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Dynamic Simulation and Structure Optimization of the Folding Hoistable Mast Based on Adams

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Abstract. In order to improve the safety and the dynamic stability of the hoistable mast, the method of parametric optimization was introduced and the dynamic model was established by the multi-rigid-body dynamic analysis soft of Adams in the beginning of the product design. Then, the dynamic simulation and the structure optimization were carried out. It was shown that the maximum force on the primary oil cylinder was reduced by 10%, the maximum force on the secondary oil cylinder was reduced by 8%, the structure layout of the mast was more reasonable and the dynamic stability were improved. Also, it was proved that the optimized structure of the hoistable mast was reasonable and feasible by simulation results.

Introduction

As the key equipment of the marine robot to maintain navigational and operational activities near water, the hoistable mast is the bridge which gets the information from outside world for communication. Also, it's the intake and exhaust channel which provides the combustion air for the marine robot driven by the internal combustion engine. Its performance is related to the survival of the marine robot [1].

The mast is distinguished into two forms: the folding mast and the telescopic mast. In this paper, the folding mast which uses the symmetrical structure works driven by the oil cylinder. Choosing a suitable oil cylinder within the limited space and realizing the unfolding and folding of the mast safely are important tasks in the design of the mast. So, it has important significance to realize the reasonable layout of hinge points and reduce the force on the oil cylinder.

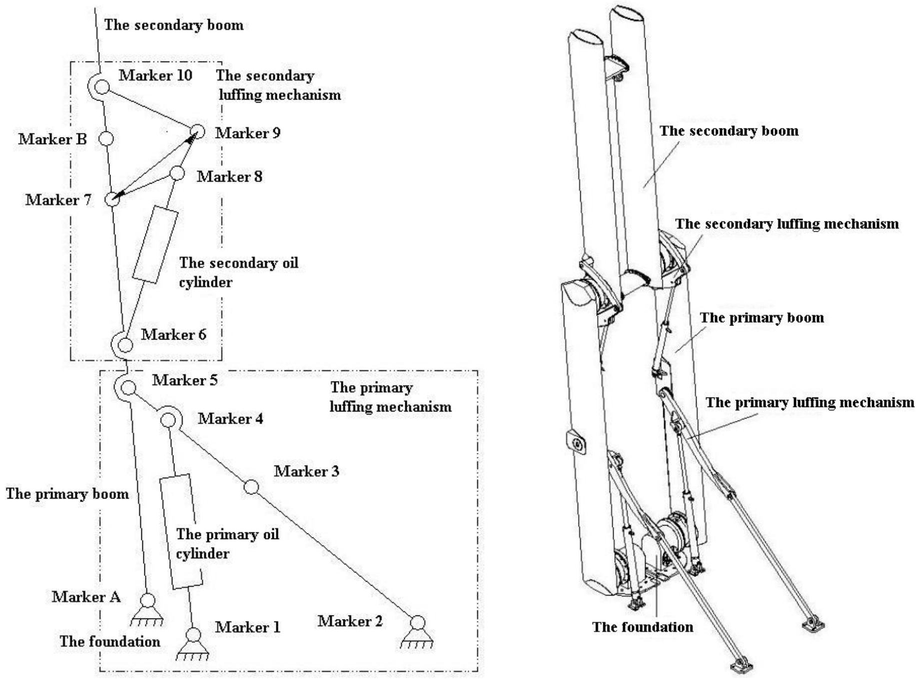
In recent years, the research on the safety of the mast focused on: (1) The impact of welding residual stress on the fatigue property of the mast under the cyclic load [2,3]; (2) The impact of the wind vibration on the fatigue property and reliability of the mast [4,5]; (3) The impact of the composite materials and the complex shape on the stealth of the mast [6,7]. The research above mainly adopts new technology, new material and more complex shape to improve the safety of the mast. There is little attention to improving the safety of the mast on the structure by the optimization of key parameters in the beginning of the product design.

