Application of Uniform Design on Improvement Design of Detector Slides in Switch Machine system

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Abstract

The purpose of this paper is to present the use of uniform design of experiments method in improving the von Mises stress of the detector slides in the switch machine. Four system parameters of the detector slide are selected as the control factors to be improved. Uniform design of experiment is applied to create a set of simulation experiments. Applying ANSYS/Workbench software, the finite element modeling is investigated and the von Mises stress of each detector rod is calculated under fatigue testing. From the numerical results, the best detector slide of all the experiments which causes the smaller von Mises stress is selected as the improved version of design.

Keywords: **Uniform design, Detector slide, ANSYS/Workbench, von Mises stress**

Introduction

Railway turnout consists of switch machines and crossings with specific complexity which is exposed to several defects. When the train through the turnout area, the safe and reliable operation of switch machines and crossings must be assured by high levels of routine maintenance. Figure 1 shows the all elements in the turnout area. [1]

Some literatures have presented the dynamic analysis of the switch machine system. By using the dynamic switch machine model, Xu et al. [2] studied the lock calculation of nose rail after conversion and presented the stress and deformation for the nose rail and wing rail. Wang et al. [3] investigated the effect of different bedplates, different friction coefficient, lateral stiffness of switch rail end, stroke error and performance of fasteners on switching force and deviation. Based on envelope and morpheme match algorithm, exact curve matching method is used to match the detected current curve with the reference curve by Mo et al. [4].

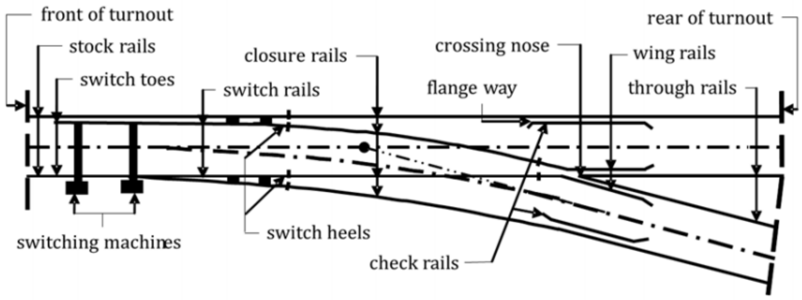


Figure 1. Turnout system and its components [1]

In this article, the fatigue analysis of detector slides under the dynamic forces is investigated. The uniform design of experiment is used to create a set of simulation experiments. According to the GB/T 25338.1-2010 fatigue testing standard, the maximum von Mises stresses of the upper and lower detector slides are obtained by using ANSYS/Workbench and HyperMesh software. Finally, from the numerical results, the best detector slide of all the experiments which causes the smaller von Mises stress is presented.

Finite Element Modeling for Detector Slide

The S700K switch machine system, including motor, clutches, control system, throw bar, detector slides, gear reducer system and case, is shown in Figure 2. [5] The throw bar, which is connected to the points, is held with a defined force in the end positions by the trailing clutch. During the trailing of a trail-able point machine, it is released once the retention force is exceeded. For fail-safe detection of the blade end positions, the point machine is equipped with detector slides. The detector slides are linked to the point blades via the detector rods and prove whether the blades have reached the end position. The end position of the point blades is detected continuously.

Figure 2. S700K switch machine system

Fatigue testing standard

Figure 3 illustrates schematically the detector slide fatigue test. The upper and lower detector slides are assembled in the guide sleeve as shown in Figure 3. Then, the upper and lower detector slide connects to a fork joint to translate the force to the lock member linked the switch rails. The guide sleeve is fixed on the case and the case is fixed on the ground. Next, the dynamic loads 6000 N act on the lock member in the horizontal direction as shown in Figure 3. The dynamic loads of the upper and lower detector slides are given in Figure 4. According to the GB/T 25338.1-2010 fatigue testing rule [6], the maximum endured loading is conducted to 10^6 cycles.

