Flexible boom numerical simulation and vibration characteristics analysis

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Abstract

Truck mounted concrete pump boom is typical flexible structure. Due to the increasing of boom length, the flexible characteristics play important role in the dynamics behavior. Three simulation models are built. The first is rigid model. The second is flexile model with four booms flexible used modal reduction technique. The last is added with boom hydraulic cylinder equivalent virtual spring damper with the second one. Then the trajectory, hydraulic cylinder force of the flexible booms are analyzed. Finally a test is done on a boom test rig to validate the proposed approach is correct. It provides method to vibration control , trajectory prediction for such flexible structure.

***Keywords**: flexible boom; multi-body dynamics; tip displacement; vibration*

1.Introduction

Truck mounted concrete pump boom is typical multi-body system consisting of pumping boom, joint, link. Until to now the long boom becomes more and more popular(vertical elongation more than 40 m), especially in recent years 66 m, 72 m, 80 m, 86 m and even 101 m's boom has appeared. So influence of flexibility, large deformation and non linear characteristics must be taken into account[1].

By far many methods have been developed for flexible multi-body dynamics of truck mounted concrete pump boom system: Oliver Lenord did research on a 4 booms concrete pump test rig, then he established three models of the interdisplinary system and obtained a simplified linear damping to simulate the model[2]. Liu jie, Dai li established a boom model and done numerical computation about it using rigid- flexible multibody dynamics theory[3]. F. Resta, F. Ripamonti, G. Cazzulani establish a nonlinear flexible multi-body test rig and the modal observation method and disturbance estimate strategy were adopted to study the boom and hydraulic device. Finally flexible boom and pump vibration suppression and control are researched[4-5].

Among the above experts, different boom and model influence to the system are not studied. So in the first part of this paper a rigid model of a truck mounted concrete pump boom was established, then modal reduction and virtual spring damper method are used to build flexible simulation models on which kinematics and dynamic response was studied. Finally an experiment was done on a test rig to prove the established model and proposed method are correct.

2. Flexible multibody boom test rig model methods

2.1 Virtual spring damper method

The boom system is driven and controlled by hydraulic cylinder. It is equivalent to certain stiffness and damping system by virtual spring damper method as shown in Fig. 1. Driving force and simulation position can be written[6-7]:

$$F_{\mathrm{cy1}} = k\cdot(y_0(t)-y_{\mathrm{cyl}}(t)) + c\cdot(y_0(t)-y_{\mathrm{cyl}}(t))' \tag{1}$$

$$y=\int_{t_0}^{t} -\frac{F_{\mathrm{cyl}}-k(y_0(t)-y_{\mathrm{cyl}}(t))}{c}\,\mathrm{d}t \tag{2}$$

$$c=\frac{\pi\eta l d^2}{(D-d)^3}[3+\frac{3d}{4(D-d)} \tag{3}$$

In Eq.1 $y_0(t)$ is the initial position of the cylinder. $y_{\mathrm{cyl}}(t)$ is the terminated position. t is the time. The damping c of each cylinder is obtained by Eq.3 , they are $1.08\,\mathrm{N{\bullet}s/mm}$, $0.9\,\mathrm{N{\bullet}s/mm}$, $0.2\,\mathrm{N{\bullet}s/mm}$, $0.02\,\mathrm{N{\bullet}s/mm}$, η is the kinematics viscosity, l is the piston length, d is the piston Diameter. D is the cylinder inner diameter. The stiffness k of each cylinder is 40 kN/mm, 30 kN/mm, 20 kN/mm, 6 kN/mm.

2.2 Modal reduced method

Modal reduced method is also called FMBD theory (finite element multi-body dynamics) [8]. Flexible body point i in the three dimensional coordinate can be expressed as:

$$\overline{r}_i=\overline{r}+A\overline{S}_i n=\overline{r}+A(\overline{S}_i^0 n+\overline{u}_i n) \tag{4}$$

