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THE STRESS EVALUATION OF THE TOGGLE MECHANISM OF THE THREE-PLATEN INJECTION MOLDING MACHINE BY R-F COUPLED MBD MODEL

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ABSTRACT
The aim of the paper is to evaluate the mechanical behavior of the toggle mechanism of an injection mold machine. Different commercial simulation tools were combined to create a rigid-flexible (R-F) coupled multibody (MBD) model for the toggle system of the injection mold machine. Several flexible parts were included by importing the MNF files of the parts generated by the FE model. Then the R-F coupled MBD model of the toggle system were developed in the MBS software. The stress distribution of each component of the toggle system was illustrated. The results show that less stress is loaded at the middle of all the levers. Greater load is applied at the end of the crosshead toggle lever. Finally, some suggestions are given for the lightweight improvement of the toggle system.

KEYWORDS: Injection machine, toggle lever, mechanical features, flexibility.

1. INTRODUCTION
An injection molding machine is a cyclical manufacturing machine that allows for cost efficient production of large number of identical parts made of either thermoplastic or thermoset materials. The machine consists of injection unit and clamping unit. The injection unit is used for plasticizing and injection, and clamping unit is employed for holding. In the plasticizing process, the materials are commonly fed into the heated barrel of the machine, where a screw conveys them forward creating shear heat to melt the materials. When the raw plastic material is melted, it is injected into a mold under high pressure. The clamping unit produces a clamp force to prevent the mold from being pushed open by the force created during the injection. The toggle system is one of the most important parts of the clamping unit to produce clamping force and to open/close mold. It consists of front toggle lever, rear toggle lever, sub toggle lever, crosshead, as shown in Fig. 1. The stiffness of the toggle system plays a very important role to decide the precision of the final product.

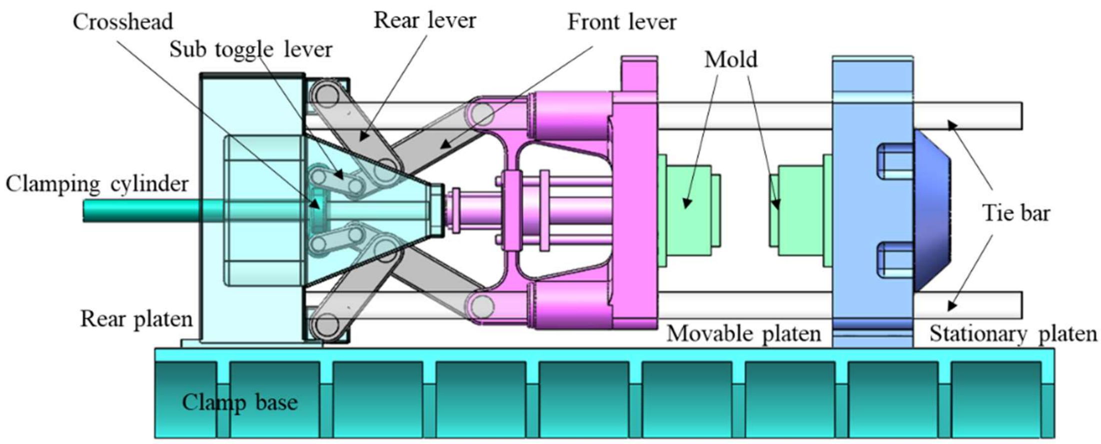

Fig. 1 the mechanical system of the injection molding machine

The FE method is always employed to check the mechanical features of the mechanical systems by carrying out the static analysis. Meanwhile, the dynamic features of the mechanical systems are often investigated by multi-

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rigid body dynamics (MBD). However, it could not present the stress of the parts since the object is set as rigid body. Combined with the Finite Element (FE) method and multi-rigid body dynamics, a rigid-flexible coupled dynamic model could be developed to investigate not only the mechanical features but also the dynamic behaviors of the mechanical systems. Therefore, the rigid-flexible coupled dynamics is paid more and more attention in the industry to peruse the more real mechanical behaviors in the simulation.