The traditional structural optimization needs to simplify the structure. So, there is a gap between analysis results and the actual structure. By contrast, it can test the movement of components, evaluate the performance of the system, modify the design flaws and get the better design scheme by the dynamic simulation and the optimization of key parameters [8].

In this paper, the dynamical model was established by the multi-rigid-body dynamic analysis soft of Adams to realize the reasonable layout of hinge points in the structure design of the mast and reduce the force on the oil cylinder. The dynamic simulation and the structure optimization were carried out by the method of parametric optimization. It's showed that the maximum force on the oil cylinder was reduced and the dynamic stability and the safety of the mast were improved.

The folding hoistable mast

The hoistable mast consists of the primary boom, the primary luffing mechanism, the secondary boom, the secondary mechanism and the foundation. The primary boom and foundation are connected by marker A. The primary boom and the secondary boom are connected by marker B (See Fig. 1).



a The mechanism diagram of the mast b The three-dimension diagram of the mast

Fig. 1 The structure of the mast

The working process of the mast is driven by the oil cylinder. The primary boom is unfolded and folded by the primary luffing mechanism and the secondary boom is unfolded and folded by the secondary luffing mechanism. It’s determined that the mast can work normally or not by the reasonable layout of hinge points. It’s contributed to the selection of the oil cylinder and the load distribution near hinge points by reducing the load on oil cylinder.

The force on parts changes with the movement of the luffing mechanism in the working process of the mast. So, it’s difficult for statics calculation to get all the value. It takes a long time to determine the position of hinge points by the traditional mapping method and it has a low accuracy. Then, the dynamic simulation and the structure optimization were carried out by the method of parametric optimization in Adams.

Dynamic modeling

The multi-rigid-body dynamic analysis started with the geometric model, established the dynamics model by mathematical modeling and got optimization results through the parametric optimization and the numerical solution in the end. The process was shown in Fig. 2.

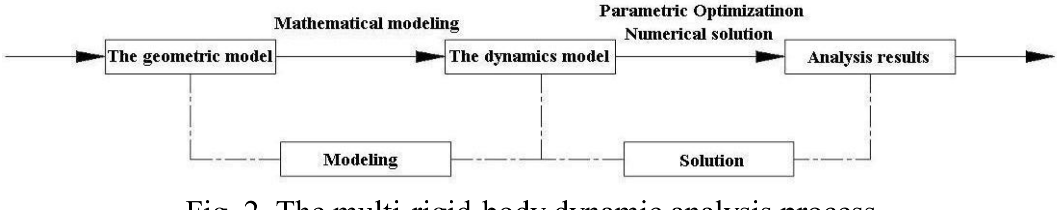


Fig. 2 The multi-rigid-body dynamic analysis process

Due to the boom of the mast uses the low resistance airfoil of NACA, the three-dimension model was set up in Solidworks to finish the dynamic analysis accurately. It’s imported into Adams by the intermediate format. Then, the geometric model was established. The driving functions on the oil cylinder were added to simulate the working process (see Table 1). On the basis of the above, adopting automatic modeling technology in Adams, the dynamic model was established.

Table 1 The driving functions

The driving function	The function expression
The driving function on the primary oil cylinder	Step(time,0,0,3,30)+step(time,3,0,21,0) +step (time,21,0,24,-30)+step (time,24,0,45,0)
The driving function on the secondary oil cylinder	Step(time,0,0,24,0)+step(time,24,0,27,30)+ step(time,27,0,40,0)+step(time,40,0,44.3,-30)

Dynamic simulation and optimization

Based on the dynamic model, the objective function, design variables and constrains were set in the beginning of the dynamics simulation and optimization. Then, the better objective functions were obtained by changing design variables on the basis of meeting constrains. It's shown in Fig. 3.

