ATLANTIS PRESS
Advances in Computer Science Research, volume 63
International Conference on Artificial Intelligence and Engineering Applications (AIEA 2016)

Dynamics Modeling and Simulation of Loader Working Device under Unloading Condition

Chengyi Huang [a], Shaohui Su [b], Kuang Xu [c] and Chang Chen [d]

School of Mechanical Engineering, Hangzhou Dianzi University Hangzhou 310018, China.

[a]HiCkeY8293552@163.com, [b]messhhui@163.com, [c]xukuang@163.com, [d]chenchang@hdu.edu.cn

Abstract. Loader is a kind of typical engineering machinery, which plays a considerable role in the construction of the national infrastructure. As working device is a core component, which need do simulation and optimization. Because loader is composed of multisystem, how to conduct a unified simulation is a big issue. For this purpose, we introduced Dymola, which is a multidiscipline modeling software. In the Dymola, the mathematical model and its constraint function were set up by using multidisciplinary modeling language Modelica, then simulation of loader was carried out. In addition, retraction phenomenon of oil cylinder is researched, and we analyzed the reason of this phenomenon and optimized design.

Keywords: Multidisciplinary modeling; loader working device; Modelica.

1. Introduction

Loader is widely used in the course of construction, which can be used to carry out shoveling, handling, unloading, flat bulk materials and other work. The working device is the core operating mechanism in the excavation and handling of materials. Its performance is the important embodiment of the loader performance, operating efficiency and quality [1-2]. In the process of research on the working device, the traditional analogy method and mapping method were adopted in China. These two design methods have the characteristics of heavy workload and low efficiency [3-4]. Designers' experience greatly influences the quality of design results. With the continuous improvement of modeling analysis software, you can optimize the size of the working device through simulation analysis, inspection interference and other design defects which can effectively shortens the development time and reduces the production cost, and make the product more reasonable[5].

In the unloading conditions, the bucket cylinder provides the force required to move. Under this force, the bucket obtains an initial velocity. The cylinder is gradually retracted from the extended state in the external gravity and other forces. The bucket in this process will become faster, until the beam limit position when it will stop [6, 7]. In the unloading conditions, some of the loader will appear retraction phenomenon due to design reasons and structural problems. The root cause of the retraction is that the bucket generates two forces by the speed and exerted on the boom. The boom cylinder has to open the overload valve due to the boom cylinder to provide the support force, which is not enough to balance the two forces. The retraction of the cylinder is thereby generated [8]. The phenomenon of retraction will greatly reduce the effectiveness in the unloading conditions. It is necessary to re-raise the boom to ensure the continued operation of the working device, which will result in a series of crash barriers and other accidents [9, 10]. So we need to avoid the phenomenon of boom cylinder retraction in the design of the working device.

In this paper, the simulation model of the working device is established by the three-dimensional model, the mathematical model and the constraint function. The simulation model is established by the multidisciplinary modeling language Modelica. The feasibility of the model is verified by Dymola.

2. Mathematical model of working

2.1 Mathematical modeling

Each component connected with hinge pin, and the hinge pin parallels to each other. When analysis the institution, we can simplify the institution as a planar mechanism with the hydraulic cylinder [11]. At the same time, we ignore the friction and the weight of lever.

People usually determine the location of working device artificially. This is obviously not scientific. In fact, different structure of the working device has different dumping work condition.

For general requirement of the dump, the work device should unload at any position. If the most difficult unloading position can be solved .The problem also can be solved. In the structural design, the discharge capacity is mainly limited by the length of the bucket cylinder. If the design is unreasonable, there will be interference and the unloading is not clean. Simultaneously, the cylinder bore decide the maximum support force. If the selection is unreasonable, there will lead the phenomenon of cylinder retraction. Therefore, reasonable unloading position and cylinder bore have important significance for the safety of working device.