Due to its importance, many studies have been made to explore the mechanical stiffness of the injection molding machine. Sasikumar [1] reported the premature failure of a tie bar in an injection molding machine. The failure was found to occur at the root of the first thread by transverse fatigue fracture induced by a pulsating tensile stress with multiple points of high stress concentration. High stress concentrations had been introduced by a combination of improper molding parameters resulting in uneven tensions in the four tie bars and significant amount of material defects. Optimum topology for the plastic injection machine is one of the solutions for this kind of problems. Sun [2] investigated the structure of the stationary platen with optimized stiffness at minimal raw material cost. By reducing the deflection of the stationary platen through topology optimization of the platen structure, the bending load of the tie bars were reduced, which extended the operating life of tie bar. Dheeraj [3] optimized stationary platen by using the finite element analysis after checking the induced stresses with allowable design stress. Dome type shape was converted into box type which resulted in reduction of overall thickness of platen to the tune of 5%. Rahul [4] used Taguchi method to determine the optimum parameters settings of the hole size, lateral distance, linear distance of platen that affected the output characteristic responses as the stress and the deformation. Patel [5] reported that the substantial reduction in weight about 70 kg was obtained by topology optimization. Huang [6] developed a measuring system for recording tie-bar elongation and mold separation during injection molding at each corner of the mold. Correlation analysis on experimental results depicted that the increase in tie bar elongation and the maximum mold separation during injection molding were highly correlated with the thickness of plastic parts.

In this paper, a rigid-flexible coupled dynamic model including flexible parts for the clamping unit of the injection molding machine was developed to check the mechanical behavior of the toggle system in the process of the injection. The stress of all the levers were all explored to check the stiffness of the injection machine. The results could provide guidelines to the design of the mechanical system of the injection machine with three-platens.

2. THE THEORY

The rigid-flexible coupling model was built based on the multi-rigid-body model, and the multi-rigid body dynamic model is a coupling of the multi-mass dynamic model and the rigid-body motion model. In multi-body systems, due to the existence of kinematic constraints, the generalized Cartesian coordinates are generally dependent. The system of the constraint equations describing multi-body systems can be expressed as a complete system of kinematic constraints equations independent of time. In the rigid-flexible coupled multi-body dynamics model, the dynamic equation of a single flexible body is model, the dynamic equation of a single flexible body is

$$M\ddot{\xi} + \dot{M}\dot{\xi} - \frac{1}{2}\left[\frac{\partial M}{\partial \xi}\dot{\xi}\right]^T \dot{\xi} + K\xi + \frac{\partial V_G}{\partial \xi} + D\dot{\xi} + \psi_\xi^T \lambda = Q \qquad \text{(i)}$$

Where ξ the generalized coordinate, M is the generalized mass matrix depending on ξ, K is the generalized stiffness matrix only depending on $\hat{q}$, V_G is the gravitational energy, D is the damping matrix defined using modal damping ratio, thus D is diagonal, ψ is the kinematic constraint equations applied to the flexible body, λ is the Lagrange multipliers. A more detailed theoretical presentation can be found in reference [7]. The deformation vector of each point on the flexible body is $u_f = \Phi q_f$, where, Φ is the modal term matrix; q_f is the modal coordinates. The relationship between the strain vector ε and the deformation vector u_f is $\varepsilon = Du_f$, where D the matrix of differential operators is. For a linear elastic material body, $\sigma = ED\Phi q_f$, where, E is the elastic modulus of the material.