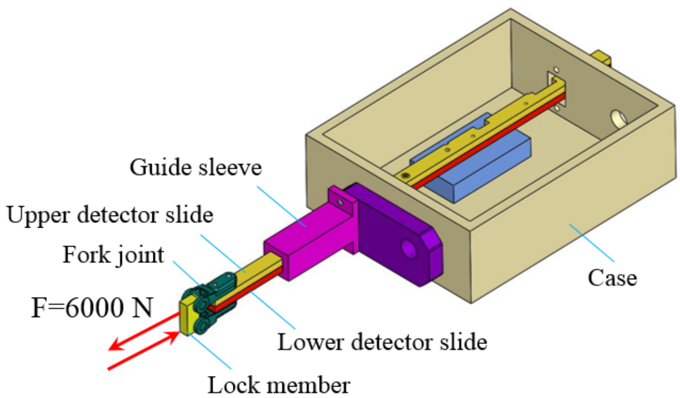


Figure 3. S700K switch machine system

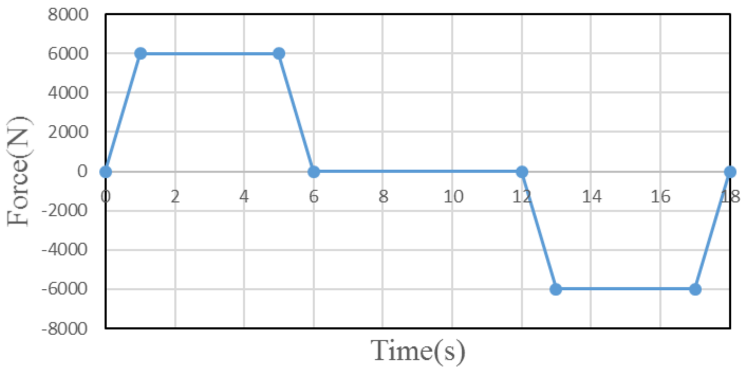


Figure 4. Time history of dynamic loads in one period

Finite element modeling

In the solving stage, HyperMesh software is used for the pre-processing. The boundary and contact conditions are given as shown in Figure 5. ANSYS/Workbench software is applied to calculate the maximum von Mises stress of the detector slide. The material properties of the detector slides, fork joint, lock member, guide sleeve, and the case are given as shown in Table 1. In addition, the S-N curve for the detector slide is given as shown in Figure 6.

In FE analysis, a convergence test is necessary for verifying the mesh quality because the solution is approximate rather than an exact solution. Consequently, each FE model executed the simulation test and the convergence condition is determined to be less than 5% of changes in the maximal magnitudes of von Mises stress with varying element sizes. Figure 7 shows the convergence curve of the obtained maximal magnitude of von Mises stress with meshing different element size. The optimized element size is 4 mm because the difference of the simulation result between element size of 4 and 3.5 mm is less than 5%. Therefore, element size is determined to be 4 mm to mesh all FE models.

The maximum von Mises stress and fatigue safety factor of each detector slide for the fatigue testing are shown as Figures 8 and 9. From the numerical results, the maximum von Mises stresses of the upper and lower detector slide are given as 117.16 MPa and 121.5 MPa, respectively. In addition, the minimum fatigue safety factors of the upper and lower detector slide are given as 1.34 and 1.29, respectively. Figure 10 shows the deformation of each detector slide. From the numerical results, the maximum deformations of the upper and lower detector slide are given as 0.84 mm and 0.52 mm, respectively. It means that the strength performance of the upper detector slide is better than the lower detector slide.

Table 1. Material types and properties

Body	Young's Modulus (Pa)	Poisson's Ratio	Density (g/cm^3)
Detector slide	21×10^{10}	0.29	7.9
Fork joint Lock member guide Sleeve the case	20×10^{10}	0.2	7.85

