Dynamics analysis of crankshaft for high-speed punch based on ADAMS

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Abstract

High-speed punch has a wide range of applications in industry because of its advantages such as high effective, high quality and low cost. The crankshaft is a key part of slider-crank mechanism of high-speed punch, which has fateful consequence to the performance and reliability of the punch. After analyzing the structure of crankshaft, the model of slider-crank mechanism is built and the boundary condition and motion generator are confirmed in ADAMS. The dynamics analysis of slider-crank mechanism under different strokes are carried out. Under different punch strokes, the change of the displacement, velocity and acceleration in vertical direction of slider, the change of the stress of crankshaft in two limit positions, are analyzed. The dynamics analysis results provide a basis for the design and optimization of crankshaft for high-speed punch.

Keywords

Dynamics analysis, crankshaft, high-speed punch, ADAMS.

1. Introduction

The high-speed punch is the fundamental equipment of metal forming process. The high-speed punch is employed in the industry of aerospace, automobile manufac-turing and chemical metallurgical because of the characteristics of high efficiency, high quality, low cost and wide range [1-5].

Fan [6] built a complete mufti-body dynamics shafting model of the internal combustion engine and he carried out mufti-body dynamics analysis to crankshaft. He got force conditions of each main journal through the analysis of main journal forces, gained large axial center deviations of each main journal and their corresponding angular coordinates through orbit analysis, and obtained the unevenness of the rotor speed fluctuation, which turns out to meet the design requirements. Ma [7] created a virtual prototype model based on virtual prototype technology and the dynamics theory of flexible multi-body systems. He obtained the real-time kinetics response of the crankshaft during a working cycle, which is a foundation for crankshaft optimal design. Fan [8] builds a vir tual prototype of crankshaft and link mechanism of a engine. He used ADAMS to do a kinematics and dy namic simulation to get dynamic loads on the crankshaft and the results found its dangerous parts to offer references for crankshaft design. Wu [9] carried out dynamic nonlinearity analysis to crankshaft of an inline six cylinders engine. He discussed the kinematics and dynamics in detail including its displacement, velocity and acceleration and the pressure of cylinder and the results can be used to improve the design level and the design efficiency of the diesel engine crankshaft system. Hu [10] established a virtual prototype model of a diesel engine crankshaft using the ADAMS software. He analyzed the force acting on the crankpin and the torque on the crankshaft. Using Solidworks, ADAMS and ANSYS, Wang [11] created the virtual prototype of a diesel engine crankshaft (crankshaft mechanism). He got the movement disciplinarians (displacement, velocity, acceleration, etc) about every component at any moment and any position and the results offered reference for the crankshaft optimum design. Han [12] established a model of crankshaft under working condition based on LS-DYNA. He got results that the obvious stress concentration exist in the upper end of fillet on main journal and the lower end of fillet on rod journal when the piston arrives at top dead center, and the maximum equivalent stress occurs at the fillet on rod journal, which provides the theory basis for the selection of residual stress.

This dissertation mainly carries out a dynamics analysis of crankshaft of high-speed punch, include structure analysis, modeling of crankshaft and discussion of analysis results.

2. Dynamics analysis modeling of crankshaft

2.1 Structure of crankshaft

The structure sketch of crankshaft is shown as Fig. 1. This type of crankshaft is used for 800KN high-speed punch made by a company. The working conditions of the punch are as follows: Nominal Pressure is 800 KN, Nominal Pressure Stroke is 2 mm, Slider Stroke is 30 mm, number of strokes is 600 SPM (Strokes per Minute), the thickness of punched part is 2 mm, the material of crankshaft is 40Cr.

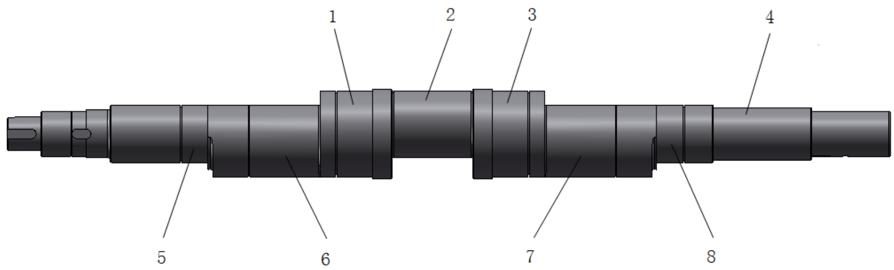

Fig. 1 Structure sketch of crankshaft

1, 3, 5, 8—Installation locations of support bearing

2—Installation location of connecting rod bearing of Balancing slider

The crankshaft transfer drive torque from the flywheel, which is installed in location 4 with clutch. The four groups of support bearings, which are installed in location 1, 3, 5, 8, form a revolute pair with the punch frame. The two groups of support bearings, which are installed in location 6, 7, form a revolute pair with main connecting rod. One group of support bearing, which is installed in location 2, form a revolute pair with balancing connecting rod.

