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Flexible impulse response of the multi-bar linkage with heavy load

Feng Xianzhang, Cheng Junwei, Cui Yanmei, Jiang Zhiqiang

School of Mechanical Engineering, Zhengzhou Institute of Aeronautical Industry Management, Zhengzhou, Henan, 450015, P.R. China

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It is based on the advantages of virtual prototyping technology, the dynamics mathematic model was established for the large mechanism by applying multi body dynamics theory. In order to adapt the users to special request of the strip width size, appeared the continuous casting and continuous rolling technology, and greatly reduce the width types of continuous casting. The components of the equipments are often considered the rigid body. The precision is not high premise in the process of work, usually the parts works as elastic under the high speed and the heavy load, neglects various components the elastic function will cause the result error, even will be wrong. Studied analysis dynamic characteristic of the adjustment width machine, and analyzed the component in detail for the rigid body or the elastic. The results provide the theoretically support to work out adjustment the width potentialities and strength analysis of the key parts.
Keywords: Rigid-elastic, dynamic system, key parts, large mechanism, heavy load.

Разработана динамическая математическая модель для больших механизмов, базируясь на технологии виртуального макетирования, путем применения многочастичной динамической теории. Для адаптации к специальным требованиям по ширине полос выработаны технологии непрерывного литья и непрерывной прокатки, существенно ограничивая требования по ширине процесса литья. Компоненты оборудования часто рассматриваются как твердые тела. Точность невелика, т.к. в процессе работы детали часто проявляют эластичность при высокой скорости или большой нагрузке, и пренебрежение этим фактором приведет к ошибочным или даже полностью неправильным результатам. Исследованы динамические характеристики согласования с деталями механизма и проведен анализ компонентов на предмет их твердости или эластичности. Результаты дают теоретическое обоснование для возможности регулировки по ширине и анализа механической прочности основных деталей.

Гнучкий імпульсний відгук многостержневих з'єднань при великих навантаженнях. Фен Сяньчжан, Цуй Яньмей, Чен Цзюньвей, Цзян Чжицзян.

Розроблено динамічну математична модель для великих механізмів, базуючись на технології віртуального макетування, шляхом застосування Багаточасткові динамічної теорії. Для адаптації до спеціальним вимогам по ширині смуг вироблені технології безперервного лиття і безперервної прокатки, істотно обмежуючи вимоги по ширині процесу лиття. Компоненти обладнання часто розглядаються як тверді тіла. Точність невелика, тому що в процесі роботи деталі часто виявляють еластичність при високій швидкості або великому навантаженні, і нехтування цим фактором призведе до помилкових або навіть повністю неправильних результатів. Досліджено динамічні характеристики узгодження з деталями механізму і проведено аналіз компонентів на предмет їх твердості або еластичності. Результати дають теоретичне обгрунтування для можливості регулювання по ширині і аналізу механічної міцності основних деталей.

1. Introduction

Steel industry is closely related to the national economy, the quality of steel products has direct influence on household appliances, automobiles, electronics, construction, and shipbuilding, aerospace and so on. Today, quality steel sheet and strip become an important symbol to measure the level of Iron and steel industry for a country. [1-5]

In recent years, in order to adapt the fierce competition, reducing energy consumption, improving product quality and productivity, and user's specific requirements of width of the strip, the producers need more different kinds of slab. To realize the convergence between continuous casting and continuous rolling, the technology of slab side pressing is an online regulation width can meet these requirements, and can effectively reduce the specification and specs of continuous casting slab. Moreover, make further improvement the level of integration for in casting and rolling. [6-10]

It is closely related between the slab casting and rolling process and width adjustment. The ability of vertical rollers is limited, in which lie in front of the vertical roller mill decaling machine and Roughing mill, cannot undertake the task of large lateral pressure-width-modulated. It is an important skill to apply the synchronous production control system between the continuous casting and continuous rolling. [11, 12]

There are two types forms in the world: staring and stopping, flying. For the type of staring and stooping, the principle of lateral pressure is shown in Figure 1.