In Eq. 4 A is the transfer matrix. $\overline{S}_i^0$ is the undeformed position vector, $\overline{u}_i$ is the deformation vector. The translation and rotation modal matrix of point i is:

$$\Psi^i=\left[\Psi_t^{iT},\Psi_r^{iT}\right] \tag{5}$$

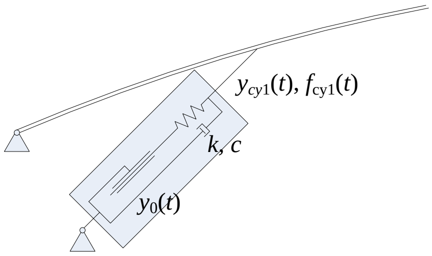

Fig. 1 Physical model of the hydraulic cylinder

The translation modal matrix and modal coordinate is written:

$$u_i^{'} = \Psi_t^{i'} \bar{a} \tag{6}$$

In Eq. 6 $\bar{a}$ is the modal position vector, applying Eq. 6 to Eq. 4 and Eq. 7 we can get:

$$\bar{r}_i = \bar{r} + A(\bar{S}_i^{0'} + \Psi_t^{i'} \bar{a}) \tag{7}$$

According to the modal information Ψ the overall displacement are as follow:

$$[u] = \sum a_i [\phi]_i \tag{8}$$

In Eq. 8, a_i is the modal participation factor; $[\phi]_i$ is the structure mode.

2.3 Physical model

Three assumptions are needed in modeling and simulation of boom system:
(1) Only considering posture transform in planar, ignoring the impact of spatial torque. (2) Translational joint and fix joint are used to connect booms with links, translational joint are used to simulate hydraulic cylinder motion. (3) Small boom motion speed. The topology model of the concrete pump boom test rig is shown in Fig. 3.

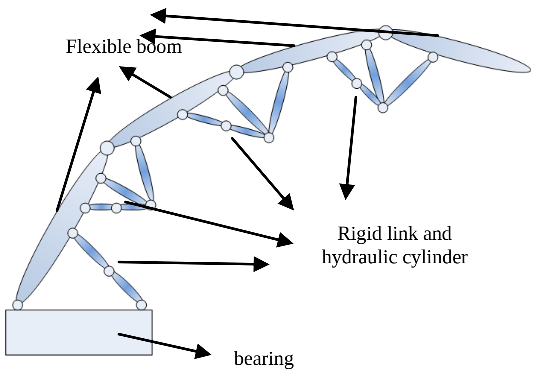

Fig. 3 Boom topology system

3.Simulation and experimental analysis

According to the above assumptions a truck mounted concrete pump boom rigid model and

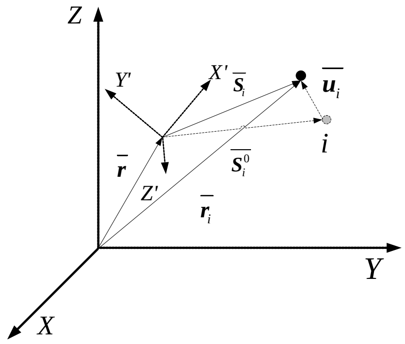

Fig. 2 Flexible body coordinate system

flexible-rigid physical model are established in Fig. 3 above.

Three simulation models are established using Recurdyn software. All the parameters of the booms are shown in Table 1:

Table 1 Main parameters of each boom

	boom1	boom2	boom3	boom4
length(mm)	3753	2830	2875	3205
Mass(kg)	88.4	37.9	32.0	18.3

The motion stress, joint force, tip trajectory of each model are studied in Recurdyn as follow.

3.1 Motion stress simulation

In Fig. 4 the maximum stress of rigid flexible model is between the 2nd and 3rd boom during simulation. Due to the flexible feature the booms stop gradually after motion stop. Under allowable operating speed the stress is 135 MPa, less than Q345B boom material’s allowable stress 230 Mpa.

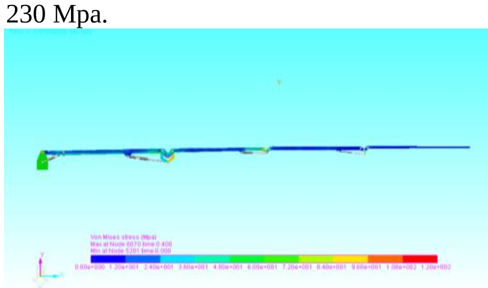

Fig. 4 Flexible model stress contour

3.2 Tip displacement simulation analysis

The tip displacement of three simulation models and test data are in Fig. 5. It can be seen the rigid model has the smallest boom tip displacement which is about 145 mm, the other two flexible model’s tip displacement are 330mm and 709 mm. The test data is 460mm. Due to the simulated cylinder stiffness error the data of the 3rd model is 349 mm larger than the test value.