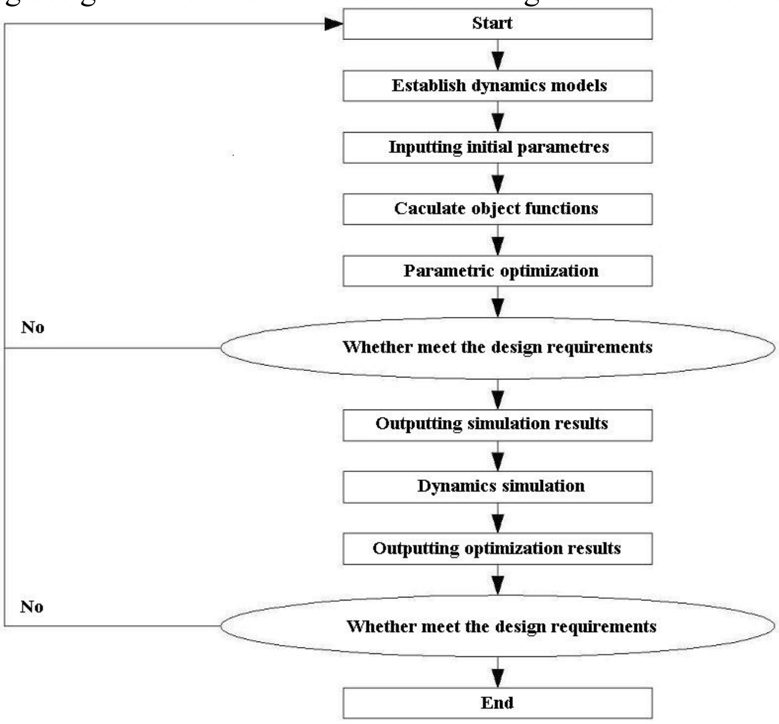


Fig. 3 The dynamic simulation and optimization process

The working process of the mast consists of the unfolding of the primary boom, the unfolding of the secondary boom, the folding of the secondary boom and the folding of the primary boom. The unfolding and folding of the mast are opposite of each other. It's shown that the force on the primary oil cylinder is passed to the primary boom from the marker 5 and the force on the secondary oil cylinder is passed to the primary boom from the marker 6 in Fig. 1. So, the maximum force on the oil cylinder relates directly to the mechanical properties near the marker 5 and marker 6. In addition, it's not only the important basis for the selection of the oil cylinder, but an important input for the structure design of the mast. Therefore, this paper took the maximum force on the oil cylinder as the research object, set the maximum force on the primary oil cylinder as the objective function Ⅰ, set the maximum force on the secondary oil cylinder as the objective function Ⅱ, chose coordinates of marker 1 to marker 10 in the rectangular coordinate system as the design variables, and took the unfolding of the boom, the maximum travel of the oil cylinder and the normal work of the luffing mechanism as constraints. Then, the dynamic simulation and optimization were carried out.

Sensitivity analysis of design variables. To determine the impact of design variables on objective functions and choose design variables used in the process of the optimization design, the sensitivity analysis of design variables were carried out. (The sensitivity reflects the influence of the design variable on the objective function when the other design variables remain the same.) It's shown in Table 2. The sensitivities of DV_1, DV_2, DV_8 and DV_10 were higher in the objective function Ⅰ and the sensitivities of DV_15, DV_16, DV_18 and DV_20 were higher in the objective function Ⅱ by analysis results. Therefore, DV_1, DV_2, DV_8 and DV_10 were set as the optimal design variables of the objective function Ⅰ and DV_15, DV_16, DV_18 and DV_20 were set as the optimal design variables of the objective function Ⅱ.

Table 2 The sensitivities of design variables

The marker	Coordinate	The design variable	Sensitivities in the objective function Ⅰ	The marker	Coordinate	The design variable	Sensitivities in the objective function Ⅱ
Marker 1	X	DV_1	-24	Marker 6	X	DV_11	-28
	Y	DV_2	98		Y	DV_12	-123
Marker 2	X	DV_3	0.4	Marker 7	X	DV_13	-135
	Y	DV_4	4.7		Y	DV_14	25
Marker 3	X	DV_5	-0.7	Marker 8	X	DV_15	397
	Y	DV_6	-7		Y	DV_16	-884
Marker 4	X	DV_7	16	Marker 9	X	DV_17	93
	Y	DV_8	-65		Y	DV_18	460
Marker 5	X	DV_9	-7.18	Marker10	X	DV_19	129
	Y	DV_10	30.8		Y	DV_20	325

Analysis of design variables' optimization results. Based on the above results, the design variables were optimized. The simulation results after optimization were got by many iterative calculations (see Table 3).