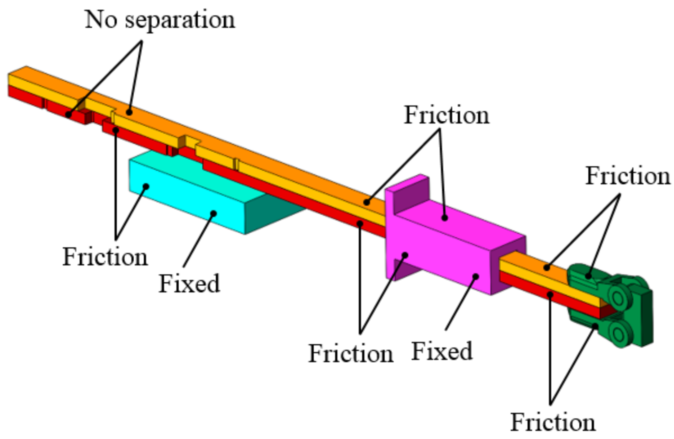


Figure 5. Boundary conditions for detector slides

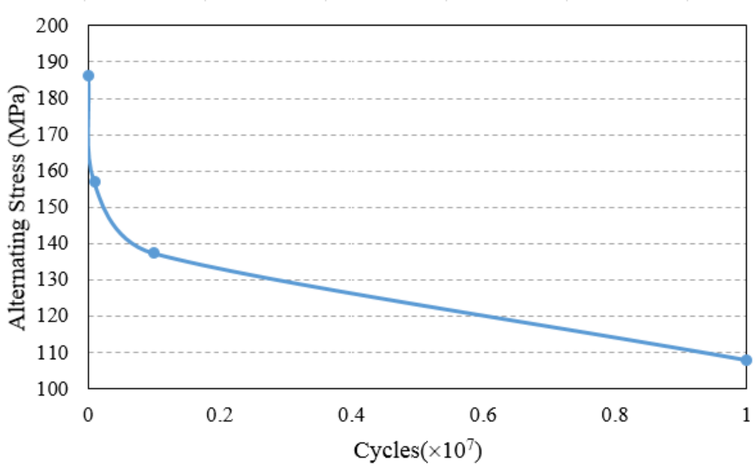


Figure 6. S-N curve for detector slide

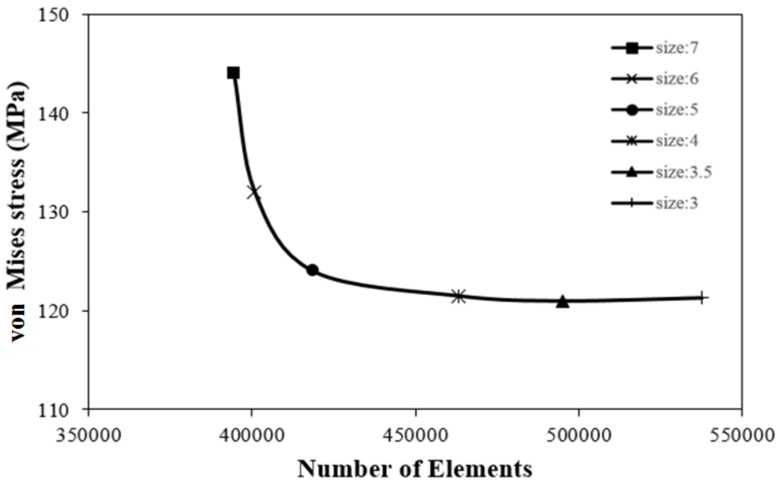
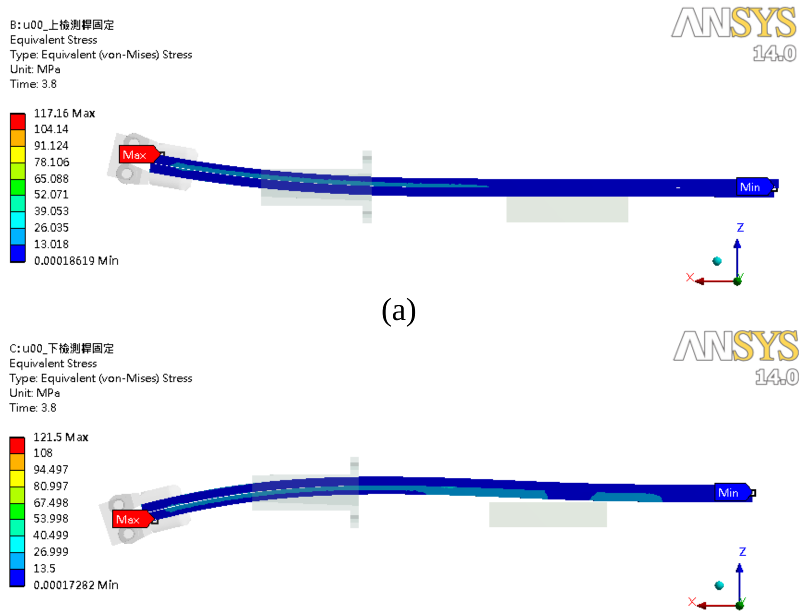


