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A robust solution for hesitate phenomenon in pick up process of aerospace electromagnetic relay

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Abstract As for aerospace electromagnetic relay (AEMR) which is of small batches and having difficulty in automatic production, the uncertainty phenomenon is remarkable due to excessive manual work involved in the assembly and adjustment processes. This kind of uncertainty may increase the coil voltage difference (CVD) caused by hesitate phenomenon in the pick up process of AEMR. Taking a certain type of AEMR for example, the CVD problem in the actual producing process has been studied in this paper. The primary cause of this issue, two-steps of armature motion (namely hesitate phenomenon) in the pick up process, has been found by analyzing the matching characteristics of electromagnetic and mechanical torques of AEMR. Through the optimization of the matching characteristics, the two-steps of armature motion problem is solved by robust design of the return reed which is a key part of AEMR. The validity of this research has been proved by the comparison of characteristics of AMER before and after the optimization.

1. Introduction

Aerospace electromagnetic relay (AEMR) is a type of high-performance relays which is sealed by a metal shell using a fusion welding method. AEMR has advantages of high conversion depth, multi-channel synchronous control, and strong ability of anti-jamming capability, which cannot be replaced by solid electronic devices. Therefore, it has played important roles in insulation, signal transmission, and power switching of high-reliability-requirement situations including aerospace, national defense, etc.

The production batch of AEMR is relatively small due to special application requirements, and together with the compact structures, an automatic process (especially the assembling process) would be in great difficulty. Excessive manual work involved in the production process results in remarkable uncertainty of product characteristics. Taking the 1/2 crystal cover AEMR ($21\ \text{mm} \times 11\ \text{mm} \times 11.5\ \text{mm}$) discussed in this paper for an example, over half of the products in the assembling process have the problem of high coil voltage difference (CVD) and large dispersion. The CVD means the value difference of two coil voltages corresponding to the different action time of two unsymmetrical transition contacts during the slow increment of the coil voltage. The phenomenon occurs mainly in the assembling process. If the voltage difference is over a certain value, the AEMR is proved to have defects. High

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CVD may result in serious arc erosion while relays operate with load, and would affect the performance of the whole batch of AEMR greatly.

For the uncertainty problem of electromagnetic relay (EMR), Lu and Jin[1] took pick up voltage as a random variable, and established a calculation model of unqualified probability of EMR. Su and Lu[2] proposed a pick up reliability theory of EMR, set the minimum of operating voltage as "strength" and tested pick up voltage as "stress", and then built a mathematic model that could be used in electromagnetic system optimization design.[3] To solve the size uncertainty problem of EMR caused by manufacturing, a "stress-strength interference" theory was introduced into tolerance design in Ref. [4], and a method for tolerance design of EMR based on matching characteristics of electromagnetic and mechanical forces was proposed. To improve the dynamic fusion welding phenomenon of automobile relay in the process of breaking excitation current in motors, a robust design with internal-external orthogonal experiment was adopted by taking over-travel, contact material, coil voltage, and coil suppression component as controllable factors, while contact surface topography and breaking current as noise factors.[5] Yang[6] took stress relaxation, contact press, and reed size as random variables, and studied the reliability optimization of reed in constant section and arbitrary shape using a simplex method. Weng et al.[7] adopted the Taguchi method to optimize the electromagnetic system of a linear antenna array.

For EMR, scholars did a lot of research works in the fields of contact arc[8–10] and optimization design,[11,12] but the uncertainty problem of EMR caused by machining dispersion attracted less attention to. The CVD problem researched in this paper has not been reported till now.

Taking the 1/2 crystal cover AEMR for example, this paper studies the CVD problem and its dispersion by analyzing matching characteristics of electromagnetic and mechanical torques. The results prove that the primary cause of this issue is a two-steps phenomenon of armature motion in the pick up process of AEMR, which is caused by the bad matching characteristics of electromagnetic and mechanical torques. Based on the analysis, the return reed is recognized as a key part of matching characteristics optimization and two-steps-problem solutions. Then an orthogonal experiment is adopted to optimize the parameters of the return reed. The simulation results and products testing outcome before and after the optimization also have been compared.

2. Analysis of matching characteristics

Fig. 1 shows the inner structure of a certain type of AEMR studied in this paper, which has a nominal operating voltage of DC 28 V and contains two sets of transition contacts. Ideally, two transition contacts should be completely symmetrical, which makes the mechanical torque curve consist of four parts, as shown in Fig. 2.

Segment "*a*" is provided by the return reed; segment "*b*" by combination of the return reed, the normally open (NO) fixed reed, and the moving reed; segment "*c*" by combination of the return reed and the moving reed; segment "*d*" by combination of the return reed, the moving reed, and the normally closed (NC) fixed reed.

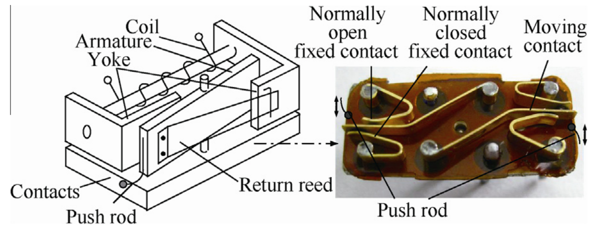

Fig. 1 The 1/2 crystal cover AEMR.

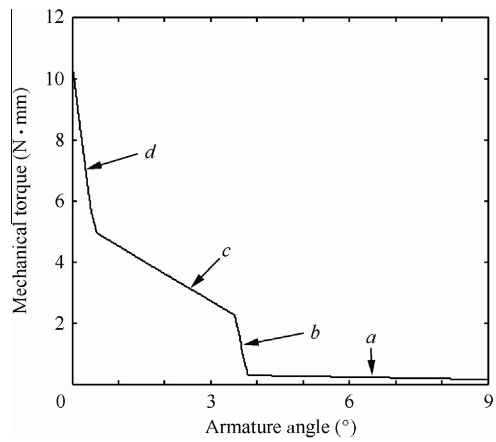

Fig. 2 Mechanical torque curve.

For a relay with this mechanical structure, the asymmetry of two sets of transition contacts is the essential reason of the CVD problem, but generally the influence of this kind of asymmetry is not very significant. It is considered that the two-step phenomenon of armature motion in the pick up process has enlarged the influence of asymmetry on the CVD.

In order to verify conjecture mentioned above, a simulation model of AEMR is established (Fig. 3), and according to the real adjustment process of this AEMR, the matching characteristics of electromagnetic and mechanical torques under certain coil voltages are simulated.

During simulation, the coil voltage increases slowly from 0 V. Meanwhile, the armature angular velocity is monitored to stop the increment of the coil voltage when the armature begins to rotate. The simulation results are shown in Fig. 4. The electromagnetic torque is lower than the mechanical torque at the initial time. The armature keeps static until the coil voltage increases to 9.1 V, and then the electromagnetic torque is higher than the mechanical torque. The armature begins to rotate, and the coil voltage keeps constant. Because of the high gradient of segment "*b*" in the mechanical curve (shown in Fig. 2), the electromagnetic torque cannot overcome the mechanical torque, as shown in Fig. 4(b). Thus, the armature stops rotating. Then the coil voltage is increased gradually from 9.1 V. It is found that when the coil voltage increases to 15.9 V, the electromagnetic torque exceeds mechanical torque once again, and the armature continues to rotate until moving to the end position.

In the pick up process, with the coil voltage increasing slowly, the armature begins to rotate but cannot move to the end position until the coil voltage increases to the value where