2011 Fourth International Conference on Intelligent Computation Technology and Automation

Simulation and Optimization of the Driving Forces of Hydraulic Cylinders for Boom of Truck Mounted Concrete Pump

ZHONG Zhihong, WU Yunxin, MA Changxun
College of Mechanical and Electrical Engineering, Central South University, Changsha 410083, China
E-mail: zzhljx@163.com

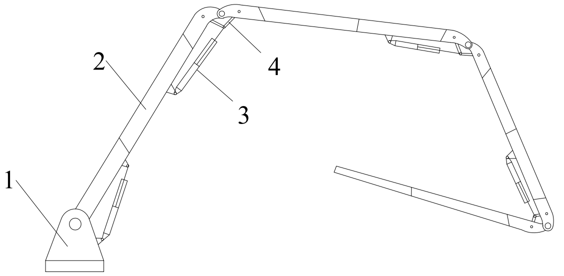
***Abstract*-In order to obtain the maximum driving forces of hydraulic cylinders in the process of boom design, the solid model was built in Pro/E and then imported into ADAMS where the dynamic simulation model was established. Processes of the boom transforming from horizontal to typical poses were simulated and driving force variation curves of the hydraulic cylinders were generated. According to the results, location of the joint connecting cylinder 2 and the links was optimized in ADAMS and the driving force decreased as a result. It is instructive to structure design of boom.**

Keywords-simulation; optimization; driving force; hydraulic cylinder; boom; Pro/E; ADAMS

I. INTRODUCTION

Truck mounted concrete pump is a large engineering machinery used for concrete pouring. It is mainly composed of chassis, concrete pump and boom system, among which boom system best reflects characteristics of a truck mounted concrete pump. Boom system's safety, reliability and advancement are key factors that determine the competence of a truck mounted concrete pump [1] and its structure is as shown in Figure1. In order to study the boom system better, a laboratory designed a four-arm boom model which is approximately 13 meters long. After devising the boom structure and hydraulic system principle preliminarily, dynamic simulation and structure optimization are necessary in order to determine the oil pressure and cylinder dimensions et al.

There are many previous literatures studying the structural strength [1-4] and dynamics [5-7] on boom of truck mounted pump, but less concerning structural design and optimization. In this paper virtual prototype of the boom was established with combination of Pro/E and ADAMS, and processes of the boom transforming from horizontal which is traditionally treated as the most dangerous working case to several typical poses in a four-arm-rotate-together way were simulated. Then the structure was optimized according to the simulation results.



1 Turret 2 Arm 3 Hydraulic cylinder 4 Link

Figure 1. Structure of boom

II. ESTABLISHMENT OF SIMULATION MODEL

A. 3-D model building in Pro/E

In order to obtain accurate mass attributes including mass, centroid and moment of inertia, 3-D model should be built according to the dimension formerly designed as much as possible. Synchronously, details which have insignificant influence on overall mechanical property of the model should be simplified because too complicated model may result in curves or surfaces missing in ADAMS. Based on this, in this paper each arm of the boom is built as a part and some details are simplified.

According to the preliminarily designed drawings, turret, arms, hydraulic cylinders and links are built in powerful 3-D model building software Pro/E respectively, and then assemble them in bottom to top way into a boom which presents a horizontal pose as shown in Figure 2.

978-0-7695-4353-6/11 $26.00 © 2011 IEEE
DOI 10.1109/ICICTA.2011.230

Figure 2. Solid model of the boom

B. Model transfer and simulation model building in ADAMS

3-D model built in Pro/E can be imported into ADAMS by means of Mechanism/Pro which is the exclusive interface software between Pro/E and ADAMS provided by MSC. After installation and initial settings, Mechanism/Pro will appear in Pro/E's assembly environment as a cascading menu in which rigid body definition, constraints applying, data transfer parameter settings and simple simulation et al. can be performed. Here we define each part of the boom as a rigid body, and establish a marker at every center of all the shafts for convenient positioning where a revolute joint will be created later. Then the model can be transferred to ADAMS by Mechanism/Pro. There may be problems with the model that it does not display but its mass and moment of inertia et al. exist. This can be solved by returning to Pro/E to simplify the model further or doing as what is introduced in reference [8], which the paper will not elaborate.

Firstly the materials of the boom and the gravity should be defined in ADAMS. Then constraints between parts should be created according to actual situations of truck mounted concrete pump: the rotational degree of freedom of the boom as an entirety will not be considered in this paper, so we fix the turret to the ground; we establish revolute joints at each center of all the shafts connecting different parts and translational joints between every pair of cylinder and piston rod. What's more, four translational joint motions are applied on the four translational joints respectively.