2. Dynamics analysiss

2.1 Many-body dynamics analysis

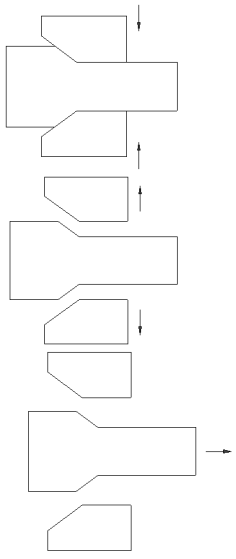

Fig. 1. Schematic go and stop

There is physical contact between die and workpiece during the working of width mechanical press. Lateral linkage and the main eccentric rod work under the majority load, in which is from rolling force by the transmission line from die to main eccentric axis of side pressing machinery. It's paramount importance to analyze stress and strain of major components.

At the same time, it's significant to study more accurate equations of die, normal operation and function of equipment.

Multi body system is consists of some flexible bodies and rigid bodies, and interconnected among these. Rigid multi-body system dynamics is the study of is a discipline about the movement of multiple body systems, and developed on the basis of classical mechanics, involving kinematics and biomechanics, space control, robot dynamics, vehicle design, mechanical dynamics, etc.

2.2 Problems analysis

It can be divided into two different kinds of problems by the task of research dynamics:

Inverse dynamics analysis:

Known the movement status and working resistance, and to solve the variation ruler of reaction force and the input torque in these kinematic pairs.

The normal dynamics analysis:

Known the variation ruler of reaction force and the input torque in these kinematic pairs, and to solve the really the movement of the motion mechanism.

Also there are many types of body dynamics analysis, such as static analysis, dynamic static analysis, dynamic analysis, elastic dynamic analysis, etc.

Static analysis:

Without consideration of influence of inertial force for the mechanical device with slow motion. By static method, it can obtain the load balancing, where located at different position of mechanical movement, then applied to the input force or torque for drive component, as well as reaction force in the motion pairs. This is the method of force analysis in earliest history.

Kinetics static analysis:

Consideration of influence of inertial force for the mechanical device with raise of speed. It can obtain the balancing static load and dynamic load, where located at different position of mechanical movement. Using Alembert principle, the balance equation included static inertia forces, and then applied to the input force or torque for drive component, as well as reaction force in the motion pairs. This is the method of f kinetics static analysis in history.

Dynamic analysis

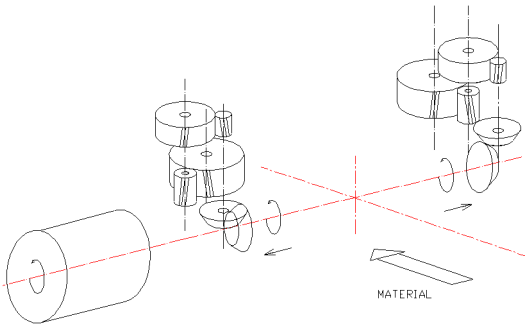

Fig. 2.Transmission system

For the idealized assumptions, although this assumption is allowed in many cases, but the machinery equipment can not maintain constant speed of the drive components under the load.

However, many engineering problems are also often required to know the real movement of the mechanical system in practical.

Consideration of influence of mechanical external force, solving real motion by the method of the so-called dynamic analysis.

Abandoned ideal assumptions of the ruler of movement of drive components, the mechanical systems should be included Part of the original motivation

Therefore, the entire object for dynamic analysis is the whole mechanical systems. The mathematical model solve linear algebraic equations for the static analysis and kinetic static analysis, however, the mathematical model solve Differential equations for the dynamic analysis.

Kinetic elastic dynamics:

The components are assumed to be rigid for the above three methods. But the real mechanical components is a flexible body in the many case,

The size of the elastic deformation is responsible for its force, shape, stiffness and so on. The natural frequency increases with increase the flexibility of mechanical systems.