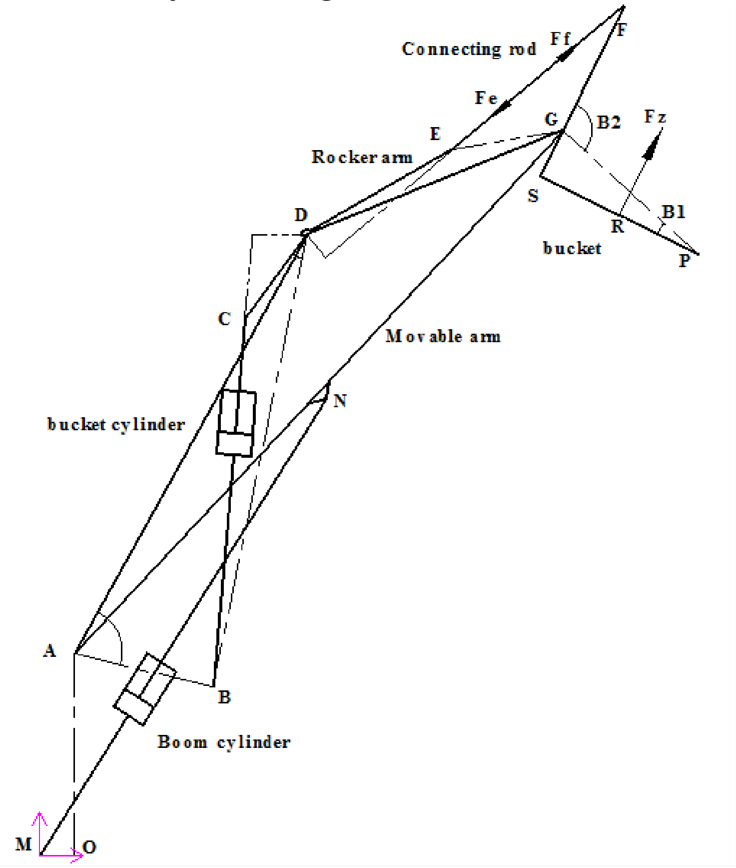

Fig.1 The force transfer diagram between cylinder and supporting force

As can be seen from fig. 1, when the boom is in any position, the length of the bucket cylinder is

$$L_{BC} = \sqrt{{L_{CD}}^2 + {L_{BD}}^2 - 2L_{CD} \times L_{BD} \times \cos^{-1} \angle BDC} \tag{1}$$

$$L_{BD} = \sqrt{{L_{AD}}^2 + {L_{AB}}^2 - 2 \times L_{AD} \times L_{AB} \times \cos^{-1} \angle BAD} \tag{2}$$

$$\angle \mathrm{BDC} = \angle \mathrm{CDE} - \angle \mathrm{ADG} - \angle \mathrm{EDG} + \angle \mathrm{ADB} \tag{3}$$

Using L_{DE}, L_{EF}, L_{DG}, L_{FG} and the apex angle $\angle$DGF obtain the function relationship as

$$\angle \mathrm{BAD} = \angle \mathrm{OAG} - \angle \mathrm{OAB} + \angle \mathrm{DAG} \tag{4}$$

$$\angle \mathrm{ADB} = \cos^{-1}\left(\frac{{L_{AD}}^2 + {L_{BD}}^2 - {L_{AB}}^2}{2 \times L_{AD} \times L_{BD}}\right) \tag{5}$$

From the above formula, the length L of the working device is determined. The bucket cylinder's length just depends on the position angle of the boom.

The unloading length of the bucket cylinder consists of unloading stroke and structure length. The specific formula is

$$\mathrm{S} = L_{BC} - \mathrm{L} \tag{6}$$

S represents unloading stroke, L represents structure the length of bucket cylinder.

In order to ensure that the working device will not interfere with the phenomenon, we must ensure that the $S \geq 0$.