III. SIMULATION OF DRIVING FORCES

Dynamic simulations include forward simulation and reverse simulation: the forward studies dynamic responses including accelerations, velocities, displacements and constraint forces et al. of a mechanical system under external forces or couples; the reverse solves forces with known motion parameters such as velocities, accelerations and trajectories el al. In this paper we carry out reverse simulation of the boom model in ADAMS, that is, we define velocities of the four cylinders according to actual situation and simulate them in order to obtain their driving force variation curves in different motions.

Boom works in diverse poses which usually can be divided into several typical working poses such as foundation, roof, wall and so on. The boom can transform poses in a four-arm-rotate-together way; also it can rotate each arm independently. So there are thousands of movement combinations. It is not only unnecessary but also impossible to simulate all cases. In this paper processes of the boom transforming from horizontal to the above three typical poses and vertical are simulated.

A typical working pose does not mean a unique attitude. In this paper we define the angle combinations between arms and the horizontal of the three above typical poses as [75°,15°,-15°,-75°] 、 [75°,45°,15°,-45°] 、 [75°,75°,45°,-30°] respectively. According to the preliminary design of the hydraulic system, the maximum velocity of piston is 20 mm/s with which in simulation velocity settings should comply. Regulating the velocities of each piston, simulations of the four processes mentioned above can be accomplished. After that, driving force variation curves of the cylinders in these processes are generated as shown in Figure 3-Figure 6.

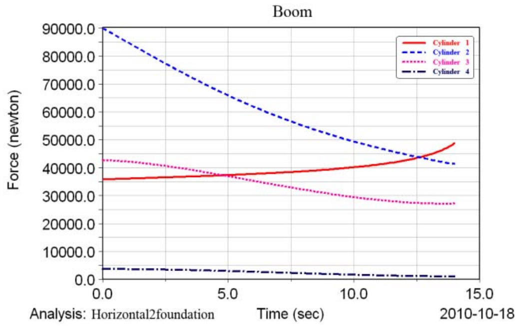


Figure 3.Driving force curve from horizontal to foundation

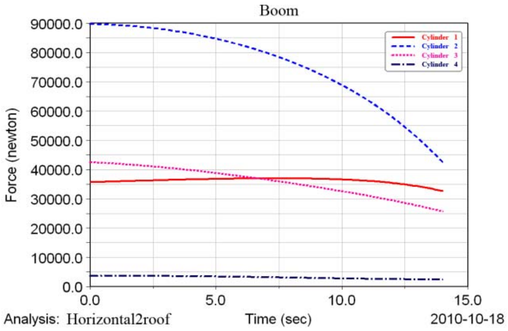


Figure 4. Driving force curve from horizontal to roof

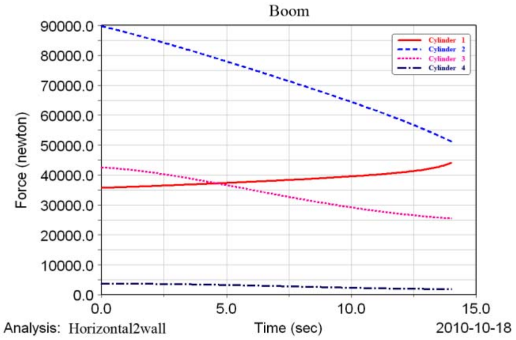


Figure 5. Driving force curve from horizontal to wall

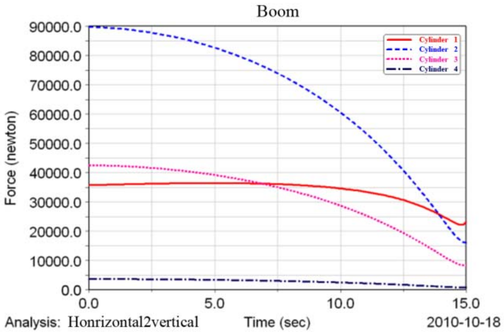


Figure 6. Driving force curve from horizontal to vertical

From the graphs shown above we can find that driving forces of cylinder 2, 3 and 4 reach their maximums when the boom is horizontal, while cylinder 1 is not the case. Therefore, designing a boom just as the traditional opinion that the horizontal pose is the most dangerous is not reasonable. Considering the special structure, driving force of cylinder 4 is far lower than the others is easy to understand. However, the maximum driving force of cylinder 2 reaches 90000 N which is much larger than cylinder 1 and 3. This may result in excessive high oil pressure or too large cylinder by tentative calculation. The former is unfavorable to design of hydraulic system; the later may lead to interference. As a result, structure of cylinder 2 and the links should be optimized in order to diminish the driving force.