When the excitation frequency is close to the natural frequency, it can occur a strong vibration to damage the movement accuracy of mechanical, also affect the fatigue strength, and increase the friction in the motion pairs.

In the case, as a rigid body the analysis of the component can not meet the requirements. Therefore, there is an analytical method of kinetic elastic dynamics, considered the driving force for the elastic component [17-20].

3. Motion analysis

The research of the transmission system is shown in Figure 2.

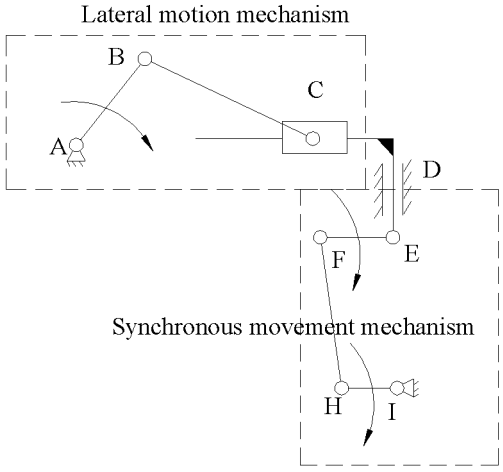

Fig. 3.Force model of liner

The Figure 2 shows that have a main motor for the main transmission system make the direction of transmitted to change 0.5π , after two conical helical gear systems. By decelerate device of cylindrical helical gear, pass movement of the main motor drive system to vertical shaft of side pressing mechanism, at last, the dies can move along lateral direction, in which lie in the front of lateral framework.

In order to analyze to sectional characteristic and the quality of all the components for entity model of the adjust machine, and acquire the quality and its mechanics characteristic for the synchronous mechanism and side pressing mechanism, it can supply the useful information to dynamics analytical.

For the stress of joints in the pressing mechanism, consider the symmetry of the mechanism, taking one part of the mechanism as the research object. In the process of adjust width, the movement diagram of mechanism is shown in Figure 2.

The Figure 3 shows that the mechanism includes lateral machine, synchronous machine and width machine. Lateral machine is compose by two pieces with crank slide block. Completing the side pressing is important function for the slab.

synchronous machine is constitute by synchronous electric motor, increase machine, two eccentricity shifts and synchronous frame, it supply the movement weight of the die to ensure the slab velocity to close the dies along the direction of rolling line.

The width machine can adjust the distance of the both dies, by screw turns to push side presses a frame go forward or retreat, base on the two sets adjust the breadth electrical engineering, the umbrella wheel gear box, machine device of worm pole and worm wheel with nut.

4. System equation

4.1 Kinematics analysis

Basis the related knowledge of the theories and kinetics of element finite and kinematics, a point in the elastic body, the elastic displacement and rigid displacement can describe as following:

$$\begin{cases} \{\delta\} = [N]\{\delta^e\} \\ \{\delta_r\} = [N_r]\{\delta_r^e\} \end{cases} \quad (1)$$

Where $\{\delta\}$, $\{\delta_r\}$ are the elastic displacement and rigid displacement for a point in the elastic body. $[N]$, $[N_r]$ are the shape function matrix elastic body and rigid body, no relation with time. $\{\delta^e\}$, $\{\delta_r^e\}$ are the elastic displacement and rigid displacement for a node in the element.

Base on the formula (1), a point in the element body, the deform velocity $\{\dot{\delta}\}$ and acceleration $\{\ddot{\delta}\}$ can express as:

$$\begin{cases} \{\dot{\delta}\} = [N]\{\dot{\delta}^e\} \\ \{\ddot{\delta}\} = [N]\{\ddot{\delta}^e\} \end{cases} \quad (2)$$

Where $\{\dot{\delta}\}$, $\{\ddot{\delta}\}$ are the velocity and acceleration of a point in the element body. $\{\dot{\delta}^e\}$, $\{\ddot{\delta}^e\}$ are the velocity and acceleration of a node in the element body.