2.2 Model of crankshaft

The crankshaft is a key part of slider-crank mechanism. If only carry out dynamics analysis to itself, the analysis result would be a big gap compared with the actual situation. So the dynamics analysis of slider-crank mechanism should be carried out to get the accurate force loading status of crankshaft.

The slider-crank mechanism is composed of crankshaft, main slider, main connecting rod, balancing slider and balancing connecting rod. The complexity of the model will decide the computation of dynamics analysis. To guarantee that the dynamics model is correct, need to pay attention to the following aspects in simplifying models: (1) the mass characteristic of geometry should not be changed; (2) the inertia characteristic of geometry should keep the same; (3) the detail of geometry could be incompletely accordant with the actual part. The geometric model of slider-crank mechanism is as shown in Table 1.

Table 1 Geometric model of slider-crank mechanism

Part	Material	Density / kg/m^3	Volume / m^3	Mass / kg
Crankshaft	Alloy steel	7.7×10^3	0.02687	206.9
Main connecting rod	Alloy steel	7.7×10^3	0.01156	89.0
Main slider	Grey cast iron	7.2×10^3	0.09728	700.4
Balancing connecting rod	QT500-7	7.31×10^3	0.00554	40.5
Balancing slider	Grey cast iron	7.2×10^3	0.08331	599.8

The three-dimentional model of slider-crank mechanism is as shown in Fig. 2.

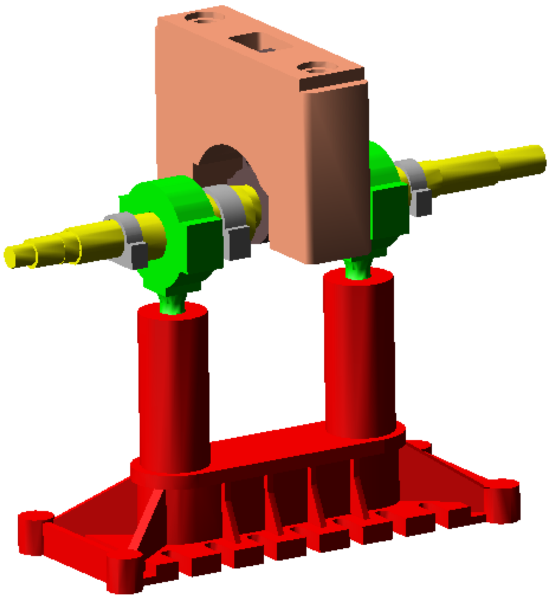

Fig. 2 The three-dimentional model of slider-crank mechanism

2.3 Boundary conditions

The finite element package ADAMS is employed to establish the dynamics model and analyze the force loading status of crankshaft. Adams View supports two types of idealized joints: simple and complex. Simple joints directly connect bodies and include the following: revolute joints, translational joints, cylindrical joints, spherical joints, planar joints, constant-velocity joints, screw joints, fixed joints and hooke/universal joint. Complex joints indirectly connect parts by coupling simple joints. They include: gears and couplers.

The constraint is established based on the movement characteristics of high-speed punch and the constraint is shown in Table 2.

Table 2 The constraint of slider-crank mechanism

No	Relevant part	Type of constraint	Amount	Number of degree of freedom	Remark
1	The punch frame, ground	Fixed	1	0	Fixed
2	Main slider, punch frame	Translational	1	1	Moving up and down
3	Balancing slider, punch frame	Translational	1	1	Moving up and down
4	Crankshaft, punch frame	Revolute	1	1	rotation
5	Crankshaft, main connecting rod	Revolute	2	1	rotation
6	Main connecting rod, main slider	Spherical	2	3	rotation
7	Crankshaft, balancing connecting rod	Revolute	1	1	rotation
8	Balancing connecting rod, balancing slider	Revolute	1	1	rotation

2.4 Motion generator

Adams View provides two types of motion: (1) Joint Motion, prescribes translational or rotational motion on a translational, revolute, or cylindrical joint. Each joint motion removes one degree of freedom (DOF) from the model. Joint motions are very easy to create, but they limit to motions that are applied to the above listed joints and movements in only one direction or rotation. (2) Point

Motion, prescribes the movement between two parts. When a point motion is created, the direction along which the motion occurs should be specified. A point motion can be imposed on any type of idealized joint, such as a spherical or cylindrical. Point motions can build complex movements into the model without having to add joints or invisible parts.

