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NUMERICAL MODEL OF VIBRATION CONTROL STRATEGY FOR TRUCK-MOUNTED CONCRETE PUMP BOOMS

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The vibration of truck-mounted concrete pump booms during concrete pouring process will result in fatigue failure and even fracture, imprecise positioning, and shortening lifespan, et al. This paper aims to study the vibration control strategy for truck-mounted concrete pump booms in order to reduce/eliminate the booms vibration by combining the booms with pump unit completely. First, the mathematical models of hydraulic system of booms and pump unit are established respectively, and the dynamic characteristics of booms and pump unit are analyzed independently. Second, the reason and influence factors of vibration of truck-mounted concrete pump booms are analyzed. Then, the vibration control strategy for truck-mounted concrete pump booms is proposed, and a numerical model is established to identify the validity of the vibration control strategy. The research findings offer a new powerful tool for dealing with the issue of vibration control for truck-mounted concrete pump booms and other rigid-flexible coupling machinery.

Keywords: vibration control strategy, concrete pump booms, rigid-flexible coupling

1. Introduction

A truck-mounted concrete pump is the special engineering equipment combining concrete delivering procedure with concrete pouring procedure by integrating boom system used to placing concrete and placing boom and pumping mechanism on the chassis of a truck [1]. It has been used widely in constructions of highways, bridges, high-rise buildings, etc. because of the characteristics of high efficiency, high automation degree, excellent flexibility and mobility [2]. More and more construction sites are considering selecting truck-mounted concrete pump as the priority construction device for delivering concrete because the use of truck-mounted concrete pump can increase productivity and improve the quality of products and services significantly [3]. With the rapid development of economic and the expanding of construction scale all over the world, lots of large construction projects have huge demand for truck-mounted concrete pump, and the design and manufacture technologies of truck-mounted concrete pump have been rapidly developed [4].

A boom system mainly consists of foldable placing booms, hydraulic cylinders and conveying pipes, etc. The movement of a boom system is not only the coupling of spatial large-scale rigid motion and elastic deformation, but also the coupling of flexible multi-body dynamics and pipeline rheological dynamics. Furthermore, a boom system is a typical complex system of multi-input multi-output (MIMO), highly nonlinear and various physical laws coupling [1]. Since a truck-mounted concrete pump continuously works in a harsh environment for a long time, and the stress situation of boom structure is complicated and changeable, it will cause vibration of a boom system with complex structure. Especially when external disturbance excitation frequency is close to natural frequency of a boom, resonance phenomenon occurs, thus it will influence the construction efficiency and support stability, meanwhile will easily result in some crackle in part of a boom, and even lead to fracture, thus cause serious incident of personnel and equipment. In addition, the vibration of a boom system will make it difficult to locate the end accurately and influence the control precision. In the development trends of long boom, light weight, multi joints and high control efficiency, etc., the vibration problem of a boom system of a truck-mounted concrete pump is more prominent. It is reducing the vibration of a boom system of a truck-mounted concrete pump during its work process that is the issue needed to be solved urgently in the field of vibration control of a truck-mounted concrete pump.

