interface coupling and good model compatibility, which jointly improves simulation efficiency and accuracy.

3.2. Establishment of the soft and hard coupling model for micro-movement travel switches

According to the above analysis, the micro-motion travel switch has nonlinear dynamic characteristics, and if the fully rigid structure is used to simulate, it cannot reflect the change of reed flexibility and cannot meet the accuracy requirements required for analysis. Therefore, when modeling the dynamics of the micro-travel switch, it is necessary to flexibly process the reeds [7-8] to form a rigid-flexible coupling dynamic model for analysis.

The rigid-flexible coupling model needs to establish a flexible body and a rigid body respectively, and the establishment process is shown in Figure 5. The Fbi file is then imported into SIMPACK, assembled with a micro-travel switch, and a fixed articulation is established to apply a load element.

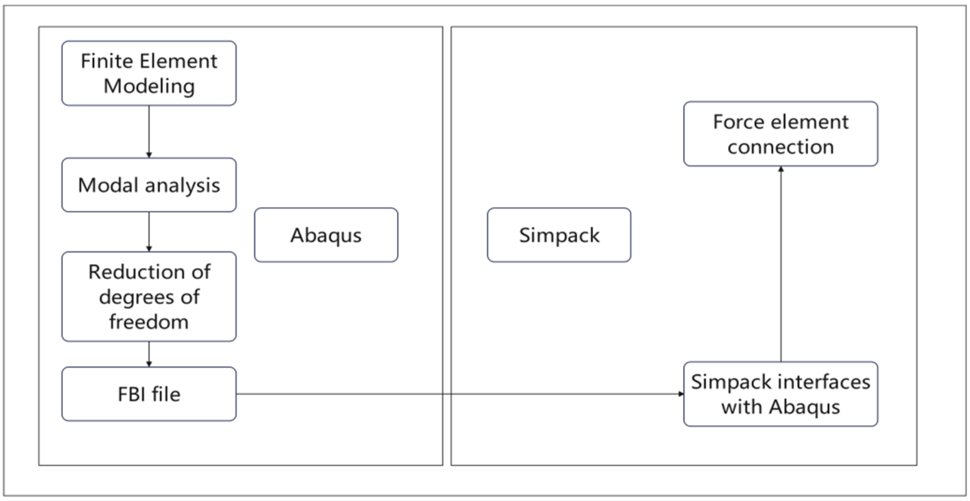

Figure 5. Rigid-flexible coupling model establishment process

3.2.1. ABAQUS flexible body establishment

As shown in Figure 6, the reed is imported into the ABAQUS software as a part type, and the unit coefficient is kept as m by default, so as to clarify the reed installation method, force action area, and moving contact movement. Reference points are established in the reed mounting hole setting and force action area, and the coordinates of the reference points are (-0.00227, 0.00163, -0.00397) and (-0.00227, 0.00213, 0.0181).

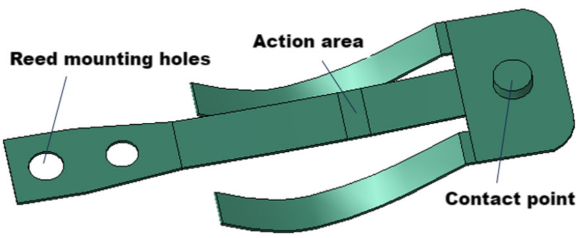

Figure 6. ABAQUS model import

In the ABAQUS Constraint Manager module, select the coupling coupling unit, select the reed mounting hole reference point and the force action area reference point for the master node, and select the corresponding face from the node. Figure 7 shows the coupling unit.

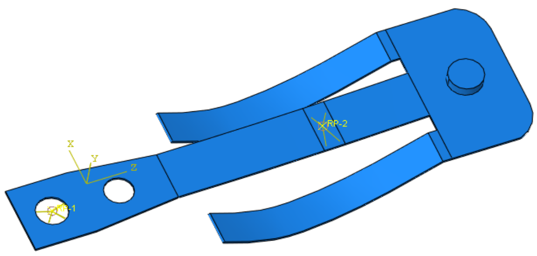

Figure 7. Coupling Unit of Master-Slave Nodes

To ensure the accuracy of the model, the cell size is 0.4 mm and the total number of meshes is 15,600, as shown in Figure

8.

