Optimal Design of the Mover Considering the Electrical Characteristic of Linear Motor

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Abstract

LMTT(Linear Motor based Transfer Technology) is a new type of transfer system used in the maritime container terminal for the port automation, and largely consists of a controller, shuttle car, and rail. The shuttle car is divided into the frame part, the driving part, and wheels. In order to design this system, various researches on each part of it must be conducted. In this study, we dealt with the optimum design for the mover of the shuttle car designed from previous studies on the strength of the frame with respect to the number of cross beams to minimize the weight of the shuttle car and to satisfy design criteria of cargo-handling systems in container terminal. For the optimization of the mover, thicknesses of each beam were adopted as design variables, the weight of the frame as objective function, and stress and deflection per unit length as constraint condition.

Keywords: Linear Motor, Mover, LMTT, Optimal Design

1. Introduction

We expect that ULCS (Ultra Large Container Ship) of 15,000TEU appears within 20 years as a trade scale of container increases 7.3% annually. In order to cope with the change of harbor successfully, every country uses all their energy to develop a high speed and automated new type cargo-working system. So the various researches, such as a new type container crane, transfer system, gate and operating system etc., are being conducted, for automation of cargo-working system. In this investigation, we deal with the investigation about transfer system by LMTT (Linear Motor based Transfer Technology) (Sakamoto et al, 1997).

We have dealt with the AGV (Automated Guided Vehicle) to automate a transfer system of a container box in existing terminal. AGV is operating in ECT port, Nether-land, and it expects to install AGV in Singapore, German, China etc. However, operating velocity of AGV is about 5m/s, and AGV have various problems due to uncertainty of sensors, composition of subsystem etc. Accordingly, in order to solve these problems, and in order to achieve automation of system easily, LMTT has been suggested as new model of transfer system. They developed transfer system of container box using a large size linear motor already, and are making test working in Hamburg port, German (Frank, 2001).

LMTT is horizontal transfer system in the maritime container terminal for the port automation and driven by PM LSM (permanent magnetic linear synchronous motor) that is consists of a stator module between the rails and a mover beneath shuttle car. In order to design a shuttle car for LMTT, we have to conduct the research about a frame, stator module, and rail and wheel (Lin et al, 2001). In this study, we dealt with the optimum design for the mover of the shuttle car designed from previous studies on the strength of the frame with respect to the number of cross beams to minimize the weight of the shuttle car and to satisfy design criteria of cargo-handling systems in container terminal (Han et al, 2004).

For the optimization of the mover, thicknesses of each beam were adopted as design variables, the weight of the frame as objective function, and stress and deflection per unit length as constraint condition.

2. Optimal Design of a Mover

2.1 Analysis Model and Load Conditions

A shuttle car of a 10 ton dead load, 2.5 meter in width, 15 meter in length is applied to a 40 ton container load, 30 ton magnetic levitation or suction generated by the mutual interaction between a permanent magnet and an electromagnet. When the Stator turn on/off the electricity, it lifts up/settles down the mover at regular intervals. This is the 30 ton magnetic levitation or suction.

On the other hand, the mover of the shuttle car is supported with 4 point which is constrained to a wheel.

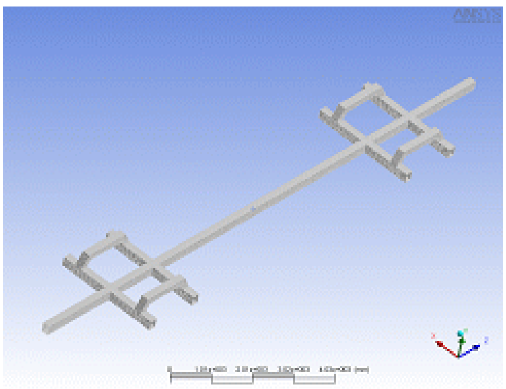


Fig. 1 Meshed shape of the mover in a shuttle car for LMTT

Consequently, the mover is bended to the up and down. At this moment, a gap between the mover and the stator is changed irregularly. Due to irregular intervals, the thrust force generated by the linear motor drive is variable.