IV. OPTIMIZATION

According to mechanism theory, the structure which is comprised of two arms, two links, a cylinder and a piston rod as shown in Figure7 is a planar six-bar mechanism and diminishing the driving force of cylinder 2 can be realized by changing the location of joint A. We may build several groups of links with different lengths and reassemble the model and simulate them respectively, then select the best. However this is not an efficient approach. ADAMS provides convenient parameterization and optimization function. In this paper we perform the optimization of location of joint A in ADAMS.

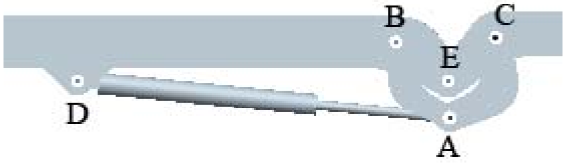


Figure 7. Structure of cylinder 2 and the links

Solid model imported in ADAMS cannot be optimized directly. The method we take is as follows: firstly delete cylinder 2 and the two links which are to be parameterized and substitute standard components such as links in ADAMS for them; then parameterize coordinates of joint A and their lengths can be optimized by doing so. Optimization is a process of finding the objective function extrema under the condition that all design variables meet the constraints during their value ranges.

A. *Design variables*

Here we define coordinates of joint A as design variables and mark them as DV_X, DV_Y respectively.

B. *Constraint functions*

In order to meet requirements of the boom's arbitrary transformation, folding and avoid interference after optimization, coordinates of joint A should be restricted and some constraints should be set as follows:

$$3750 \le DV_X \le 4100, 0 \le DV_Y \le 175 \tag{1}$$

$$\text{s.t.}\begin{cases} f_1(DV_X,DV_Y) = 200 - L_{AB} \leq 0 & (2)\\ f_2(DV_X,DV_Y) = L_{AB} - 400 \leq 0 & (3)\\ f_3(DV_X,DV_Y) = 200 - L_{AC} \leq 0 & (4)\\ f_4(DV_X,DV_Y) = L_{AC} - 400 \leq 0 & (5)\\ f_5(DV_X,DV_Y) = \text{Abs}(L_{AB} - L_{AC}) - 20 \leq 0 & (6) \end{cases}$$

where s.t. means subject to; L_{AB} and L_{AC} are the lengths of the two links which are functions of coordinates of joint A; (2)~(5) limit the two links' lengths between 200 mm and 400 mm; (6) restricts the link length deference no more than 20 mm.

C. *Objective function*

According to the previous results generated by simulation we know that driving force of cylinder 2 is largest when it is horizontal, so we replace cylinder 2 with a link and just perform static optimization when it is horizontal so as to simplify the process. So we can define the objective function as minimizing of the reaction force measurement function of the substitute link:

min(Force_MEA(DV_X,DV_Y)

D. *Outcome of optimization*

Optimization in ADAMS shows that the optimum location of joint A is（4013.10，43.89）, when lengths of the two links are 344.07 mm and 324.04 mm. Round the lengths to 344 mm and 324 mm, rebuild the solid models of the links, reassemble the boom and simulate the several processes mentioned above as before. Results generated are as shown in Figure 8-Figure 11.