Table 3 The contrast of design variables and objective functions before and after optimization

The design variablea and the objective function	The initial value	The value after optimization
DV_1	305	335.5
DV_2	-232.0	-255.2
DV_8	-16.45	-14.8
DV_10	75	67.5
DV_15	2262.0	2307.2
DV_16	-159.5	-151.53
DV_18	-20.0	-19.8
DV_20	-72.0	-70.6
The objective function Ⅰ	15353.1	13886.6
The objective function Ⅱ	5833	5376

The maximum force on the oil cylinder was shown in Fig. 4 and Fig. 5. It's shown that the maximum force on the primary oil cylinder was reduced by 10% and the maximum force on the secondary oil cylinder was reduced by 8%. In addition, the force on the oil cylinder changed more smoothly over time. It's beneficial to improve the dynamic stability of the mast.

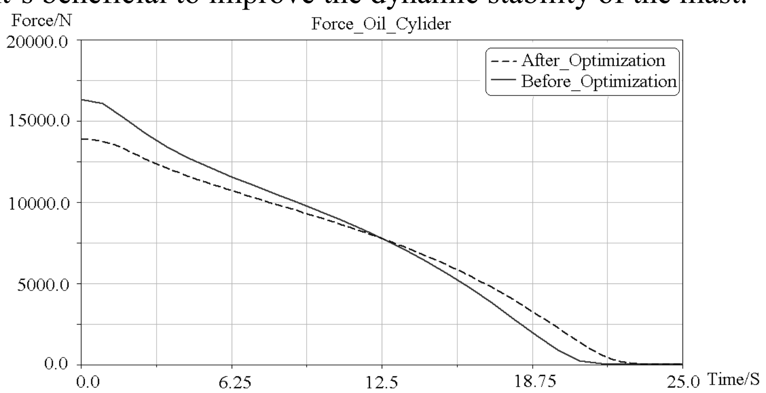


Fig. 4 The contrast of the objective function Ⅰ before and after optimization

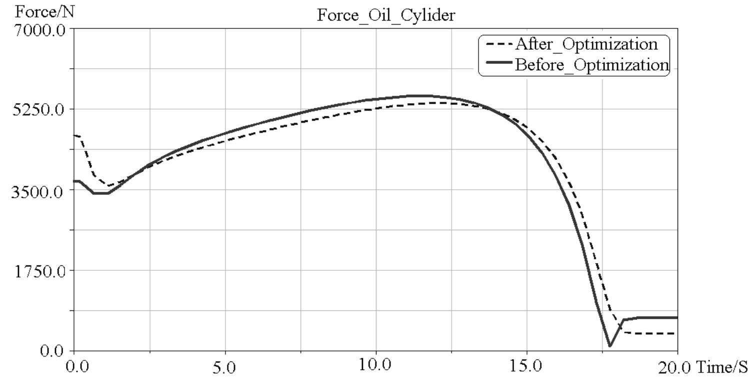


Fig. 5 The contrast of the objective function Ⅱ before and after optimization

Analysis of dynamic simulation results. In order to verify whether the optimization result met design requirements, it was inputted into the dynamic model. Then, the unfolding angle of the boom, the travel of the oil cylinder and the force on hinge points were got. This paper took them as research objects and set the safety factor as 1.5.