In order to obtain the thrust force, we investigate the structural optimum design for the mover with respect to the thickness of a cross section beams to limit the weight of the shuttle car and to satisfy the design criteria of cargo-handling systems in container terminal (MMAFF, 2004).

The mover of a shuttle car consists of the longitudinal beam, transverse beam, wheel beam. And the meshed shape of the mover was shown as Fig. 1. In this research, 3-kinds of load cases were adopted as the design parameter to evaluate the effect of the load case which is applied to the mover.

The element used in this analysis is the hex-dominant which is five node pyramid element. And the element number is 35,325 and node number is 15,596.

1) Load case 1: The case of considering to a shuttle car of a 10 ton dead load which is applied to a 40 ton container load.
2) Load case 2: The case of considering to a shuttle car of a 10 ton dead load which is applied to a 40 ton container load and the mover applied to 30 ton magnetic levitation.
3) Load case 3: The case of considering to a shuttle car of a 10 ton dead load which is applied to a 40 ton container load and the mover applied to 30 ton magnetic suction.

2.2 Formulation for Optimal Design of a Mover

To minimize a weight of the Mover and satisfy the design criteria of cargo-handling systems in container terminal, Formulation of the structural optimum design is as follows.

$$X = [T_{LB}, T_{TB}, T_{WB}]^T \quad (1)$$

Minimize :

$$W_M(X) \quad (2)$$

Subject to:

$$1.5 - \left|\frac{\sigma_y}{\sigma_{max}}\right| \leq 0 \quad (3)$$

$$|\delta_{max} - \delta_{min}| - 10 \leq 0 \quad (4)$$

As shown Fig. 2, shapes of the each beam of the mover are box-type beam. To carry out the optimization for the mover with respect to the thickness of a cross section, the design variables set up the thickness of each beam and the width, height of each beam is fixed. Table 1 shows the initial dimensions of cross section for each beam.

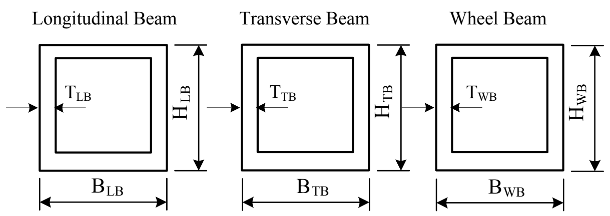


Fig. 2 Section shape of each beam in the mover of a shuttle car

The objective function is established a weight of the mover, constraints set up the maximum equivalent stress isn't over the yield stress of the material in the ratio of 1 to 1.5. And difference between the maximum and the minimum deflection of the mover set up within the constraint 10mm.

Table 1 Dimensions of cross section for each beam in a mover

Items	B_{iB}	H_{iB}	T_{iB}
Longitudinal beam	200	300	10
Transverse beam	200	300	10
Wheel beam	200	200	10

