The structure design and performance analysis of the transportation fork in hot stamping production line

Yi Sun, Liang Wang, Bin Zhu, Yilin Wang and Yisheng Zhang*

State Key Laboratory of Material Processing and Die &Mould Technology,

Wuhan 430074, P.R. China

*zhangys@mail.hust.edu.cn

Keywords: hot stamping; fork; vibration; structure design; performance analysis

Abstract. To meet the automotive lightweight trend, hot stamping production technology is becoming a key technology of automotive body manufacturing. In the hot stamping production line, multi-chamber furnace is been adopted for its batch of high heating efficiency. The heated blank is transported by tray-type fork with high speed. However, due to the system inertia, the fork would vibrate. The measured vibration amplitude is 5.65mm with our initial designed fork, which affects the delivery speed seriously. Then, the fork is simplified as a cantilever beam model based on its geometry with different size, and corresponding finite-element (FE) analysis and verification experiments have taken place. A model with the minimum inertial vibration amplitude which is 4.11mm under the working conditions is found. It has the highest stiffness and the smallest swing radius of gyration. This model has good stability at high speed and its vibration amplitude is decreased by 28%.

Introduction

The technology of high strength steel hot stamping develops rapidly in automotive industry at home and abroad after 2008. And it is widely used in the automotive field [1]. The typical process of high strength steel hot stamping is shown in Fig. 1, in which every blank need to heat 300-330Sec. However, the pressure maintaining time just need 10 Sec [2].Therefore， the heating process restricts the efficiency of production line.

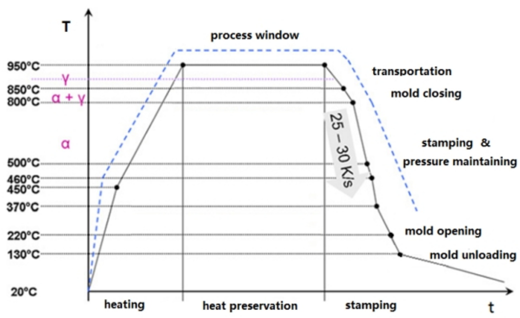


Fig.1 The typical process of high strength steel hot stamping

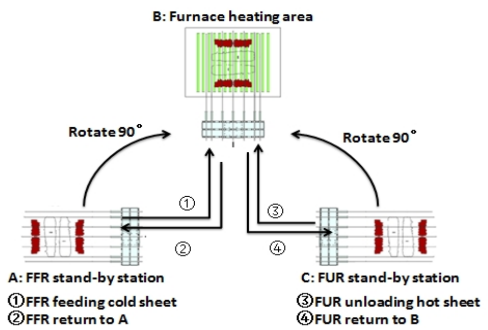


Fig. 2 Blank feeding process of multi-chamber furnaces

Multi-chamber furnace has the advantages of multi-blanks heat at the same time with no difference. It is good to improve the production efficiency of hot stamping. According to the characteristics of multi-chamber furnace, fork-tray is designed for blank transportation. The fork's fast-stability determines the delivery time. In order to found a method for structure optimization design and performance improvement to the fork, the fork is simplified as a cantilever beam model based on its geometry, and 4 different structures of the forks are designed. Then their performances are compared through a series of FE analysis and experiments. Finally, based on the results, several optimization structures are found out.

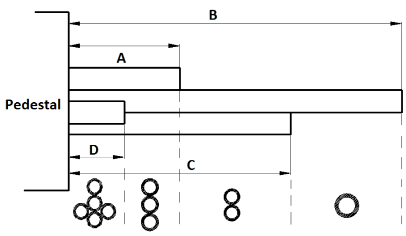
Structure design of transport fork

The blank is placed on the bottom shelf. The distance between each two adjacent carrier pipes is 65mm. In Fig. 2, FFR is the furnace feeding robot, and FUR is the furnace unloading robot.

For the requirement of rapid production, the fork needs to spin at high speed, which will result in its violent vibration. If the vibration amplitude was too large, the fork might can't enter the furnace rapidly and steady, or it may even collide with the pipes. This would impact the effect, and lengthen the open time of the furnace door, and then it would cause more heat dissipation [3].