In this paper, the motion is created at the crankshaft, as shown in Fig. 3.

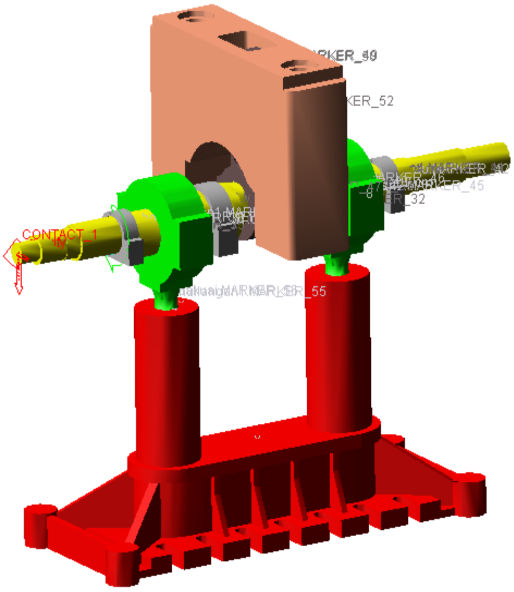

Fig. 3. The model of slider-crank mechanism with boundary conditions and motion

3. Results and discussion

3.1 Dynamics analysis result of slider

To simplify the analysis process, the part of slider-crank mechanism is considered as rigid body and this will not affect the accuracy of analysis results. The dynamics analysis of slider-crank mechanism under different strokes (from 300 SPM to 1000 SPM, the incremental change is 100 SPM) were carried out. The initial position of slider is at the bottom dead center. The displacement, velocity and acceleration in vertical direction of slider under 1000 SPM is shown in Fig. 4.

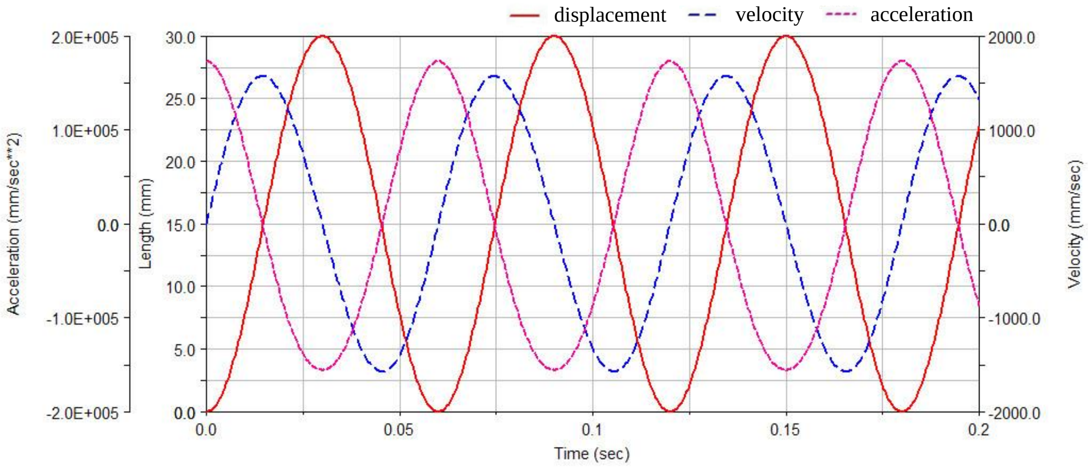

Fig. 4. The displacement, velocity and acceleration in vertical direction of slider under 1000 SPM

The dynamics analysis begins at the bottom dead center of main slider and the motion is moving up and down in vertical direction of high-speed punch. As can be seen from the chart, the maximum displacement of main slider is 30 mm and the displacement, velocity and acceleration change as sine wave in a punch period. The displacement of main slider does not change, but the velocity and acceleration increase with the increase of the strokes, as shown in Table 3.

Table 3 The velocity and acceleration amplitudes under different number of strokes

Number of strokes / SPM	300	400	500	600	700	800	900	1000
Velocity amplitude / mm/s	471.9	629.2	786.5	943.7	1101.1	1258.3	1415.6	1572.7
Acceleration amplitude / mm/s*2	15583.6	27704.2	43287.8	62334.4	84844.0	110820	140250	173150

Fig. 5 shows the curve of velocity and acceleration amplitudes of slider under different strokes. As can be seen from the chart, the velocity of main slider shows a linear variation with the value of the punch stroke and the acceleration of main slider shows an index change. And the inertia force of slider-crank mechanism also increase in an index change with the value of the punch stroke, so as the vibration of the whole punch.