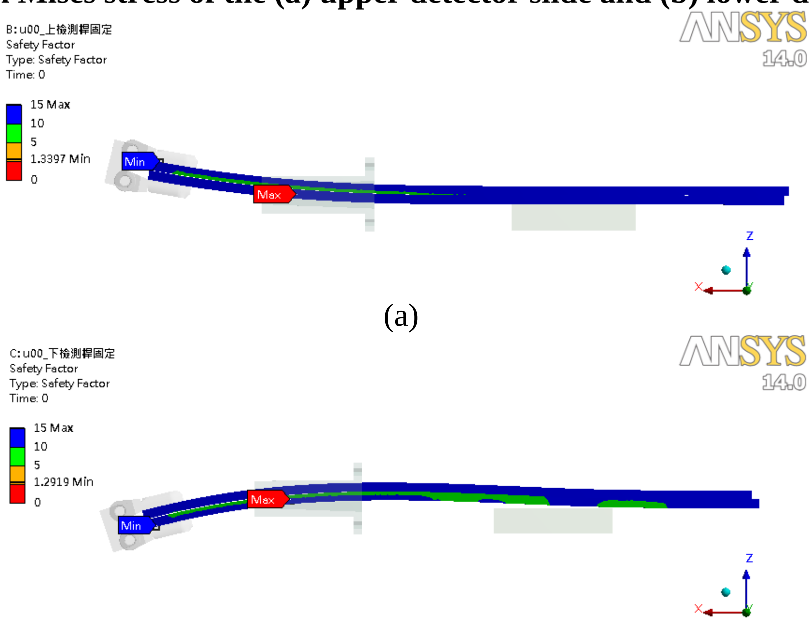
Figure 7. Convergence curve of the obtained maximal magnitude of von Mises stress



(a)

(b)

Figure 8. von Mises stress of the (a) upper detector slide and (b) lower detector slide.



(a)

(b)

Figure 9. Fatigue safety factor of the (a) upper detector slide and (b) lower detector slide.

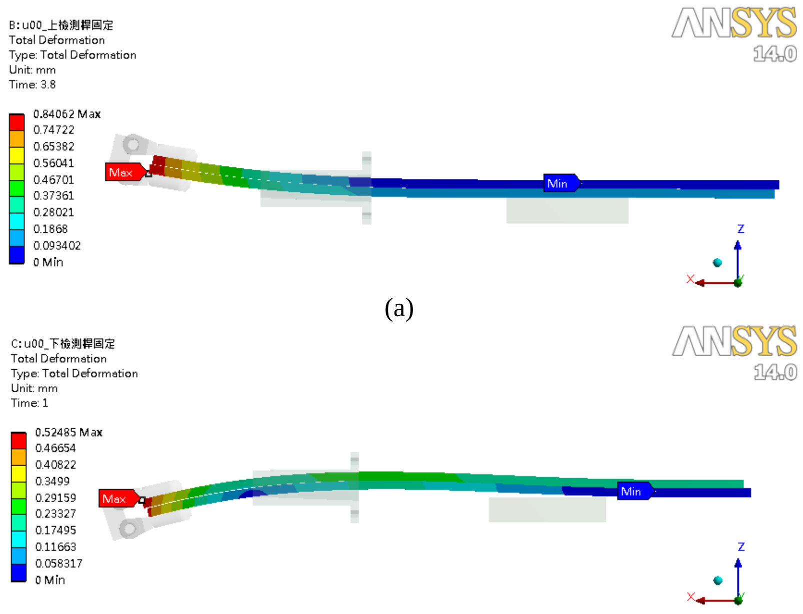


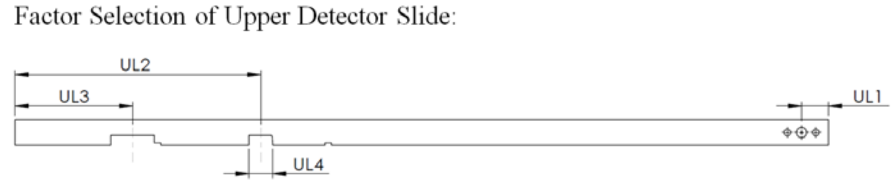
Figure 10. Deformation of the (a) upper detector slide and (b) lower detector slide.