In recent years, some publications regarding vibration control of booms can be found in the literature. Xiaojie Sun et al. [5] proposed a strategy including closed-loop detection and open-loop control. J. Henikl et al. [6] presented a decentralized control concept for damping elastic vibration actively by using a feed forward controller in combination with a passivity-based feedback control law [7], and a systematic approach for the mathematical modeling of a truck-mounted concrete pump by taking into account both elasticity and static friction [8], and an infinite-dimensional decentralized damping control strategy [9]. G. Cazzulani et al. [10, 11] investigated the systems including boom and pump independently to identify their individual aspects, and built a mathematical model to reproduce the behavior of the whole system and the interaction between boom and pump. Dirk Nissing et al. [12, 13] used a model independent approach to damp control actively. Rongsheng Liu et al. [14] developed an active control strategy of constant-position commandless input shaping technique. Wu Bin-xing et al. [15] developed an adaptive vibration control system of composite material booms based on positive hydraulic control system and vibration properties expert system and realized the real time vibration control of booms under all working conditions. WANG Bin-hua et al. [16, 17] established the fluid-solid interaction dynamic equation regarding boom structure and concrete based on the fluid-solid interaction theory of cantilever conveying pipe. HUANG Yi et al. [18] designed an active control strategy via using modal filtering and optimal control theory. Kuang Hao et al. [19] studied the active control algorithm regarding boom vibration under the excitation of pumping concrete based on independent modal space control method and developed an active vibration control system of boom system based on CompacRIO in combination with LabVIIEW. Wu Zhiyong et al. [20] used the time-series approach to predict the vibration posture of the boom’s tip in advance in order to let the predicted vibration posture be close to its real posture possibly based on the historical vibration displacement data of the boom’s tip. WANG Jiaqian et al. [21] used Fuzzy PID compound control algorithm to calculate offset control current and adjust the position of booms so as to guarantee the stability of active vibration reduction control.

This paper is organized as follows: In section 2, the mathematical models of hydraulic system of booms and pump unit are established respectively, and the dynamic characteristics of booms and pump unit are analyzed independently. Section 3 contributes to influence factors of vibration of truck-mounted concrete pump booms, a novelty vibration control strategy, and the numerical model of vibration control strategy. In section 4, the simulation results of vibration control strategy are shown and discussed. Finally, conclusions are provided in section 5.

2. Mathematical models of hydraulic system of pumping unit and booms

2.1 Mathematical model of booms hydraulic system

When a truck-mounted concrete is pumping concrete, the concrete in concrete cylinder is pumped out and reaches the destination along the conveying pipes installed on the booms. The change of destination is realized depending on expansion and fold of the booms driven by the booms hydraulic system. This paper uses the M-type 4 booms to analyze the vibration control strategy of booms as shown in Fig. 1.

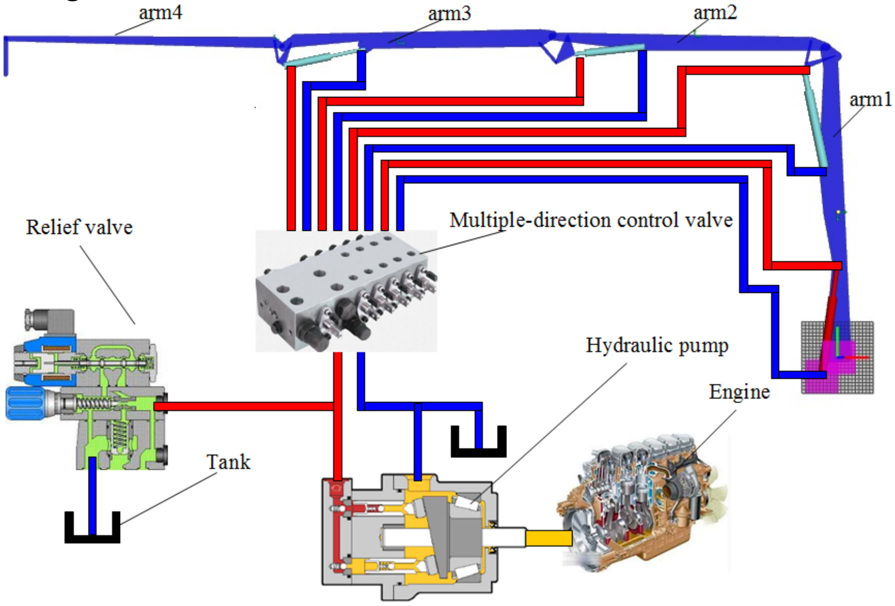


Fig. 1 Booms hydraulic system

The engine drives the hydraulic pump and the pressure oil from the hydraulic pump flows through Multiple-direction control valve and enters into hydraulic cylinders installed on booms. By controlling the movement of rods of these hydraulic cylinders, the expansion and fold of booms can be realized accordingly.