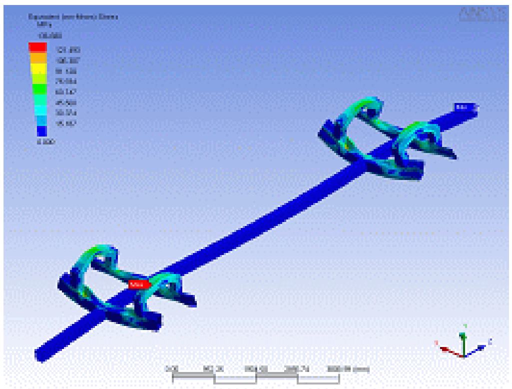
3. Results and Discussions

3.1 Considering only a Self-weight of Container and Frame (Case 1)

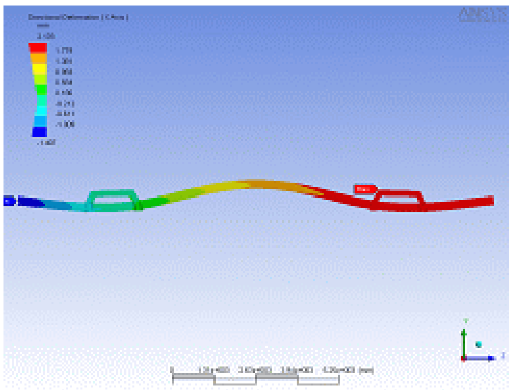
Using ANSYS Workbench – DesignXplorer applied to the VT method, we performed optimum design of the mover with respect to the thickness of each beam. Then the optimization result of load case 1 is shown in Table 2. As from the application of the optimum values, the stress and deflection of the mover are shown in Fig. 3.

Table 2 Initial and Optimal value of the mover (Load case 1)

Item	Design Value			Stress	Deflections		Weight
	T_{LB}	T_{TB}	T_{HB}	σ_{max}	δ_{max}	δ_{min}	W_M
	mm	mm	mm	MPa	mm	mm	N
initial	10	10	10	120	1.58	-1.7	255.9
optimal	7	9	11	131	1.05	-1.6	226.0



(a) von Mises stress of the mover



(b) deflection of the mover

Fig. 3 Stress and deflection distribution of the mover as optimum condition (Load case 1)

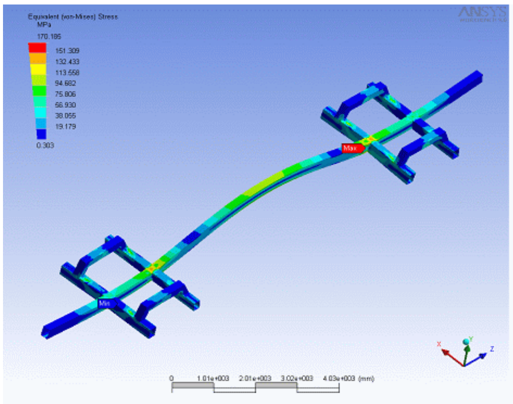
As shown in Table 2, the optimum values of the longitudinal beam, transverse beam, wheel beam obtain each 7, 9, 11mm. Also, the difference between the maximum and the minimum deflection of the mover is 2.65mm within 10mm. As this result, we are acquainted with the uniform thrust generated by the linear motor.

3.2 Considering the Up-lifting Force of LM (Case 2)

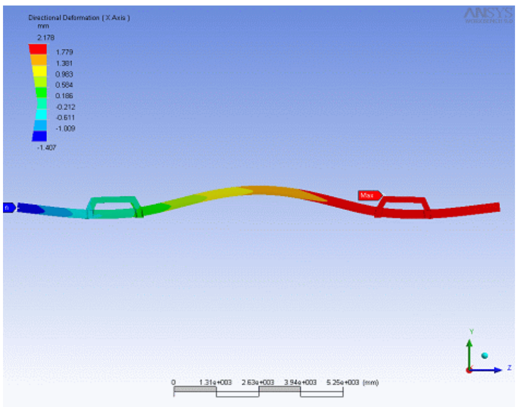
Next, we performed optimum design of the mover with respect to the thickness of each beam. Then the optimization result of load case 2 is shown in Table 3. As from the application of the optimum values, the stress and deflection of the mover are shown in Fig. 4.

Table 3 Initial and Optimal value of the mover (Load case 2)

Item	Design Value			Stress	Deflections		Weight
	T_{LB}	T_{TB}	T_{HB}	σ_{max}	δ_{max}	δ_{min}	W_M
	mm	mm	mm	MPa	mm	mm	N
initial	7	9	11	170.2	2.2	-1.4	226.0
optimal	9	13	14	121.3	1.3	-0.8	276.1



(a) von Mises stress of the mover



(b) deflection of the mover

Fig. 4 Stress and deflection distribution of the mover as optimum condition (Load case 2)