Uniform Design of Experiments for Reducing von Mises Stress of Detector Slide

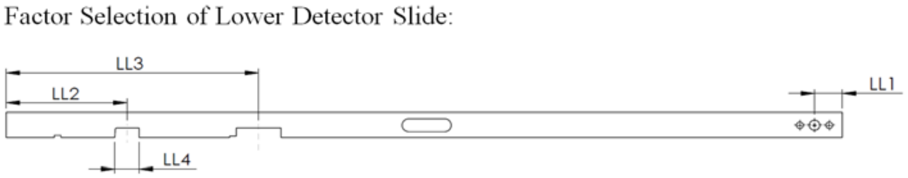
As shown in Figure 10, the detector slide studied in this paper has four dimensional control factors. The original design and variation ranges of control factors are shown in Table 2. Since all factors are continuous, the design space is also a continuous space. For a continuous design space, design points are infinite and evaluation of all design points is impossible. Therefore, this study applies uniform design method proposed by Fang and Wang [7] to construct a set of sample points which are scattered uniformly in the continuous design space. Uniform design has been widely used for optimization in many engineering applications [8-10].

In our study, due to the limitation of computational resource, each factor is divided into 12 levels and the uniform table $U_{12}^{*}\left(12^{10}\right)$ is utilized to construct 12 experiments. As shown in Table 3, the uniform table $U_{12}^{*}\left(12^{10}\right)$ has 12 rows and 10 columns (Fang and Wang [7]). Since the detector slide has four control factors, columns 1, 6, 7, 9 should be used according to the use table of $U_{12}^{*}\left(12^{10}\right)$. The constructed experiments are shown in Table 4. Each experiment denotes a specific design of detector slide. For each detector slide, SolidWorks is applied to build the geometric model of frame and ANSYS/Workbench is used to simulate the behavior of detector slide undergoing fatigue testing.

From the numerical results in Table 4, the minimum von Mises stress of the upper detector slide occurs at the 3rd experiment. However, at 7th experiment, it has the minimum von Mises stress of the upper detector slide. It is difficult to select an optimal solution. Considering the lower von Mises stress for each detector slide, the 7th experiment is regarded as the improved version of design. The improved version causes the von Mises of 104 MPa and 110.2 MPa for the upper and lower detector slide, respectively.



(a)



(b)

Figure 10. Control factors of the (a) upper detector slide and (b) lower detector slide

Table 2. Variation ranges of control factors

Control factors	Lower bound	Original design	Upper bound
LL1 (mm)	30.6	34	37.4
LL2 (mm)	120.47	133.85	147.24
LL3 (mm)	253.8	282	310.2
LL4 (mm)	27	30	33

Table 3. Uniform table $U_{12}^{*}\left(12^{10}\right)$

Experiment No.	1	2	3	4	5	6	7	8	9
1	1	2	3	4	5	6	8	9	10
2	2	4	6	8	10	12	3	5	7
3	3	6	9	12	2	5	11	1	4
4	4	8	12	3	7	11	6	10	1
5	5	10	2	7	12	4	1	6	11
6	6	12	5	11	4	10	9	2	8
7	7	1	8	2	9	3	4	11	5
8	8	3	11	6	1	9	12	7	2
9	9	5	1	10	6	2	7	3	12
10	10	7	4	1	11	8	2	12	9
11	11	9	7	5	3	1	10	8	6
12	12	11	10	9	8	7	5	4	3

Table 3. Constructed experiments and results

Experiment No.	von Mises stress of upper detector slide (MPa)	von Mises stress of lower detector slide (MPa)
1	111.3	113.9
2	118.4	114.4
3	97.5	117.4
4	110.0	150.4
5	112.2	112.2
6	115.0	120.9
7	104.0	110.2
8	113.3	129.3
9	113.8	121.1
10	113.0	118.2
11	118.2	121.0
12	116.0	120.7

Conclusions

This paper has completed the improvement of von Mises stress for the detector slides under the fatigue testing simulations by using uniform design method. Uniform design method is used to build a set of experiments and finite element modeling is fulfilled by employing ANSYS/Workbench. For the original design, the von Mises stress for the upper and lower detector slide are 117.16 MPa and 121.5 MPa, respectively. After executing uniform design improvement, the von Mises stresses of the improved version will go down to 104 MPa and 110.2 MPa. This paper has shown that uniform design is a useful tool to reduce the von Mises stress of detector slides.

Acknowledgment

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