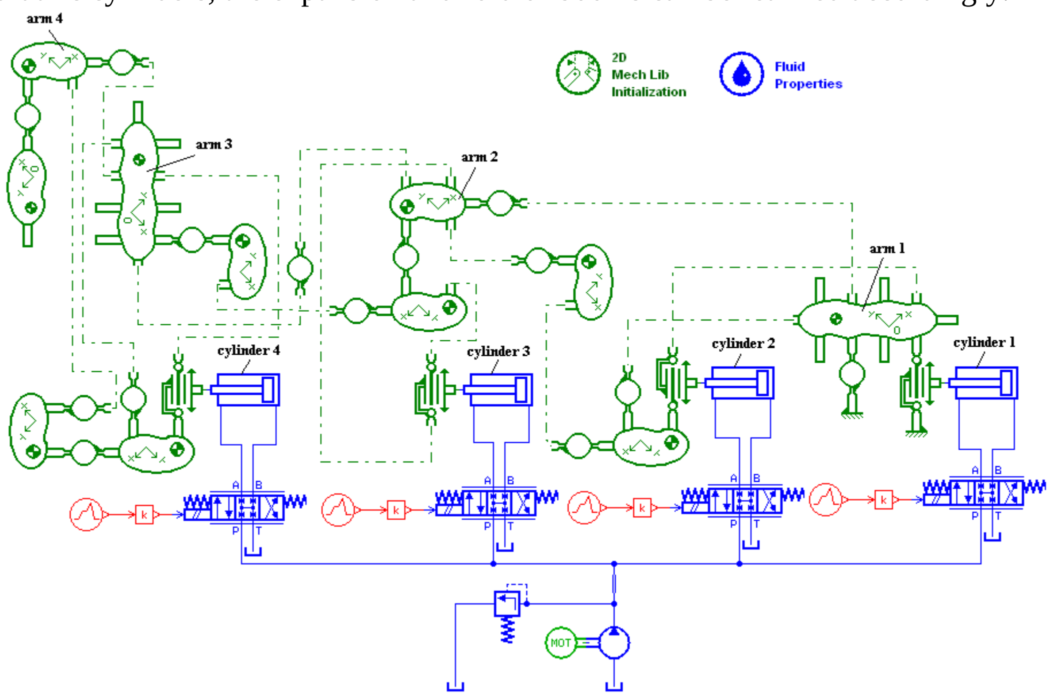


Fig. 2 Model of booms hydraulic system

AMESim is an advanced model establishing and simulation software, which provides an integral environment for system engineering design so that user can build a complex multidisciplinary field system model in this environment and furthermore carry out simulation calculation and in-depth analysis. This paper uses AMESim to build the mathematic model of the pumping unit open-circuit hydraulic system. Based on the booms hydraulic system, the mathematic model of booms hydraulic system is established in AMESim as shown in Fig. 2.

2.2 Mathematical model of pumping unit hydraulic system

Currently, an open-circuit hydraulic system has been applied in most of concrete pumps. In addition, because the pumping unit hydraulic system contributes a big proportion to the vibration of a truck-mounted concrete pump, this paper mainly establishes the mathematic model of the simplified pumping unit open-circuit hydraulic system as shown in Fig. 3.