3. THE SIMULATION

In this investigation, the simulation integrating three commercial codes, CAD, multi-body dynamics and finite element were carried out, which is so called multi-discipline simulation, to explore the mechanical behaviors of the toggle system of the injection molding machine. The clamping system was simplified from the injection machine HT80/X, which was produced by HaiTian, a famous plastic injection machine manufacture in Ningbo,

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China. A rigid-flexible coupled dynamic model for the clamping system was developed, as shown in Fig. 1. The topological relationship was shown in Fig. 2, which has been colored to identify the different joints. Dark gray, orange, green and blue represented the joint of fix, translation, contact and rotation, respectively. The platens, the tie bars and the toggle systems were all modelled as the flexible parts. During the simulation, the clamping cylinder moved forwards to push the toggles system as well as the moveable platen. Finally, the two molds contacted tightly and clamping force reached maximum, and the self-lock was achieved.

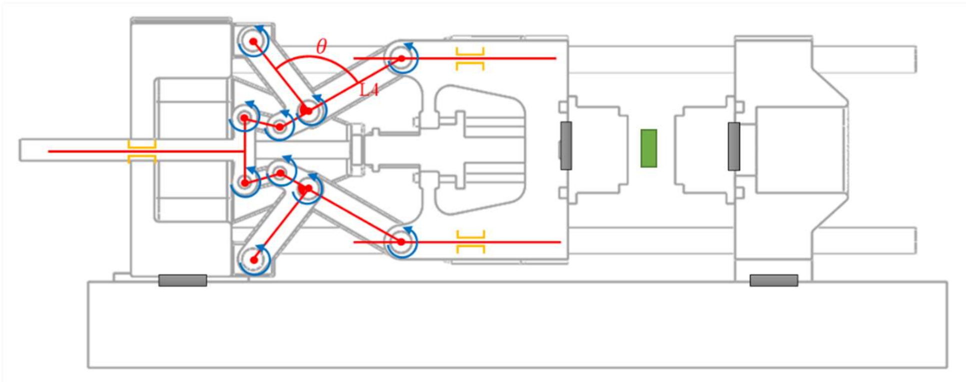

Fig. 2 The topological relationship of the parts

During clamping, the movable platen moves toward the stationary platen to make the two molds contact tightly. The clamping force reaches maximum when the toggles are fully extended ($\theta = 179°$). The self-lock was also achieved when the toggles are fully extended, which means that even when the hydraulic pressure in the clamping cylinder is relieved, the clamping force is also constant [8, 9]. All the parts bear its max loading at the same time. Therefore, the mechanical behaviors of the system were checked during this period.

4. THE RESULTS AND DISCUSSION

The stress distribution of the whole clamping system as well as three platens during the injection period when the toggle system is fully extended. The max clamping force is about 80 kN, as illustrated in Fig. 3. The stress diagram was shown in Fig. 4. It can be observed that there exists greater stress at the end of the toggle lever. Meanwhile, the tie bar is also bearing larger tensile stress at the both ends. It also could be observed that the maximum stress appeared on the sub toggle lever. Therefore, the sub toggle lever bears larger stress than that of other toggle levers during the self-lock stage.