First of all, we need to work on the mechanical analysis, and determine the equilibrium equation of the bucket cylinder force. Centering on point D, fixed the boom AG. On this basis, the equation of the column t is

$$F_{BC} \times L_{CD} \times \sin \angle BCD = F_e \times L_{DE} \times \sin \angle DEF \quad (7)$$

The next step is to request the rise of the working device, the equation of entering on point D and column is

$$F_f \times L_{FG} \times \sin \angle EFG = F_z \times (PG \times \cos \angle GPR - PR) \quad (8)$$

$$F_E = F_F \quad (9)$$

The following formula by the two formulas is

$$\frac{F_Z}{F_{BC}} = \frac{L_{CD} \times \sin \angle BCD \times L_{FG} \times \sin \angle EFG}{L_{DE} \times \sin \angle DEF \times (PG \times \cos \angle GPQ - PQ)} \quad (10)$$

Do the auxiliary line EG as

$$L_{EG} = \sqrt{{L_{DE}}^2 + {L_{GD}}^2 - 2 \times L_{DE} \times L_{GD} \times \cos EDG} \quad (11)$$

2.2 Optimization of dumping condition

We are Calculating and analysis the working device through the latest design and development. We are researching the movement process of the working device from the lower limit position to the upper limit position, and using the 0.618 method to solve the one - dimensional iterative algorithm. From this, the minimum and maximum values of the unloading stroke is

$$\begin{cases} \text{minS} -- L_{BC\min} \text{ and } \angle OAG_{\min} \\ maxS -- L_{BCmax} \text{ and } \angle OAG_{max} \end{cases} \quad (12)$$

According to the above analysis process, we also use mathematical model and constraint function to program. Fig. 2 is a flow chart of the program. The stroke position of the unloading cylinder can be determined.

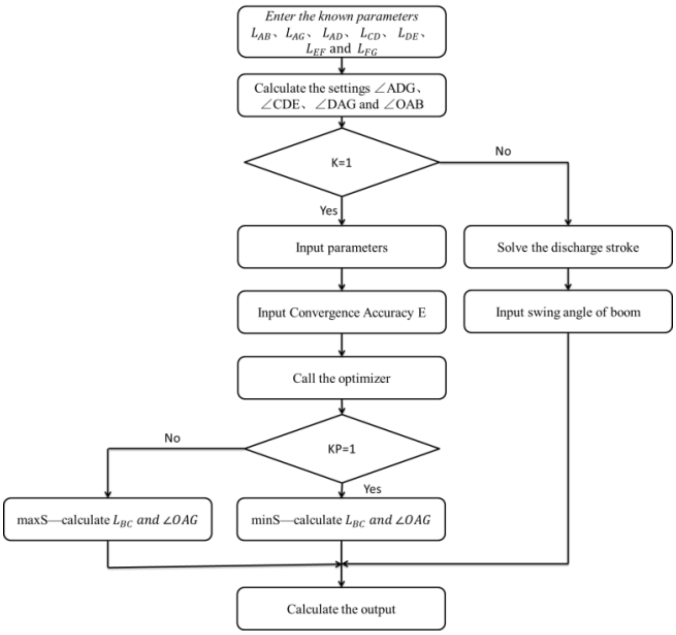

Fig. 2 Block diagram

Taking HT25J as an example, and verifies the correctness of the above procedure. The following results were obtained:

(1) In the case of K=1, the length of the bucket cylinder structure is 51.3cm.

(2) When KP=1, it follow that minS =2.77cm, $\angle OAG_{\min}$ =71.15°. When KP=0, we get $\angle OAG_{\min}$=22.62cm, $\angle OAG_{max}$=135.33°.

(3) For K=0, also verified, select one of the data sets.

∠OAG=75.71o S=2.94cm

∠OAG=88.49o S=5.09cm

∠OAG==97.01o S=7.63cm

∠OAG==114.04o S=14.41cm

∠OAG==122.56o S=18.19cm
∠OAG==131.07o S=21.48cm

3. Case Study

3.1 Modelica modeling

Modelica-Dymola modeling generally uses two ways of graphical modeling tools and text. The graphical modeling tool consists of three steps:

(1)Drag and drop the standard library of the model library;

(2)The connection between the standard components;

(3)Provide part parameters.

Another way is programing language to use the text mode of the Modelica. In this paper, we choose the graphical modeling tool.