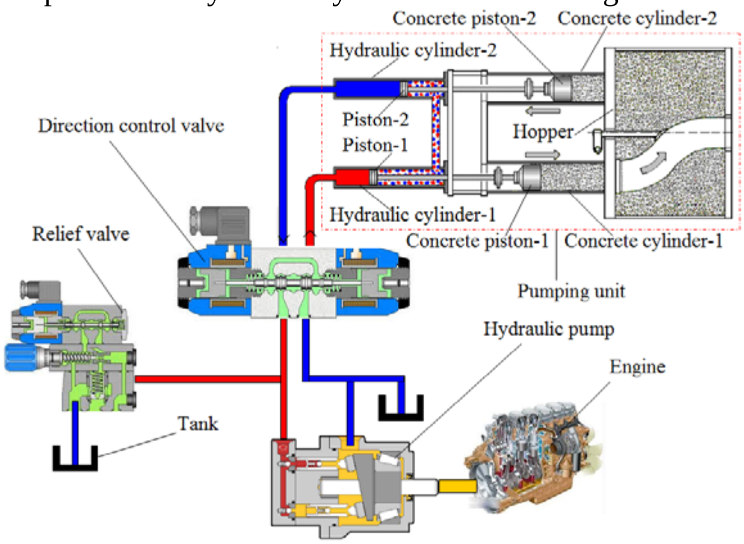


Fig. 3 Pumping unit hydraulic system

The engine drives the hydraulic pump and the pressure oil flows through direction control valve and enters into the rodless cavity of hydraulic cylinder-1, then the piston-1 moves forwards and propels the concrete piston-1 and the concrete in concrete cylinder-1 is pumped out. Because the rod cavities of hydraulic cylinder-1 and hydraulic cylinder-2 are connected, the piston-2 moves backwards when the piston-1 moves forwards, accordingly the concrete piston-1 moves backwards and the concrete in the hopper is sucked into concrete cylinder-2. The mathematic model of pumping unit hydraulic system is established in AMESim as shown in Fig. 4.

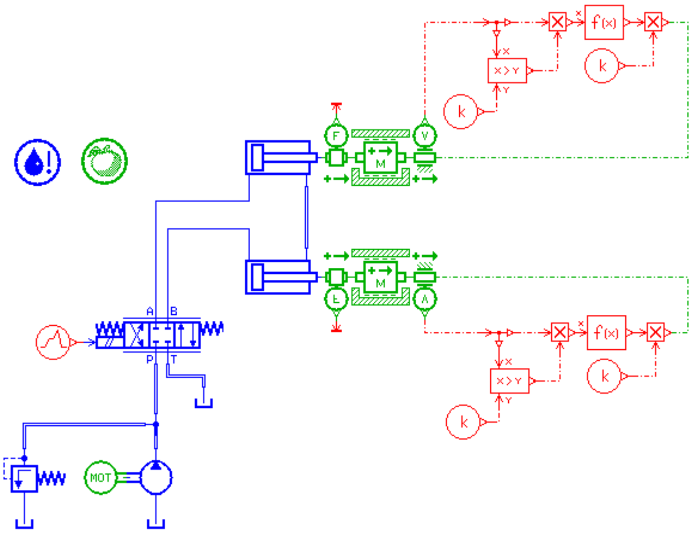
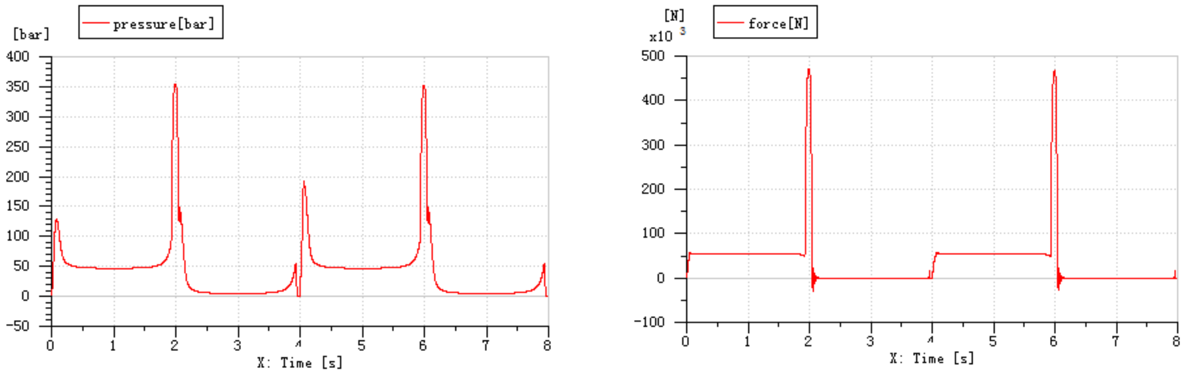