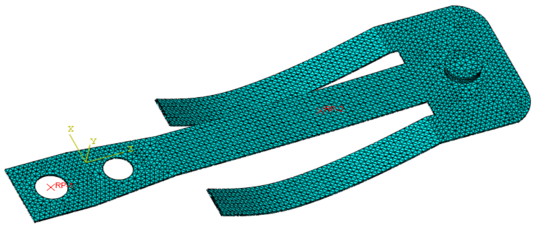

Figure 8. Grid partitioning effect diagram

The reed material was QBe2 (C17200) beryllium bronze, with a density of 8230 kg/m3, an elastic modulus of 134 GPa, and a Poisson's ratio of 0.275 [9], and two analysis steps of frequency and substructure generation were established. When creating a constraint, you need to constrain the 6 degrees of freedom of the master node in the frequency analysis step, and then release the 6 degrees of freedom of the master node in the substructure generation analysis step and submit it for solution to obtain the flexible body Fbi file of the reed.

3.2.2. Establishment of SIMPACK rigid-flexible coupling model

In SIMPACK, a flexible body refers to a structure that generates internal strain according to the load during movement and produces a change in shape that is in line with the actual situation. The flexible body used in this paper is mainly the reed in the micro switch.

The rigid-flexible coupling model established in SIMPACK is as follows:

First, import the rigid body parts of the micro switch into the SIMPACK, and then create a new body as the flexible body, the Type is LinearFlex, and the Flexbody input selects the flexible body Fbi file of the reed, so that the flexible reed generated by ABAQUS is imported into SIMAPACK, as shown in Figure 9.

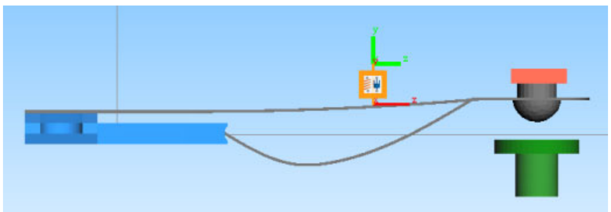

Figure 9. Micro switch rigid-flexible coupling model

Finally, it is necessary to establish a fixed hinge between the spring plate and the installation seat, and to create a load force element at the force application reference point, as shown in Figure 10.

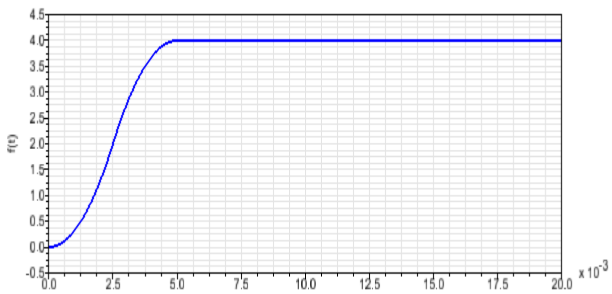

Figure 10. Load-Displacement Curve

The 199-gauge polygonal contact contact element was used to establish the contact between the reed moving contact and the contact, and the contact between the reed and the mount. The friction coefficient is set to 0.1, and SIMPACK automatically calculates the surface contact stiffness and contact depth according to the material parameters of the component, and the contact principle is as follows:

From the point of view of a many-body system, the polygon contact is like an ordinary force element. It is not much different from the conventional modeling method, but the geometry of the model can be approximated as a topological relationship composed of irregular polygons, where the nodes connected between the polygons are defined by the Euclidean spatial position coordinates.

Assuming that the surface of the contact is covered by a thin elastic layer with a thickness of b, the contact force is solved by the elastic foundation model, and the tangential stress in the elastic layer is ignored, and the relationship between the contact area A and the pressure pn is

$$p_n = A\frac{K}{b} \tag{14}$$

where: K is the modulus of elasticity, u is the Poisson's ratio, and its modulus of elasticity K can be expressed as

$$K = \frac{1-u}{(1+u)(1-2u)}E \tag{15}$$

where E is the Young's modulus. For homogeneous elastomers, the contact stiffness c is:

$$c = \frac{K}{b} \tag{16}$$

It can generally be regarded as the contact stiffness c between two contacts in tandem form, expressed as:

$$c_s = \frac{c_1 c_2}{c_1 + c_2} = \frac{1}{b_1 / K_1 + b_2 / K_2} \tag{17}$$

If there are n contacts, then the normal contact force Fn of the nth contact element is:

$$F_n = k_c A_{eff} d_n \tag{18}$$

In the equation: Aeff represents the effective contact area; dn refers to the contact depth of this contact unit. In the SIMPACK solving settings, the calculation time is set to 0.02s, and the sampling frequency is set to 8000Hz to ensure sufficient output of data and to avoid missing key details during the operation process. The solver defaults to SODASRT 2, and the software will automatically adjust the solving step size based on the solving status.