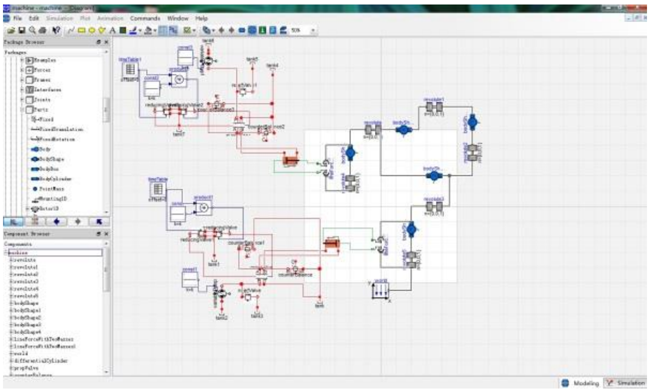

Fig. 3 Modelica model of working device

3.2 Simulation analysis

Following the hydraulic formula, we are easy to get the maximum support of the boom cylinder to provide the formula. The formula is

$$F = \frac{P\pi D^2}{4} \tag{13}$$

P represents working pressure, D represents the boom cylinder bore.

In this paper we can obtain the theoretical maximum support of boom cylinder. Also selecting the boom cylinder bore diameter and unloading valve operation pressure. D is chosen to be 160mm and P is 17MPa. The maximum support force of the boom cylinder can be determined by these two values. The specific value is 341805N.

The model of loader working device is simulated. The simulation process consists of four parts.

First of all, working device enter the bucket working conditions when the bucket cylinder elongation. The time is 2S. Secondly, from 2S to 9S, the working device enters the lifting condition, it stop the bucket cylinder and lift the boom cylinder. Followed by the focus of this article, the boom cylinder is stationary, the bucket cylinder is contracted, and the material is unloaded from 9S to 10.5S. Another important note is the occurrence of interference when the time is 10.5S. The retraction is determined by this moment. Finally, the working device decelerates until it stops.

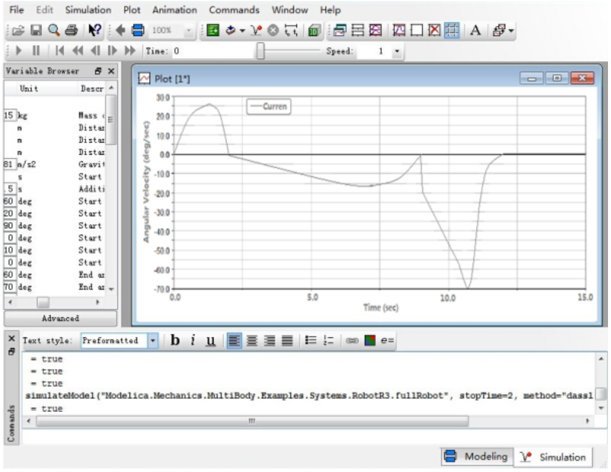

Fig. 4 Angular velocity curve of bucket

As can be seen from figure 4, the unloading condition begins from 9S. The bucket cylinder imposes an initial force on the bucket. The bucket gets an initial velocity in its role. In the next 1.5S, the bucket speeds up with tension, gravity and inertial forces. At 10.5S, the acceleration of the bucket has changed, due to the interference between the boom and the rocker arm. From this moment, the bucket starts to slow down, and the bucket gradually stops due to the drag.