Fig. 4 Model of pumping unit hydraulic system

3. Vibration control strategy for booms

3.1 Influence factors of booms vibration

The simulation results of pumping unit hydraulic system are shown in Fig. 5. It can be seen obviously that there is some shock of both pumping pressure in cylinder and force exerted by piston. Since the first boom is installed on the rotating table of a truck-mounted concrete pump, the two kinds of shock will inevitably apply the shock load on the rotating table and accordingly cause the vibration of a truck-mounted concrete pump. In addition, since there is friction force between concrete and conveying pipes when concrete flows through conveying pipes installed on booms, and the concrete flow is not continuous but periodical, thus will lead to the vibration of booms. Generally, the friction force between concrete and conveying pipes is smaller than the shock of both pumping pressure in cylinder and force exerted by piston, so this paper assumes that the shock load which booms suffer can be seen as the result of the shock force of the first hydraulic cylinder installed between the first boom and the second boom.



(a) Pressure in cylinder **(b)Force exerted by piston**

Fig. 5 Simulation results of pumping unit hydraulic system

3.2 Vibration control strategy for booms

As analyzed above, the booms vibration is mostly caused by the shock of both pumping pressure in cylinder and force exerted by piston, thereby if the pumping pressure and force could be reduced, then the booms vibration could be reduced accordingly. Since the shock happens when the piston reaches the end of a stroke, if the speed of the piston could be decreased then the shock would be decreased obviously. The hydraulic cylinder is driven by pressure oil controlled by the direction control valve under driving current, so we can adjust the driving current when the piston will reach the end of a stroke. The vibration control strategy for booms is described in Fig. 6.

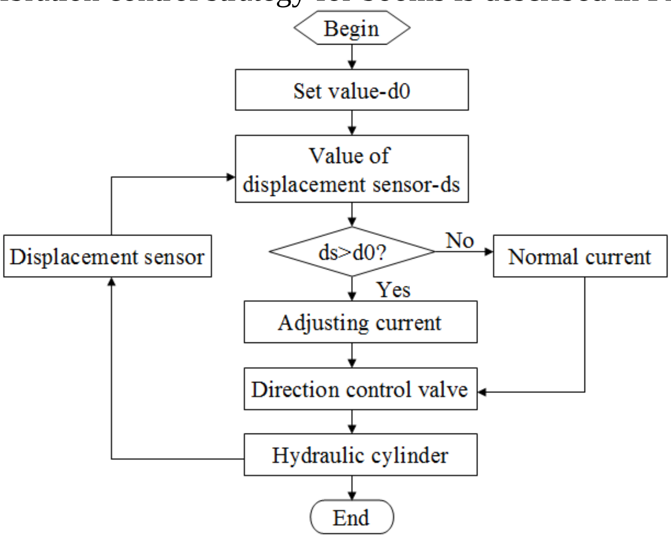


Fig. 6 Vibration control strategy

4. Results and discussion

Based on the vibration control strategy mentioned above, the numerical model of pumping unit hydraulic system with vibration control strategy is established in Fig. 7.