Base on the formula (1), a point in the rigid body, the deform velocity $\{\dot{\delta}_r\}$ and acceleration $\{\ddot{\delta}_r\}$ can express as:

$$\begin{cases} \{\dot{\delta}_r\} = [N_r]\{\dot{\delta}_r^e\} \\ \{\ddot{\delta}_r\} = [N_r]\{\ddot{\delta}_r^e\} \end{cases} \quad (3)$$

Where $\{\dot{\delta}_r\}$, $\{\ddot{\delta}_r\}$ are the velocity and acceleration of a point in the rigid body. $\{\dot{\delta}_r^e\}$, $\{\ddot{\delta}_r^e\}$ are the velocity and acceleration of a node in the rigid body.

In the analysis for flexible body dynamic, displacement, velocity and acceleration of a point in element can express as:

$$\begin{cases} \{\delta_a\} = \{\delta_r\} + \{\delta\} \\ \{\dot{\delta}_a\} = \{\dot{\delta}_r\} + \{\dot{\delta}\} \\ \{\ddot{\delta}_a\} = \{\ddot{\delta}_r\} + \{\ddot{\delta}\} \end{cases} \quad (4)$$

Where $\{\dot{\delta}_a\}$, $\{\ddot{\delta}_a\}$ is absolute velocity and absolute acceleration of a point in element.

It can solve the kinematics questions under appropriate displacement functions of rigid and elastic bodies for the elastic kinematics analysis.

2.2 Flexible dynamics equations

In order to build the equations of flexible dynamics, at first, it should obtain the quality matrix, the damping matrix and the stiffness matrix of the element.

Quality matrix of the element:

Taking a decline cell from the element j, and then quality matrix of the element j can express as:

$$[M]^e = \rho \iiint [N]^T [N] dv \quad (5)$$

Damping matrix of the element:

Taking a decline cell from the movement element in component, and then damping matrix of the element $[\mathbf{C}]^e$ can express as:

$$[C]^e = [C_m] + [C_k] = \alpha [M]^e + \beta [K]^e \quad (6)$$

Stiffness matrix of the element:

Based on the theory of finite element, and then arbitrariness stiffness matrix of the element $[\mathbf{K}]^e$ can express as:

$$[K]^e = \iiint [B]^T [D][B] dV \quad (7)$$

Where $[\mathbf{K}]^e$ is stiffness matrix of the element, $[B]$ is geometry matrix.

The finished flexible dynamics equations:

It can express as:

$$\begin{aligned} [M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = \\ = \{F(t)\} - [M]\{\ddot{U}_r\} \end{aligned} \quad (8)$$

Where $[\mathbf{M}]$ is total quality matrix, it can describe as following:

$$[M] = \sum [M_e]$$

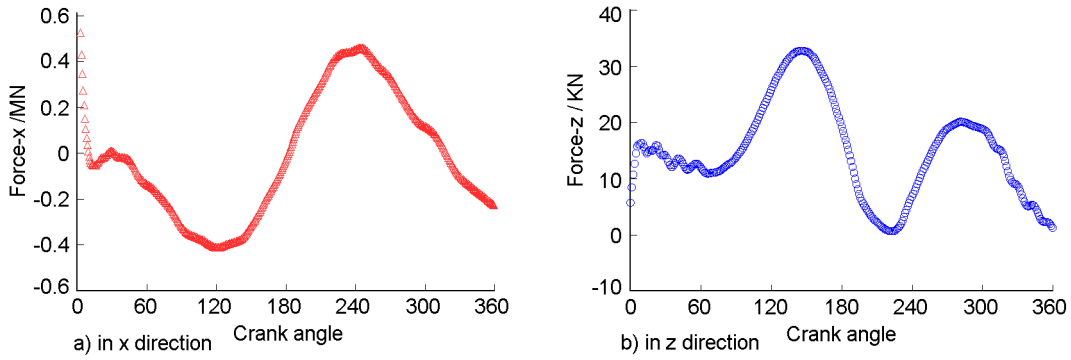

Fig. 4.Force of joint A

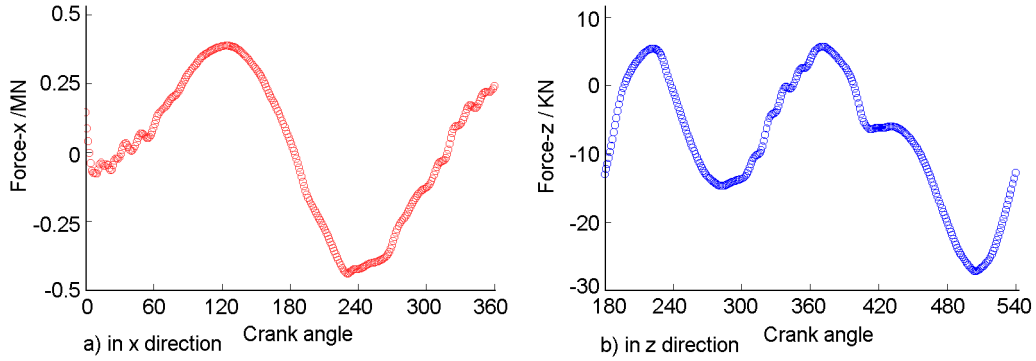

Fig. 5. Force of joint B

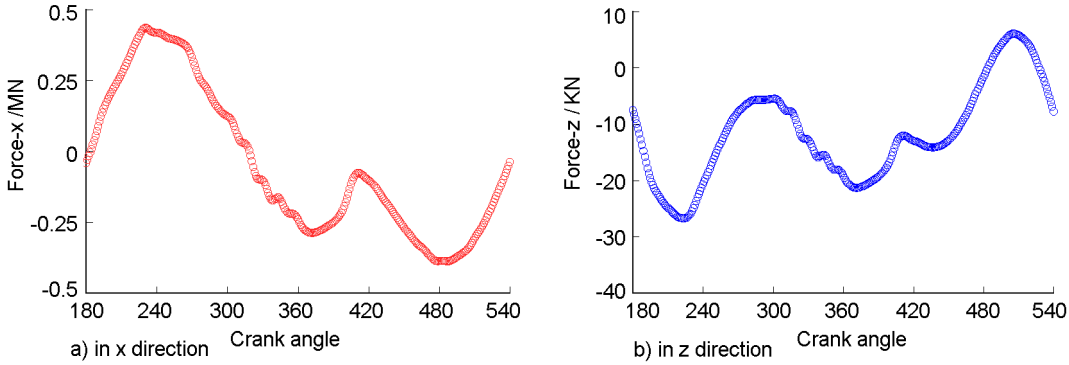

Fig. 6.Force of joint C

$[\mathbf{C}]$ is total quality matrix, it can describe as following:

$$[C]=\sum[C_e]$$

$[\mathbf{K}]$ is total Stiffness matrix, it can describe as following:

$$[K]=\sum[K_e]$$

It can obtain the result of and the equation to analyze the formula (8), the formula is non-linearity differential equation of two steps, there are many methods to solve the type equation groups, including numerical method, such as direct integral calculus method, addition vibration type, Fourier series method, and status space, the method of direct integral calculus mainly based on the point of view of mathematics, using the approach approximate method of stepwise integral for the non-linearity differential equation of two steps. It common uses the A Runge-Kutta method, Wilson method, Newmark method, etc. There have already develop more mature, and already had the business standard procedure can directly transfer to use.