Table 4 The unfolding angle of the boom

The boom	The design unfolding angle	The simulation results of the unfolding angle
The primary boom	95°	94.95°
The secondary boom	180°	179.96°

Table 5 The force on the oil cylinder and the travel of the oil cylinder

The oil cylinder	The theoretical maximum thrust F_p [N]	The maximum force on the oil cylinder F_{max} [N]	Safety factor (F_p / F_{max})	The maximum travel of the oil cylinder [mm]	The simulation results of the oil cylinder's travel [mm]
The primary oil cylinder	29960	13886.6	2.15	630	629
The secondary oil cylinder	19470	5376	3.6	500	498

Table 4 and Table 5 showed that the luffing mechanism can realize unfolding and folding normally and the safety factor of the oil cylinder met design requirements after optimized. In addition, the force on hinge points could be got by dynamic simulation. Fig. 6 showed the force on the primary oil cylinder and marker 5 over time. Fig. 7 showed the force on the secondary oil cylinder, marker 6 and marker 10 over time. The force on the primary oil cylinder and marker 5 reached the maximum at the same time and the force on the secondary oil cylinder and marker 6 reached the maximum at the same time. But, the force on the secondary oil cylinder and marker 10 reached at the different time. It suggested that the force on parts can't reach maximum simultaneously. Therefore, it needs to take the dynamic simulation results as the design input to check the strength of parts.

Summary

The dynamic model of the folding hoistable mast was established. The dynamic simulation and the structure optimization were carried out by Adams in this paper. Through the parametric optimization, the maximum force on the primary oil cylinder was reduced by 10% and the maximum force on the secondary oil cylinder was reduced by 8%. It raised the safety of the mast and improved the dynamic stability of the mast at the same time. The dynamic simulation results verified the rationality of the optimization results and the feasibility of the structure design, and provided a large number of reliable datas for the later design work as well.

In the beginning of the product design, the concept of the parametric optimization was introduced. On one hand, it can improve the mechanics performance of parts; On the other hand it also can provide the design input for the later design work. Also, it contributes to improving the efficiency and shortening the product development cycle.

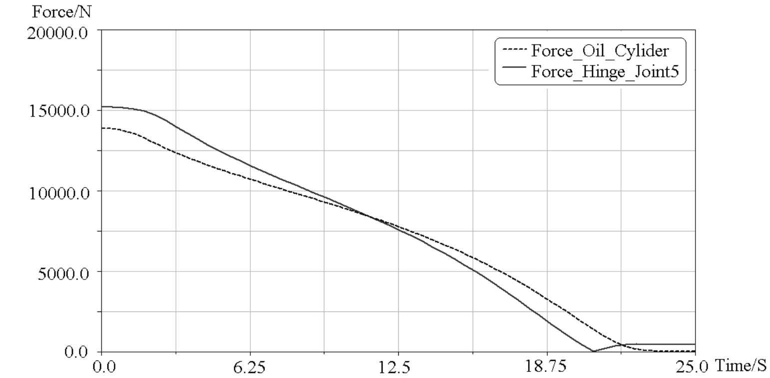


Fig. 6 The force on the primary oil cylinder and marker 5 over time after optimization

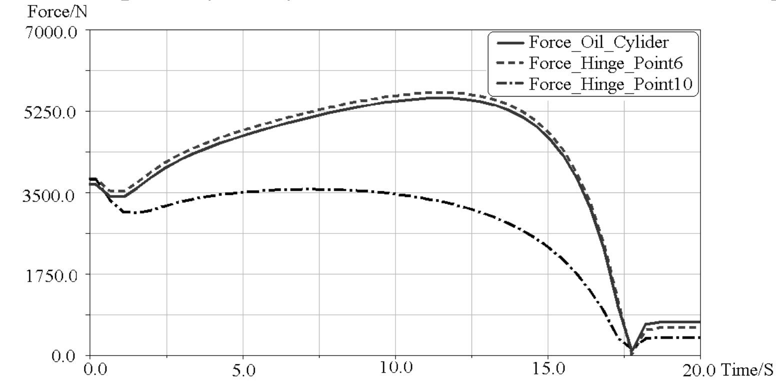


Fig. 7 The force on the secondary oil cylinder, marker 6 and marker 10 over time after optimization

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