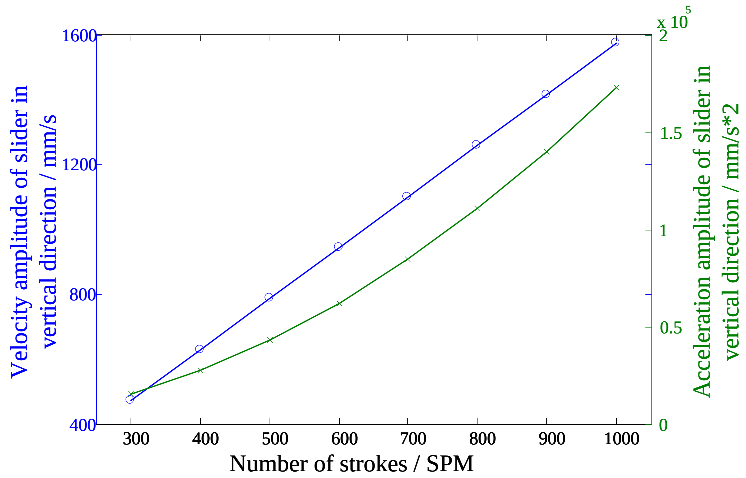

Fig. 5. The curve of velocity and acceleration amplitudes of slider under different strokes

3.2 Dynamics analysis result of crankshaft

To analyze the stress of crankshaft in a stroke period, the displacement of crankshaft in vertical direction is also shown in the chart. The stress in vertical direction of crankshaft under 1000 SPM is shown as Fig. 6. The data of the stress of crankshaft in two limit positions (the top dead center and the bottom dead center of slider) are given in Table 4.

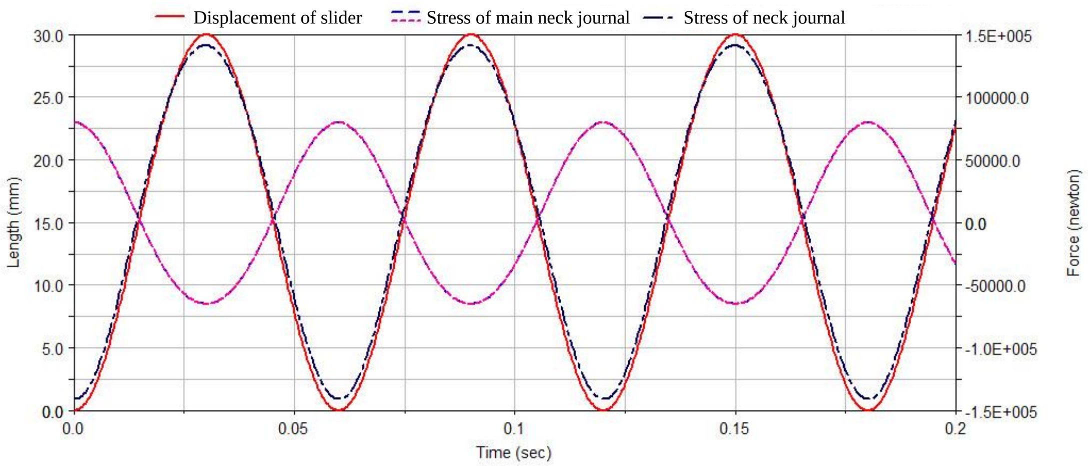

Fig. 6. The stress in vertical direction of crankshaft under 1000 SPM

Table 4 Stress of crankshaft in two limit positions

Number of strokes /SPM	Stress of the top dead center of slider /N		Stress of the bottom dead center of slider /N	
	Neck journal of main connecting rod	Neck journal of balancing connecting rod	Neck journal of main connecting rod	Neck journal of balancing connecting rod
300	-1917.86×2	18419.83	11097.97×2	-6984.14
400	-6762.49×2	27863.47	16376.77×2	-17296.46
500	-12991.29×2	40005.07	23163.80×2	-30554.63
600	-20604.26×2	54845.64	31459.06×2	-46757.96
700	-29600.70×2	72383.23	41262.55×2	-65910.97
800	-39979.01×2	92617.70	52574.27×2	-88003.79
900	-51748.26×2	115550	65394.22×2	-113050
1000	-64897.95×2	141180	79722.40×2	-141040

For convenient analysis, the changes of the stress of crankshaft in two limit positions are drawn in Fig. 7 and Fig. 8. The stress of crankshaft increases with the value of the punch stroke. At the top dead center of slider, the stress of neck journal of balancing connecting rod is bigger than that of neck journal of main connecting rod. But at the bottom dead center of slider, it is just the opposite.