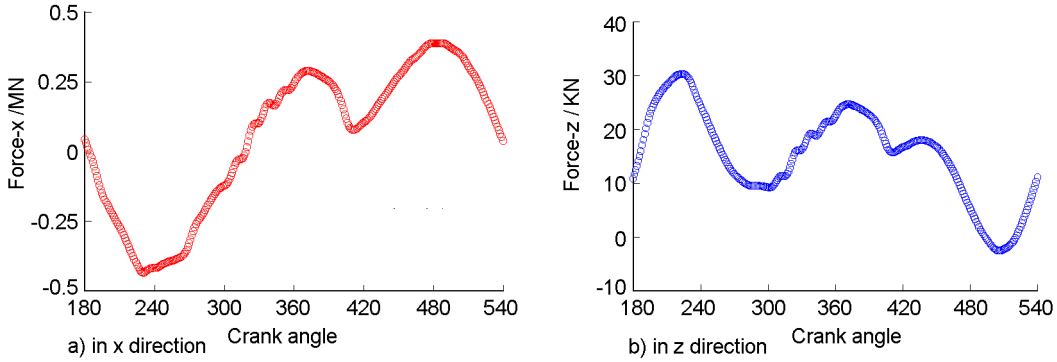

Fig. 7.Force of joint D

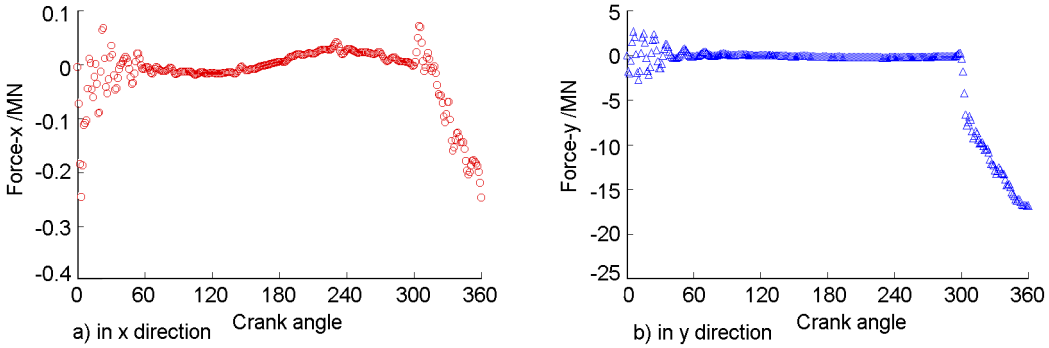

Fig. 8.Force of joint M

5. Conclusions

5.1 Synchronous mechanism

In process of working for the side pressing machine, the stress of joint A is shown in Figure 4.

From Figure 4, the x direction is the direction of the rolling line, the x direction is the direction of gravity. The force is greater than the other direction in the direction of the rolling line, with the existence of differences between the synchronization mechanism and lateral mechanism.

In process of working for the side pressing machine, the stress of joint B is shown in Figure 5.

From Figure 5, the motion pair B is similar situation with the motion pair A, they should meet the same law.

In process of working for the side pressing machine, the stress of joint C is shown in Figure 6.

From Figure 6, the motion pair C is similar situation with the motion pair A and B, they should meet the same law.

In process of working for the side pressing machine, the stress of joint D is shown in Figure 7.

From Figure 7, the motion pair D is similar situation with the motion pair A, B and C, they should meet the same law.

From Figure 4 to Figure 7, in process of side pressing for the slab, considering the effective of elastic of the lateral connecting rod, it's value is smaller than the simulation result of dynamics model with clearance, because of flexible factor of connecting rod, the clearance in the joints to occur impact, the connecting rod as the elastic body can absorb one part of energy, prolong the contact time into all the joints, ultimate making the trend to weaken for the stress in all the joints.

Connecting rod as rigid body, it can become greater or larger to the stress of in all the joints, because of existent clearance in joints, in which lead to immensity instant impact, for the reasons that the connect rod can't absorb immensity instant impact energy as the rigid body during occurring the impact in the clearance in the joints. Thereby, it can make the stress enlarge in each joint.

5.2 Lateral machine mechanism

In process of working for the lateral machine, the stress of joint M is shown in Figure 8.