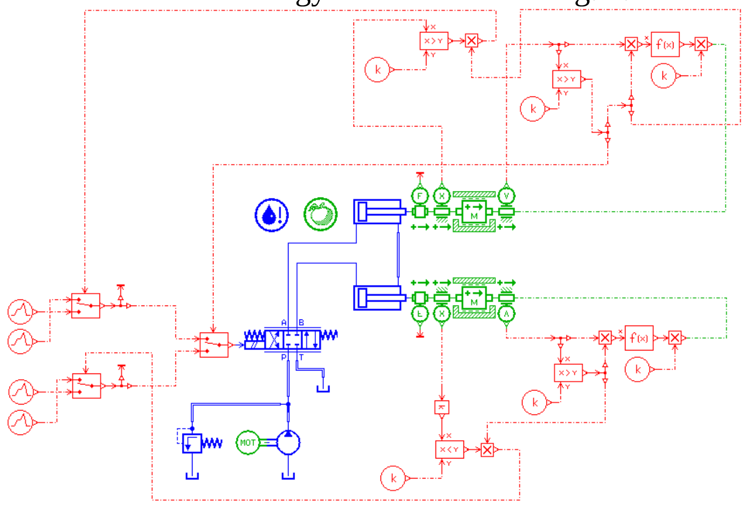
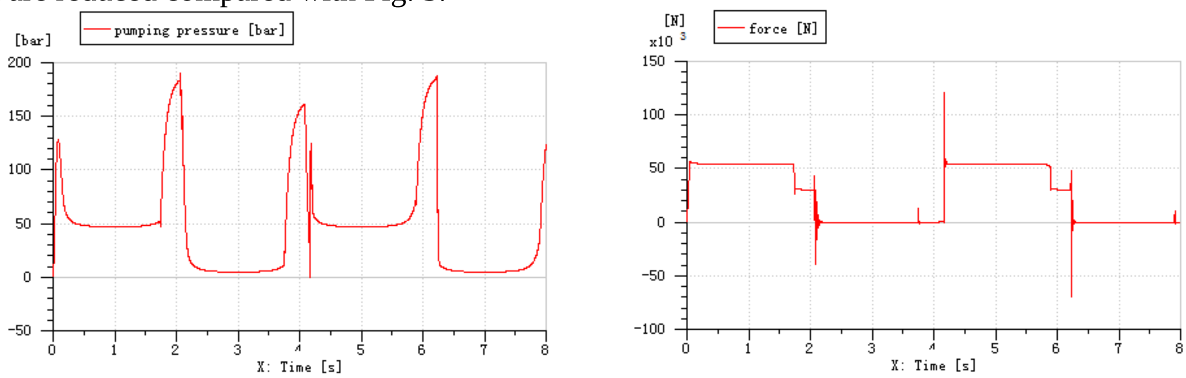


Fig. 7 Pumping unit hydraulic system with vibration control strategy

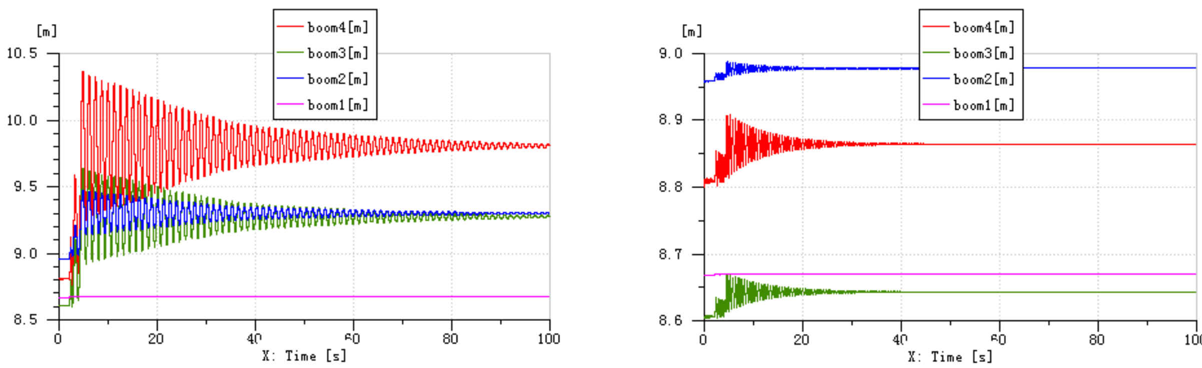
The simulation results of pumping unit hydraulic system with vibration control strategy are shown in Fig. 8. It can be obviously seen that the pressure in cylinder and the force exerted by piston are reduced compared with Fig. 5.