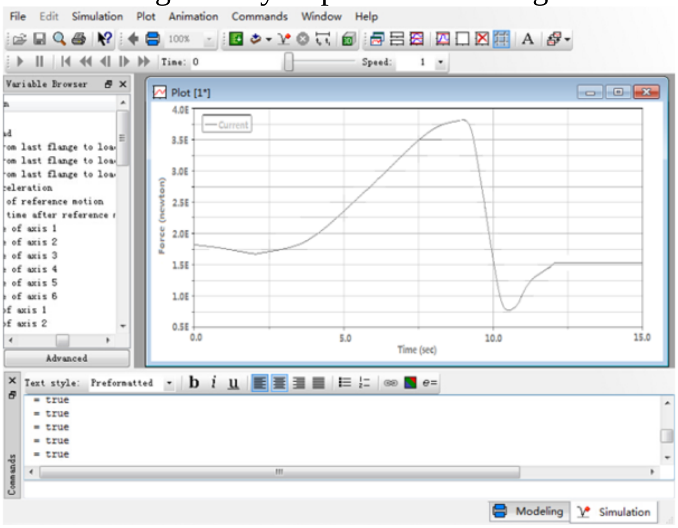

Fig. 5 Load curve of boom cylinder

Figure 5 shows the load curve of boom cylinder. At 10.5S, the working device is in the unloading condition. In this condition, the load is gradually reduced, due to the unloading and the movement of the bucket. Until 10.5S, the rocker arm and the boom have an interference limit, which increased the load of boom cylinder. Through the figure we can see the load of boom cylinder maximum about 380000N. It has exceeded the maximum support force of the boom cylinder 341805N. So in this case there will be retraction phenomenon. The main reason for this problem is that the cylinder diameter of the boom cylinder is chosen too small, which leads to the small support force. We can increase the boom cylinder bore diameter to solve the problem. At the same time, we can also install the two boom cylinders, which can increase the maximum support force of the boom cylinder to prevent possible retraction phenomenon. Loader boom cylinder is selected for the 170mm and double-arm cylinder .Simulation of the maximum support force 771732N meets the requirements. Dynamic load shock due to interference limit during unloading conditions does not cause retraction of the boom cylinder.

4. Summary

Aim at the retraction phenomenon of loader working device may occurred under unloading condition, this paper through the mathematical model of the loader working device and its constraint function, to establish the optimization process. It selects a series of parameters and adopts multidisciplinary modeling language Modelica in the Dymola to conduct simulated analysis on the mechanical and hydraulic parts of the loader working device. Through the comparison of the acquired experimental data with the values of the hydraulic principle, it draws a conclusion that the inappropriate of the selected cylinder diameter of the boom cylinder may leads to retraction phenomenon, which can be effectively solved by increasing the bore diameter or increasing the number of boom cylinders, and its feasibility has been proved.

Acknowledgements

The study is supported by the National Natural Science Foundation of China (Grant No.51475129, 51405117, 51675148)

References

[1] X M Wang, J J Zhang, H B Song, Simulation and Optimization Design of Loader Working Device Based on ADAMS, J. Mechanical Engineering. 45(2014)55-58.

[2] X H Zhang, Optimization of Working Device of ZL50 Loader Based on ADAMS, J. Mining Machine. 39(2011)44-48.

[3] E. P. Andert, JrD. Morgan. Collaborative Virtual Prototyping and Test. NAVAL ENGINEERS JOURNAL, 3(2009) 17--23 .

[4] K Cheng, W D Lian, X g Li, a Visualization and Parametric Design System for Loader Working, J. China Civil Engineering Journal. 4(2009) 127-133.

[5] G B Whang, L Q Gao, K Y Zhi, Optimization of Loading Condition of Loader, J. Mining Machine. 8(2004)35-37.

[6] Lueiana D, Adderio. Crafting the virtual prototype : how firms integrate knowledge and cabilities across organization boundaries. Researeh Poliey, J. 3(2001) 1409—1424 .

[7] H M Rygaard A Torbenloe. Multi criteria design optimization of backeroe loader front mechanism, J. American Society of Mechanical Engineering Division (Publication) DE. 116(2003)9-15.

[8] R Eugeniusz, M Przemyslaw, C Jerzy. Numerical and experimental analysis of a mine's loader boom crack, J. Automation in Construction. 17(2008)271-277.

[9] B T C, X Y L, Y Q Y. Three-dimensional Modeling and Finite Element Analysis of Loader Working Device, J. Meikuang Jixie (Coal Mine Machinery). 35(2014) 105-107.

[10] H Z Huang, X S Yao, Z R Zhou, Multi - objective Optimization Design of Loader Working Device Based on Satisfaction, J. Chinese Journal of Mechanical Engineering. 39(2003)97-103.

[11] X B Ning, B Meng, H Yao, Dynamic Simulation Analysis on Strength of Loader’s Working Device, J. Mechanical Engineering. 39(2008)16-19.