From Figure 8, the x direction is the direction of the rolling line, the Y direction is the direction of rolling force. The lateral mechanism

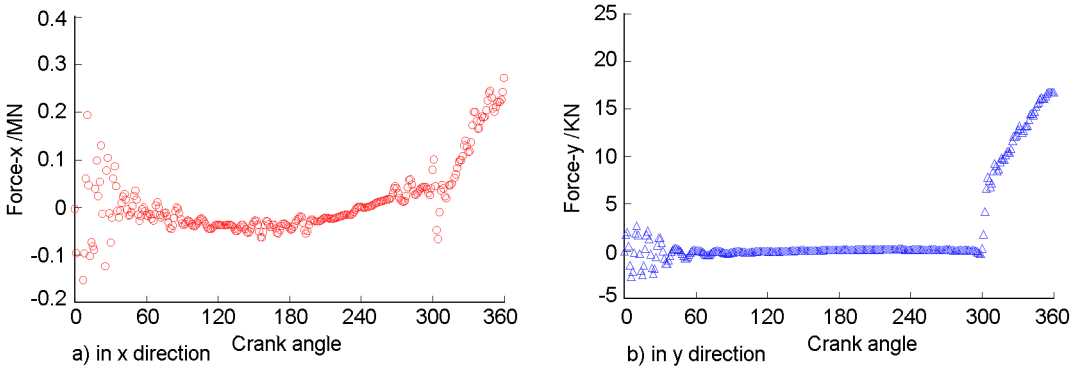

Fig. 9.Force of joint N

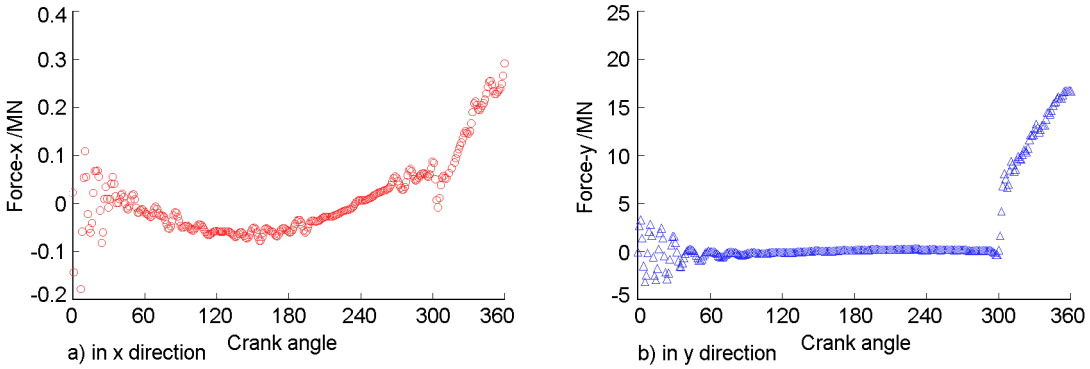

Fig. 10.Force of joint P

is mainly responsible for the rolling force during side pressing.

From Figure 9, the motion pair M is similar situation with the motion pair N, they should meet the same law.

In process of working for the lateral machine, the stress of joint P is shown in Figure 10.

From Figure 10, the motion pair P is similar situation with the motion pair N and M, they should meet the same law.

From Figure 8 to Figure 10, in turn angle range of main crank from 300° to 360°, the connecting rod as rigid body, the stress of joint M, N and P for rigid component is larger than the result for the elastic body. When the angle of main crank reach the 300°, whether the side connecting rod is rigid or not, the stress fluctuate increase in the join. It is the reason of the beginning of the side pressing stage, the impact effect of the rolling force and short action time for dies, it is non-steady-state process, and the elastic deformation had fluctuated in joint of contact area. With the further side pressing of continuous casting slab, according to the given path on the slab for width adjustment, the elastic deformation change smoothly had fluctuated in joint of contact area.

Acknowledgements

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