(a) Pressure in cylinder (b)Force exerted by piston

Fig. 8 Simulation results of pumping unit hydraulic system with vibration control strategy

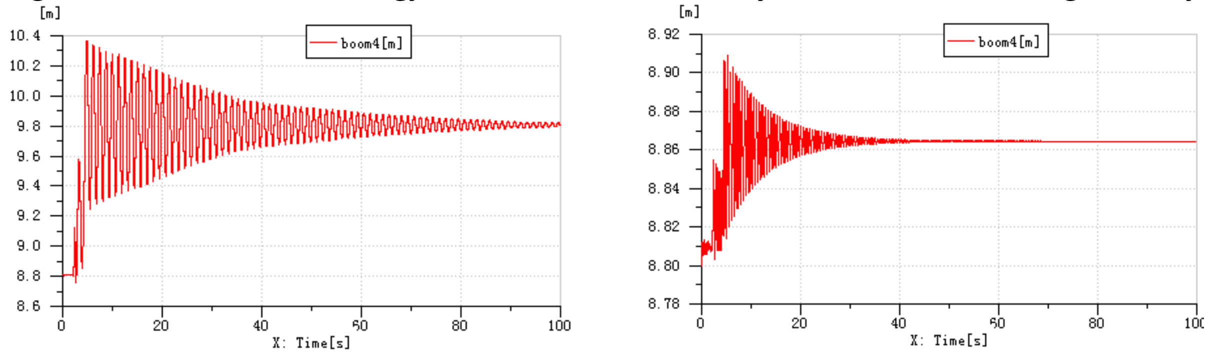
This paper discusses the horizontal working state as shown in Fig. 1. Given that the vibration of the first boom happens when the direction control valve of the first boom obtains a shock current from 0 to max (-1), and considering that the booms vibration happens two times during one pumping cycle. The booms vibration results under current from 0 to -1 are shown in Fig. 9(a). It can be easily seen that the absolute y position of boom 4 is about 9.8m, and the max vibration magnitude of boom 4 is about 0.6m.



(a) shock current from 0 to -1 (b) shock current from 0 to -0.1

Fig. 9 Vibration magnitude of booms under shock current from 0 to -1 and -0.1

This paper uses the shock current of the first cylinder from 0 to -0.1, and considering that the booms vibration happens two times during one pumping cycle. By using the vibration control strategy presented in this paper, the booms vibration results under shock current from 0 to -0.1 are shown in Fig. 9(b). Especially, the vibration result of boom 4 under shock current from 0 to -0.1 and -1 are shown in Fig. 10. As shown in Fig. 10(b), the absolute y position of boom 4 is about 8.865m, and the max vibration magnitude of boom 4 is about 0.045m. It can be easily deduced that by using the vibration control strategy, the vibration od booms system can be reduced significantly.



(a) shock current from 0 to -1 (b) shock current from 0 to -0.1

Fig. 10 Vibration magnitude of boom 4 under shock current from 0 to -0.1 and -1

5. Conclusion

5. Conclusion

The booms vibration during concrete pouring process will lead to fatigue failure and even fracture, imprecise positioning, and shortening lifespan, et al. Aiming to reduce the booms vibration, this paper presents a vibration control strategy by combining the booms with pump unit completely. By using a displacement sensor to measure the displacement of the hydraulic cylinder, and comparing the output of displacement sensor with the set value, and adjusting the driving current for the direction control valve, accordingly reduces the flow rate flowing through the direction control valve and the shock of both pumping pressure in cylinder and force exerted by piston so as to reduce the vibration of booms.

6. Acknowledgement

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