In order to facilitate the feeding and unloading, according to the furnace characters, a tray-type fork is designed for high speed transportation. Its model is shown in Fig.3. The fork consist of one pedestal and 7 to 9 tube units. Every tube units consist of 5 tubes. All of the outer diameters are 0.02m, and their inner diameters are 0.014m. The length of every tube is different, and all of them are welded together. The material of the fork pedestal is 6061 high strength aluminum alloy; and the material of the tubes is structure steel. The model could be simplified as variable-section beam structure. It can be divided into 4 parts; and every cross section is shown in Fig. 3(b). In order to facilitate the experiments, 4 different structures of units are designed for the experiments. Table 1 shows the length of every tube of the structures.

(a)



(b)

Fig. 3 (a) Fork model; (b) Variable-section beam model

Table 1.Length of every tube (unit: mm)

No.	1#	2#	3#	4#
Tube A	790	790	540	790
Tube B	2390	2390	2390	2390
Tube C	1540	1990	1540	1540
Tube D	250	250	250	400

Performance analysis of transporting Fork

FE analysis of the fork

In the production line, smaller vibration amplitude is better meeting the requirements of high precision and high stability. Vibration is an energy dissipation process. The vibration fades as the interconversion of the kinetic energy and deformation energy when the robot stops. Kinetic energy is transformed into deformation energy of beams when cantilever beam stops. According to energy conversion formulas:

$$\frac{1}{2}mv^2 = \frac{1}{2}k\Delta^2 \tag{1}$$

The vibration amplitude of the cantilever beam is related to the structure stiffness and mass distribution[4]. Assum the total energy is a constant, the higher vibration frequency, the smaller amplitude will be. Each natural frequency corresponds to a different vibration mode. The higher vibration mode is, the decay caused by damping decreases more quickly. So the effect of high vibration mode is only obvious in initial vibration. Thus only several low modes would be consider in engineering seismic design[5]. A large number of experiments showed that vibration frequency of the fork in hot-stamping production line does not meet the first natural frequency. So we only need to consider the first mode. The modal analysis results shows in Fig.4. The comparison of the natural frequency and the average vibration frequency under working condition of 1#, 2#, 3# and 4# shows in Table 2. Fig. 5 shows that the vibration frequency and the natural frequency have a positive correlativity. Therefore, improving structural rigidity can improve the stability and decrease the amplitude.