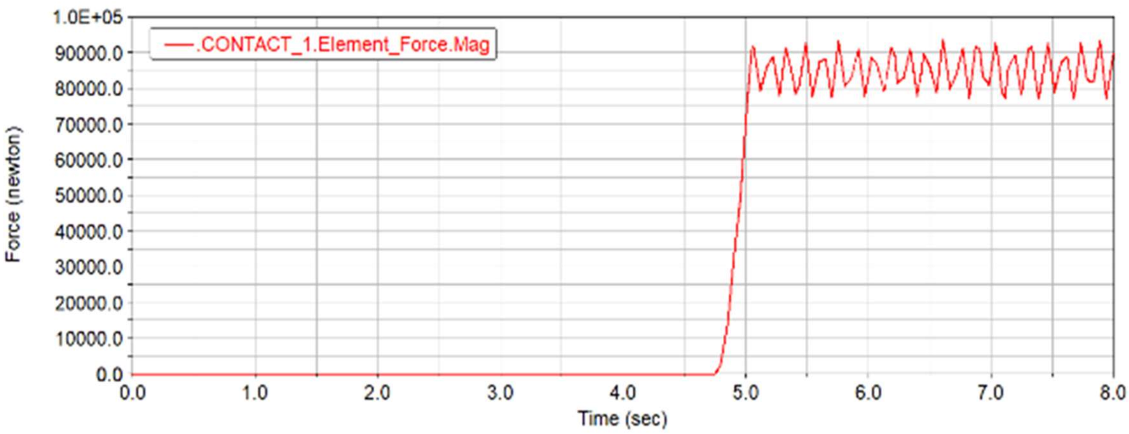

Fig. 3 The clamping force vs. time

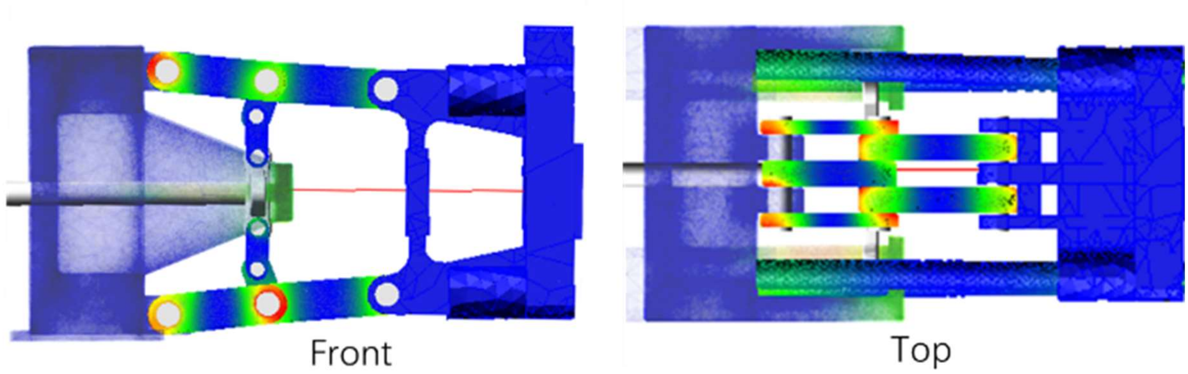

Fig. 4 The stress distribution of the toggle mechanism

Figs. 5-8 shown the stress distribution of each lever. Fig. 9 shown the maximum stress on each lever. It could be observed that the two ends of all the levers bear greater stress while the middle of those bears less stress. Take the sub toggle lever as an example, the stress on the both ends is about 500.04 MPa and 342.56 MPa, while the stress is only about 142.65 MPa at the middle of the crosshead. Therefore, it is the potential position that the lightweight design could be carried out on the middle of the toggle lever.

The maximum force of the front toggle lever is about 185.85 MPa. It means that the front toggle lever bears the least stress in the toggle system. The maximum stress, 500.04 MPa, appears at the end of the sub toggle lever, which connects one end of the crosshead. The stress of the mid and the side rear toggle lever are 316.36 and 200.99 MPa, respectively. Although the mid and the side rear toggle lever both have the same function that connect the rear platen and the sub toggle lever, the mid rear toggle lever bears greater stress than the side lever.