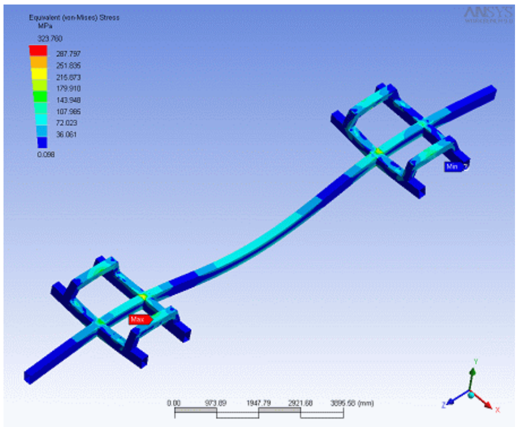
As shown in Table 3, the optimum values of the longitudinal beam, transverse beam, wheel beam obtain each 9, 13, 14mm. Also, the difference between the maximum and the minimum deflection of the mover is 2.10mm within 10mm. As this result, the thickness of the wheel beam a few more increase than the load case 1. Because the Shuttle car is supported with 4 point constrained to a wheel and is applied to the stress concentration by the weight of the frame and container.

3.3 Considering the Suction Force of LM (Case 3)

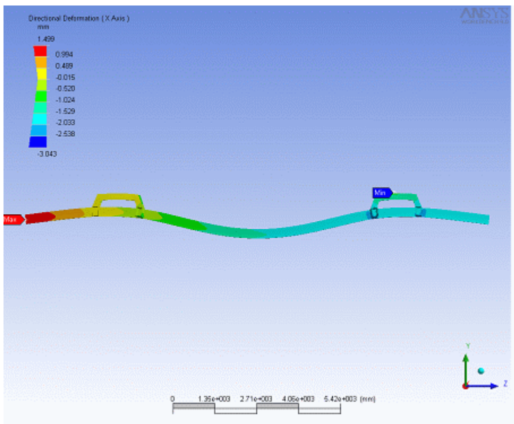
The last, we performed optimum design of the Mover with respect to the thickness of each beam. Then the optimization result of load case 3 is shown in Table 4. As from the application of the optimum values, the stress and deflection of the mover are shown in Fig. 5.

Table 4 Initial and Optimal value of the mover (Load case 3)

Item	Design Value			Stress	Deflections		Weight
	T_{LB}	T_{TB}	T_{HB}	σ_{max}	δ_{max}	δ_{min}	W_M
	mm	mm	mm	MPa	mm	mm	N
initial	7	9	11	245.3	1.49	-3.04	226.0
optimal	28	31	36	131.5	0.05	-1.53	610.6



(a) von Mises stress of the mover



(b) deflection of the mover

Fig. 5 Stress and deflection distribution of the mover as optimum condition (Load case 3)

As shown in Table 4, the optimum values of the longitudinal beam, transverse beam, wheel beam obtain each 28, 31, 36mm. Also, the difference between the maximum and the minimum deflection of the Mover is 1.58mm within 10mm. When the mover applied to the suction, the thickness of the each beam is the heaviest in 3-kinds of load case. Therefore, the mover is pleased to satisfy the deflection criteria in the suction. If that happens, the mover should satisfy the deflection criteria in the magnetic levitation.

4. Conclusions

We investigate the structural optimum design for the mover with respect to the thickness of a cross section beams to limit the weight of the Shuttle car and to satisfy the design criteria of cargo-handling systems in container terminal using finite element analysis, and the research are as follow:

1. Considering 3-kinds of the load case, we obtained the optimum design value for the thickness of a cross section of the Mover. Also difference between the maximum and the minimum deflection of the mover is satisfied within the constraint 10mm.

2. Regardless of 3-kinds of the load case, each beam of the mover not is satisfied to satisfy the deflection criteria without answering the stress criteria of cargo-handling systems in container terminal

3. We carried out the structural optimum design for the mover with respect to the thickness of a cross section beams to limit the weight of the shuttle car and to satisfy the design criteria of cargo-handling systems in container terminal.

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