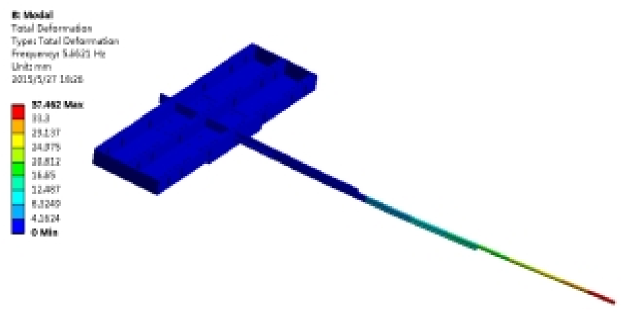


Fig. 4 Modal analysis results for moldes

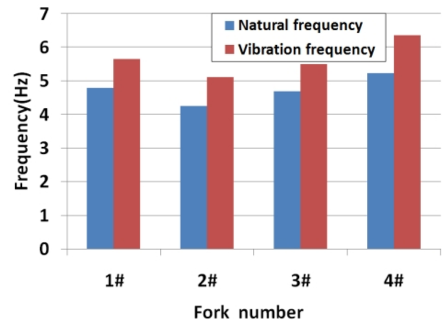


Fig.5 Relationship between vibration frequency and natural frequency

Table2. Natural frequency and vibration frequency

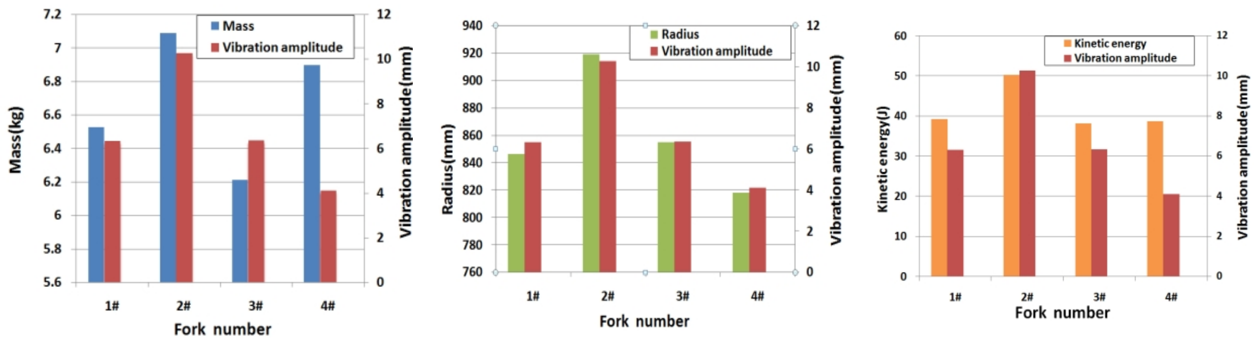
No.	Natural frequency(Hz)	Vibration frequency(Hz)
1#	5.66	4.8
2#	5.11	4.26
3#	5.51	4.7
4#	6.36	5.24

Vibration experiments

In actual working environment, the fork needs to rotate 90° within 1.44s. The mass, radius radius of gyration, kinetic energy and amplitude dates of the experiment show inTable 3.

Table 3.Mass, radius, kinetic energy and amplitude dates

No.	Mass(kg)	Radius(mm)	Kinetic energy(J)	Amplitude(mm)
1#	6.524	846	39.246	6.33
2#	7.086	919	50.300	10.27
3#	6.211	855	38.162	6.35
4#	6.898	818	38.794	4.11



(a) (b) (c)

Fig. 6 (a) Mass and amplitude; (b)Radius and amplitude; (c)Kinetic energy and amplitude

Fig. 6 shows that the relationship between kinetic energy, mass and vibration amplitude is not particularly evident. However, the radiue radius of gyration and the amplitude have a evident positive correlation: the smaller the radius is, the smaller the amplitude is.

Results and Discussion

The experiments show that the structural stiffness and radius of gyration are key factors to affect the stability of the fork. The higher stiffness leads to the better stability; and the smaller radius leads to the better stability. In the experiments, the first natural frequency of 4# is 6.36Hz, and the radius of 4# is 818mm. Under the working conditions, the vibration amplitude of 4# is 4.11mm. It could directly enter into the furnace shelf area. Based on the results, using FE parameter optimization method to design the structures of the forks, several groups of new structures are got. All of them can meet the requirements of hot stamping production line.

Conclusions

The stability of the transporting fork for multi-chamber furnace in the hot stamping production line is the most important criterion. Based on a large number of simulations and experiments, some conclusions are got:

1) Find a fork structure design method, and combine the FE simulation and experiment, then get the relationship between the first natural frequency and the vibration frequency. It shows that the higher natural frequency leads to the higher vibration frequency.

2) Obtain a preferable fork, whose first natural frequency is 6.36Hz, and its radius of gyration is 818mm. Under the working conditions, the vibration amplitude is 4.11mm. It has good stability at high speed and its vibration amplitude is decreased by 28% compare to the initial fork.

Acknowledgements

This research work is financially supported by the National Natural Science Foundation of China (Grant No. 51275185 and No.51405171)

References

[1] Jianping LIN, Liying WANG, Haobin TIAN, Guohua SUN, Zhibin WANG, Research and Progress of Hot Stamping of Ultrahigh Strength Steel, Hot Working Technology, 21(2008),pp 140-144.

[2] Zheng Wang, Yisheng Zhang, Huiqiang Liu, Optimization of industrial robots transmission path in hot stamping production line, Forging & Stamping Technology, 37(2012),No.03,pp31-35.

[3] Liang Wang, Bin Zhu, Qiang Wang, Ju Meng and Yisheng Zhang, Production Control and Optimization of Hot Stamping Line, in 5th International Conference of CHS2, Toronto, Canada, May 31 until June 3, 2015.

[4] Jian Chen, Xiaochun Yin, Investigations of The Numerical Method for The Dynamics of Rotating Beam, Journal of Mechanical Strength, 26(2004),No.05, pp484-488.

[5] Yongyu Huang, Yonggang Zhao, Weidong Zhao, Analysis on cantilever beam's natural frenquency based on Lagrang motion equation, Journal of Qinghai University(Natural Science Edition), 29(2011)No.01,pp 12-16.