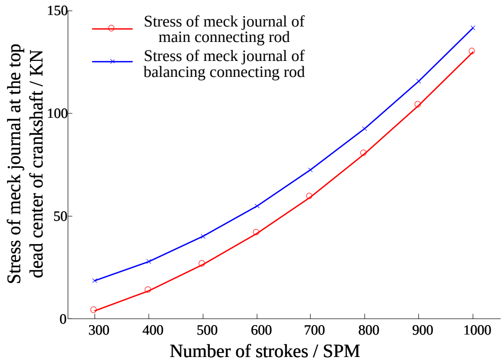

Fig. 7. Stress of the top dead center of crankshaft under different strokes

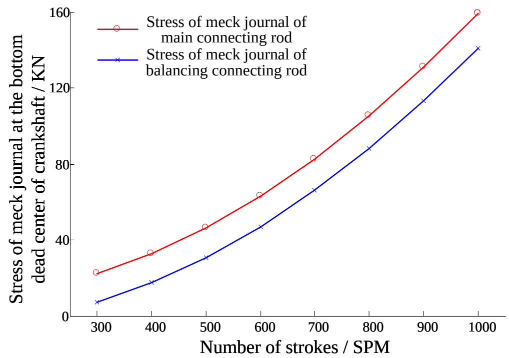

Fig. 8. Stress of the bottom dead center of crankshaft under different strokes

4. Conclusion

After analyzing the structure of crankshaft of high-speed punch, the model of slider-crank mechanism is built in ADAMS. The boundary condition and motion generator are confirmed according to the characteristics of slider-crank mechanism. The dynamics analysis of slider-crank mechanism under different strokes (from 300 SPM to 1000 SPM, the incremental change is 100 SPM) are carried out. The change of the displacement, velocity and acceleration in vertical direction of slider under different punch strokes are analyzed. The change of the stress of crankshaft in two limit positions (the top dead center and the bottom dead center of slider) under different punch strokes are analyzed. The dynamics analysis results provide a basis for the design and optimization of crankshaft of high-speed punch.

Acknowledgements

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References

[1] S.K. Kernosky, K.J. Weinmann, J.R. Michler, et al. Development of a die shoulder force transducer for sheet metal forming research, Journal of Manufacturing Science and Engineering, vol. 120(1988), p.42-48.

[2] R. Hambli, F. Guerin, B. Dumon. Numerical evaluation of the tool wear influence on metal-punching processes, The International Journal of Advanced Manufacturing Technology, vol. 21(2003), p.483-493.

[3] M.C. Doolan, S. Kalyanasundaram, P. Hodgson, et al. Identifying variation in sheet metal stamping, Journal of Materials Processing Technology, vol. 115(2001), p.142-146.

[4] J. Breitling, D. Wallace, T. Altan. Investigations of different loading conditions in a high speed mechanical press, Journal of Materials Processing Technology, vol. 59(1996), p.18-23.

[5] R. Du, W.Z. Guo. The Design of a New Metal Forming Press with Controllable Mechanism, Journal of Mechanical Design, vol. 125(2003), p.582-592.

[6] X.H. Fan. Crankshaft System Analysis Based on the Finite Element and Multi-body, Dalian: Dynamics Dalian University of Technology, 2016. (In Chinese)

[7] X.G. Ma, X.M. You, B.C. WEN. Multi-body dynamics simulation for a crankshaft system based on virtual prototype technology, Journal of Vibration and Shock, vol. 27(2008) No. 4, p.155-157. (In Chinese)

[8] Z.G. Fan, Q. Li. Dynamic Analysis of Engine Crankshaft Based on ANSYS and ADAMS, Machine Building & Automation, vol. 36(2007) No. 3, p.89-91. (In Chinese)

[9] J.X. Wu, H.Q. Li, M.S. Pang. Dynamical Simulation of Engine Crankshaft System Based on MATLAB and ADAMS, Machine Building & Automation, vol. 43(2014) No. 1, p.101-103. (In Chinese)

[10] A.M. Hu. Dynamics Simulation Analysis of Diesel Engine Crankshaft System based on ADAMS, Coal Mine Machinery, vol. 31(2010) No. 2, p.62-65. (In Chinese)

[11] Y.L. Wang. Research on dynamic characteristics and structure optimization of V8 engine crankshaft, Shenyang: Shenyang Ligong University, 2012. (In Chinese)

[12] S.J. Han, T. Wu, S.Q. Liu, et al. Research on the Dynamics of Crankshaft Under the Condition of Operating Mode Based on LS-DYNA, MATEC Web of Conferences, vol. 61(2016), p.05015.