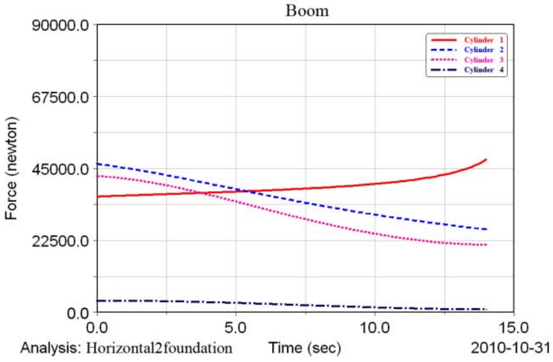


Figure 8. Driving force curve from horizontal to foundation after optimization

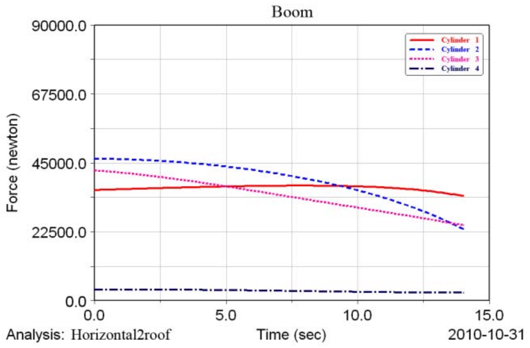


Figure 9. Driving force curve from horizontal to roof after optimization

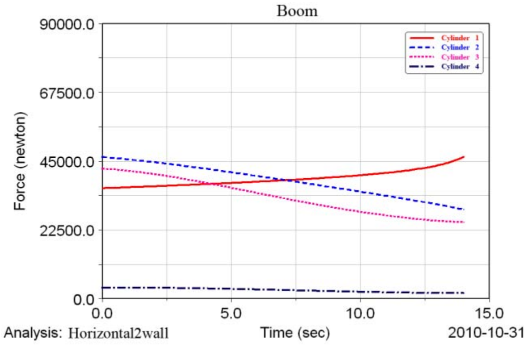


Figure 10. Driving force curve from horizontal to wall after optimization

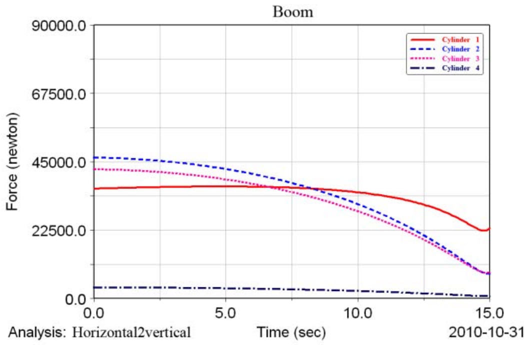


Figure 11. Driving force curve from horizontal to vertical after optimization

From the above graphs we know that the curve shapes of driving forces after optimization resemble the ones before optimization, and driving force of cylinder 2 decreased to the same level with cylinder 1 and 3.

V. CONCLUSION

In this paper a complete procedure of simulation and optimization of the driving forces of hydraulic cylinders for boom of truck mounted concrete pump has been presented. Firstly establish the virtual prototype by combination of Pro/E and ADAMS with Mechanism/Pro which is the exclusive interface software between the two; then simulate several processes of the boom transforming from horizontal to typical poses and generate the driving force curves; lastly optimize the structure according to the simulation results.

With this approach, we could carry out design, simulation and optimization of mechanical system conveniently without complex mathematic formula derivation and get satisfactory results.

REFERENCE

[1]SHI Xianxin, ZHENG Yongsheng, XU Huaiyu, FENG Min, ZHANG Pengcheng, Finite Element Analysis on the Boom of Truck Mounted Concrete Pump Based on ANSYS, Construction Machinery, 2009, “”(04): 79-82. (In Chinese)

[2]YAN Lijuan, FENG Min, XU Huaiyu, Finite Element Calculation and Analysis for Placing Boom of Model HB37 Concrete Pump Truck, Construction Machinery and Equipment, 2005, 36(1): 30-32. (In Chinese)

[3] ZHANG Yanwei, TONG Li, SUN Guozheng, A Structure Analysis of Concrete Pump’s Boom Based on ANSYS, Journal of Wuhan University of Technology (Transportation Science & Engineering), 2004, 28(4): 536-539. (In Chinese)

[4]ZHANG Daqing, LU Pengmin, HE Qinghua, HAO Peng, Experimental Research on Structural Dynamic Strength of a Concrete Pump Auto, Journal of Vibration and Shock, 2005, 24(3):111-113. (In Chinese)

[5]LU Pengmin, WANF Hongbing, ZHANG Daqing, Influence of Structural Dynamic Characteristic by Concrete Pump Truck’s Impact Load, China Journal of Highway and Transport, 2003, 16(4): 115-117. (In Chinese)

[6] LIU Jie, DAI Li, ZHAO Lijuan, CAI Juan, ZHANG Jing, Modeling and Simulation of Flexible Multi-Body Dynamics of Concrete Pump Truck Arm, Chinese Journal of Mechanical Engineering, 2007, 43(11): 131-135. (In Chinese)

[7]SU Xiaoping, YIN Chenbo, WANG Dongfang, JIANG Tao, XU Cheng, Simulation of the Boom of Concrete Bump Truck Based on Multi-body Dynamics, Chinese Journal of Construction Mechanery, 2004, 2(2): 167-170. (In Chinese)

[8]NI Jinfeng, XU Cheng, The Method of Transforming Complex Model from Pro/E to ADAMS, Mechanical Engineer, 2004, “”(9): 15-16. (In Chinese)