Fig. 6 is different cylinder Equivalent spring damping influence to the tip displacement of the 3rd model. We can see the 2nd and 3rd cylinder play more important role to the total displacement.

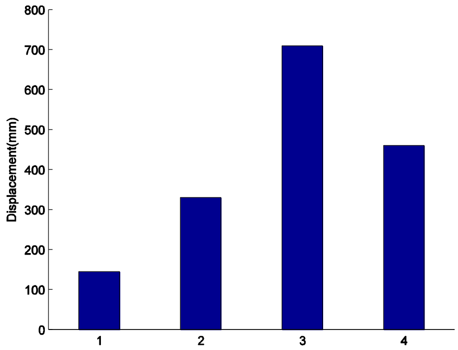

Fig. 5 Different models tip displacement
1-The 1st model; 2-The 2nd model; 3-The 3rd model; 4-test data

3.3 Cylinder force simulation research

The three model cylinder force are in Fig. 7 it can be seen the maximum force between the second and third cylinder in the rigid model is about 52.8 kN, while the other two flexible model are 98.6kN and 90.1 kN.

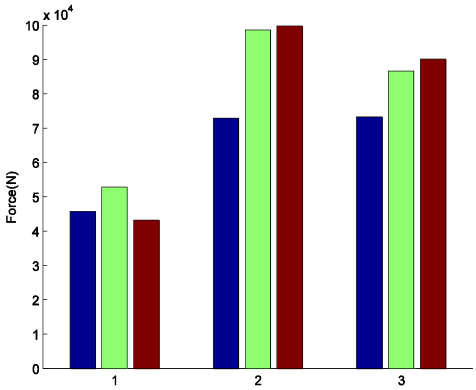

Fig. 7 Different models hydraulic cylinder force

1-rigid model; 2- Flexible rigid model; 3- Flexible rigid model with cylinder mass damping mode

In Fig. 7 the blue column represents the first cylinder force; while the green and brown are the 2nd and 3rd

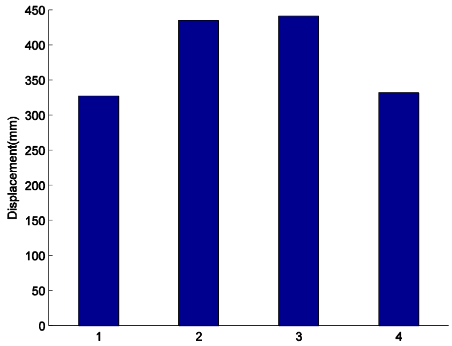

Fig 6 Different boom spring damper influence
1- The 1st boom; 2-the 2nd boom;
3- The 3rd boom; 4- the 4th boom;

cylinder force. The two flexible model forces are nearly two times of the rigid one. Therefore the flexible deformation should be taken full account in hydraulic cylinder design process

3.4 Experimental study and analysis of results

In order to verify the proposed method and simulation result, an experiment is done on a 13 m truck mounted concrete pump boom test rig (Fig. 8). Dewesoft multi channel signal acquisition instrument (Fig. 9), three axis acceleration sensor, tilt sensor, strain rosette are used. The measured boom stress, simulation value and MSC / Nastran value are in Table 2. It is well proved the established model is appropriately. The different model vibration displacement and cylinder force are discussed above.

Table. 2 Maximum stress comparisons between Simulation and test

	By Nastran	Simulation	Test value
stress [Mpa]	138.6	135.0	118.3

Fig. 8 flexible boom test rig

Fig. 9 24-channel multi-signal test System

4.Conclusion

(1) A 13 m rigid boom model was established. Then modal reduction method is adopted to build a flexible body model. Next spring damping method is used to simulate the hydraulic cylinder.

(2) Boom motion stress is calculated of different model. It can be found the stress of flexible model is closed to the actual structure. The hydraulic cylinder force, tip displacement of the rigid model is smaller than the flexible model. The 2nd and 3rd cylinder have the most significant influence on the boom tip displacement.

(3) An experiment is done on the boom test rig to verify the simulation result proposed above. And it provides theoretical basis to vibration control, trajectory prediction and life assessment for such structure.

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