3.3. Results of kinetic analysis

After processing the simulation result data, the velocity displacement curve at the moving contact node 22 and the contact force curve of the moving contact were obtained. As shown in Figures 11 to 13, the total travel of the moving contact is 1.26 mm, the dynamic and static contacts initially made contact at 2.5 ms and reached a stable contact state at

6.25 ms, with a bounce time of 3.75 ms. The displacement curve exhibits six distinct peaks during the bouncing period, indicating that the moving contact underwent six collisions and bounces, which correspond to the variations in the velocity and contact force curves. The maximum speed during the bouncing process of the moving contact is 1.8 m/s, the maximum contact force is 47 N, and the final stable contact force is 1.92 N.

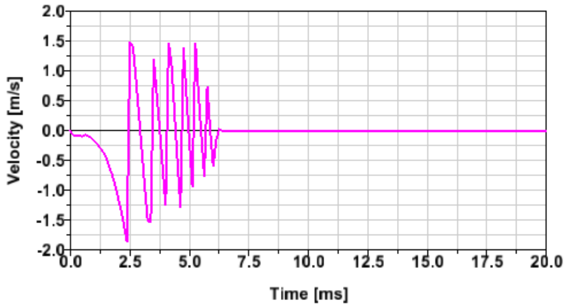

Figure 11. Variation of moving contact velocity

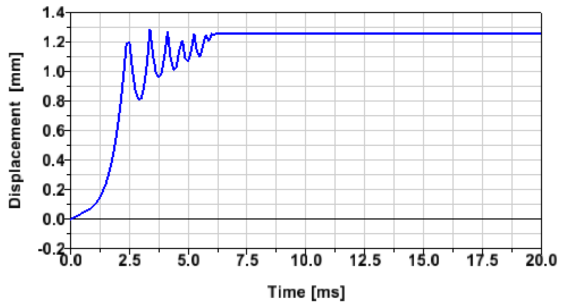

Figure 12. Moving contact displacement

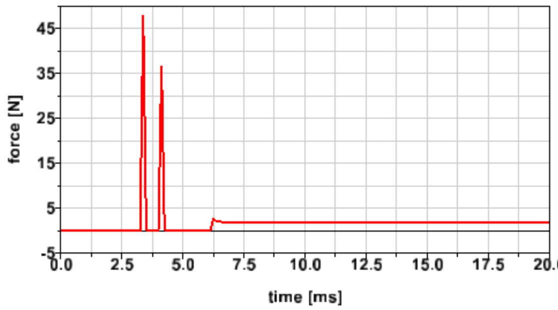

Figure 13. Diagram of the results of the contact force analysis

4. Optimization of Micro Switch Structure

4.1. Introduction

Optimized design is a technique that improves existing designs through a systems approach that aims to improve efficiency, performance, or reduce costs while embodying innovative thinking. Widely used in engineering, science, and everyday life, it involves multidisciplinary knowledge and is an important tool for driving innovation and competitiveness.

This paper focuses on the structural optimization design of micro switches by using the improved genetic algorithm. By taking the main structural parameters as the optimization variables, establishing the objective function and combining the constraints, the optimization method is used to solve the optimal solution of the parameters, so as to suppress the contact bounce phenomenon and improve the product performance.

4.2. Genetic algorithm is used for structural optimization

Genetic algorithms (GA) is an optimization algorithm based on natural selection and genetic mechanisms, which realizes the optimization of problems by simulating the process of biological evolution. The core idea is to gradually optimize the population through selection, crossover and mutation operations, and finally find the optimal solution or quasi-optimal solution [10].

In this paper, an improved genetic algorithm was used for structural optimization [11].

(1) Variables for optimal design: There are 6 main parameters, which are set to x1, x2, x3, x4, x5, and x6, and these six parameters are: In order to make the design variables more realistic and improve the computational efficiency of the optimization process, the range of these parameters is given as follows:

$$\mathrm{Gen} = \{x_1、x_2、x_3、x_4、x_5、x_6\} = \{l_2、l_3、b_1、h、\Delta、r\} \tag{19}$$

$$\begin{cases} 0 < l_2 < 10mm \\ 0 < l_3 \leq 25mm \\ 0 < b < 15mm \\ 0.1mm < h < 0.5mm \\ 30mm < \Delta < 40mm \\ r \geq 1mm \end{cases} \tag{20}$$

(2) Constraints

In order to speed up the convergence process of searching for the optimal solution and obtain a reasonable and reliable optimal solution, combined with the action characteristics of the micro switch, the following constraints are imposed on the bounce process of the micro fast shutdown:

a. The leaf spring should meet the stiffness design requirements, and the stiffness of the reed can be inhibited by the contact bounce theory, but the stiffness of the reed will be accelerated by excessive rigidity. According to the actual production experience, the stiffness of the micro switch reed is valued, $0.5N/mm < k = \frac{3EI}{L^3(1-\mu^2)} < 1N/mm$.