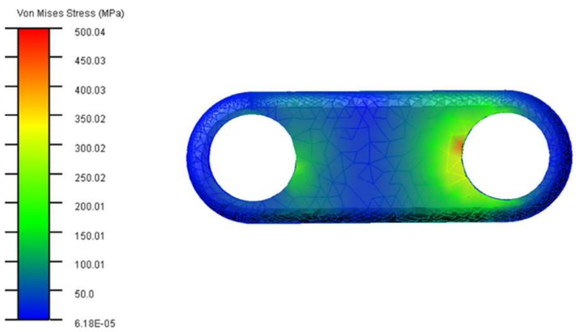

Fig. 5 Stress distribution of the sub toggle lever

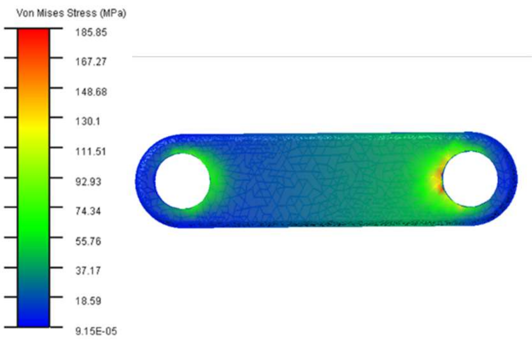

Fig. 6 Stress distribution of front toggle lever

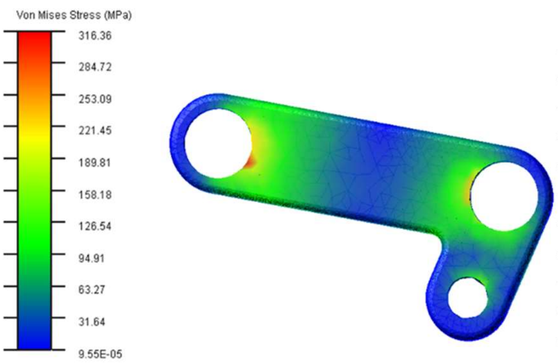

Fig. 7 Stress distribution of mid rear toggle lever

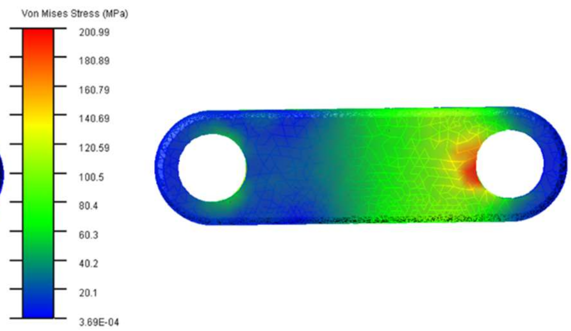

Fig. 8 Stress distribution of side rear toggle lever

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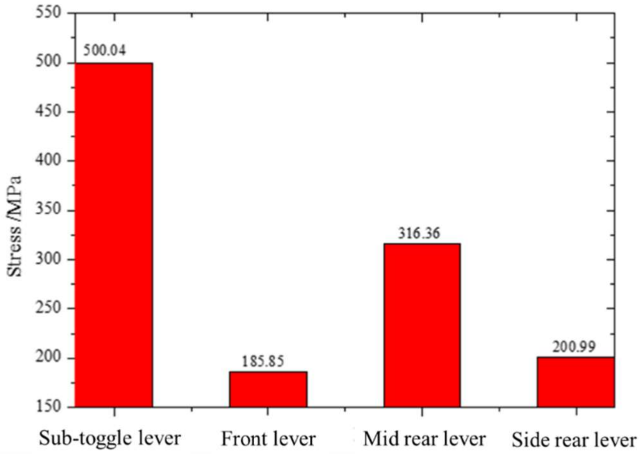

Fig. 9 The maximum stress on each lever

5. CONCLUSION

In this study, we investigated the mechanical behavior of the clamping system. The rigid-flexible coupled multi-body model was developed and employed for stress evaluation of the system. The results conducted in this study are summarized as follows:

- The stress distribution of the mechanical system of the injection molding machine, including 21 parts, was obtained by the rigid-flexible coupled multi-body model. Global view of the mechanical features of the toggle system could be obtained.
- Less stress is loaded at the middle of all the toggle levers. The light-wight attempt could be carried out in the region.
- Greater load was applied at the end of the sub toggle lever. Structure design could be paid more attention to reduce the stress in this region.

6. ACKNOWLEDGEMENT

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