b. In order to ensure the non-linear variation law during the action process of the micro switch and the adaptability of the design variables to the micro switch body, the length of the leaf spring should not be too long, and the main length should satisfy $10mm < l_1 + l_2 < 20mm$; the width-to-thickness ratio should meet $20 < \frac{b_1}{h} < 50$.

c. To ensure stable contact of the micro switch, the final stable contact force should not be too small, $F > 0.5N$.

d. According to strength requirements, the maximum stress on the leaf spring should be less than the required stress, and the constraint equation is

$$\frac{6Pl_2}{b_0 h^2} - [\sigma] \leq 0 \tag{21}$$

3. Establishment and transformation of objective functions

The objective function, also known as the evaluation function, is to suppress the contact bounce phenomenon in the working process of the micro switch structure. From the analysis in Chapters 3 and 4, it can be seen that the influence on the contact bounce phenomenon of the microswitch is mainly evaluated by five main variables in the contact collision, and they affect each other [12].The degree of harm caused by the bounce of the tentacle is mainly reflected by the bounce time [13],When the bounce time of the contact bounce system decreases, the maximum velocity of the system increases, and it can be seen from the kinetic energy theorem that the kinetic energy before the contact collision in the system increases, and the impact force at the moment of the collision of the dynamic and static contacts increases. Although the impact force increases, the stiffness of the reed also increases, making it more difficult for the contact to collide repeatedly due to the impact force, and the bounce amplitude of each collision is also reduced. Therefore, the objective function of genetic optimization is determined as:

$$minf(x) = [t, d_{max}] \tag{22}$$

For multi-objective optimization problems, there is often no optimal solution, and the weight of each objective needs to be judged. Generally, it is transformed into multiple single-objective optimization problems by linear weighting and expressed by fitness function. The better the adaptability of the target in the population, the greater its moderation value [14].In order to improve the iterative efficiency in the optimization calculation process, the proportional method is used to perform the linear weighting of the moderate function, and the moderate function is transformed by the objective function and the moderate value is generally non-negative, then the moderate function in this paper is:

$$P(x) = \omega_1 \frac{t(x)}{t_0} + \omega_2 \frac{d_m(x)}{d_{m0}} \tag{23}$$

where ,$\omega_1 + \omega_2 = 1$,t_0, d_{m0} is the initial value of the pre-optimization sub-target.

4. Analysis of results

According to the operation steps, set the running parameters: the coding type is binary, the initial population size is $M = 50$, the maximum number of iterations is 100 times, the cross generalization, the mutation probability is , and the coding length is 25. The solution is solved in the GA toolbox in MATLAB, and the output results are shown in Table 1.

Table 1. Optimization results

Name		Before optimization	After optimization	Magnitude of change
Bounce time	t/ms	3.750	2.549	-32.04%
Maximum bounce amplitude	d_{max}/mm	0.069	0.030	-55.97%

After optimization, the initial kinetic energy at the moment of contact of the optimized contacts increases, leading to an increase in the instantaneous impact force. Generally, the greater the impact force, the more intense the bouncing process of the micro switch. However, after optimization, the stiffness of the micro switch's spring significantly improves, reducing the spring's ability to repeatedly make contact between the dynamic and static contacts, and thereby decreasing the impact reaction force after each contact. Consequently, the bouncing time and maximum bouncing amplitude of the optimized micro switch decreased by 32.04% and 55.97%, respectively; the vibrations after collision became more stable, and the intensity of bouncing was effectively reduced.

5. Conclusions

In this paper, the YBLXW-5 series micro switch is taken as the research object, and the bouncing phenomenon and structural optimization problem are studied, and the following results are obtained: through static and dynamic modeling and simulation analysis, the dynamic characteristics of contact bounce are revealed, and the energy dissipation mechanism and influencing factors in the bounce process are discovered; Using the joint simulation of ABAQUS and SIMPACK, the dynamic model was established, the structural parameters were optimized, and the bounce time was reduced by 32.04% and the maximum bounce amplitude by 55.97%, which significantly improved the dynamic performance. The effectiveness of genetic algorithm in multi-objective optimization is verified. The research provides a theoretical basis and practical guidance for the performance optimization of micro switches, which is helpful to improve their stability and reliability.

Future research can further explore optimization algorithms (e.g., particle swarm optimization, ant colony optimization), new materials (e.g., shape memory alloys, graphene), multiphysics coupled simulation (e.g., thermal-structure, electrical-thermal coupling), and performance research and intelligent design and monitoring under extreme working conditions, so as to promote the development of microswitch technology and expand its application fields.

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