Stress Analysis of Machine Supporting Beam System for Large Tonnage Lift

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Abstract. With the development of social economy and industry, people's demands for automation, batch production and high efficiency become higher which also stimulate the development of lift industry. Some kinds of lifts have higher requirements for carrying capacity and safety, so the large tonnage lift came into being in large manufacture factories. The distance between the supporting points of the machine supporting beam is wider. During the lift's operation, the deflection and the stress of the machine supporting beam are larger, so a reasonable machine supporting beam structure system is needed. Design of large tonnage lift is beyond the conventional standard of professional design, normally has to meet some special requirements according to the requirements of customers. In this paper, the layout and the stress analysis of the machine supporting beam system for traction machine of large tonnage lift, as well as the corresponding finite element analysis of important load-bearing parts were performed and the checks also carried on, finally the design and material selection of the machine supporting beam system are determined and practically applied.

1 INTRODUCTION

Generally, the common large tonnage lift is the freight lift. It has a rated capacity of 4~15 tons. The «China GB 7588-2003 lift manufacture and installation safety norm» as well as the «GB 25856-2010 freight lift manufacture and installation safety norm» are referred to give dual attention to parameter requirements that the non-specialized operation security and equipment itself needs to satisfy on large tonnage lift [1,2]. The traction machine is an essential component of the lift driving device, and the machine supporting beam of the traction machine is an important supporting component. Due to the structural features of the lift, the machine supporting beam is a load-bearing steel beam supporting the weight of lift car, counterweight and other equipment. The load-bearing beam not only supports the traction machine but also the whole lift. The car, load, counterweight, traction sheave, cable, hoist rope and so on are hung on the load-bearing beam through the traction machine. It is really "a beam of a beam", which bears all static and dynamic loads of the lift. It is generally fixed on the civil load-bearing beam at the top of the lift shaft, and the material used is the channel steel or I-beam. For large tonnage lifts, the role of the machine supporting beam system is self-evident and has irreplaceable effect in ensuring the service life, running safety and comfort of the lift. The bearing beam of overhead type transmission is arranged in the machine room.

2 PRIMARY DESIGN OF MACHINE SUPPORTING BEAM

The roping method of the lift depends mainly on the position of the traction unit, the rated load and the rated speed of the car. In selecting and determining the way of rope winding, it is necessary to consider the high transmission efficiency, reasonable energy consumption and the extension of the service life of the wire rope. Different roping methods have different transmission speed ratios, called traction ratio. It is the ratio of the tangential velocity of the traction sheave to the velocity of the car. According to roping arrangement and traction ratio, the traction lifts can be classified as roped 1:1 or multiple reeving systems. The roping method of the steel wire rope is closely related to the lift machine room type. The rated capacity of the lift is 15 tons, the rated operating speed is 0.5m/s, and the guide rail type is the symmetrical arrangement of two guide rails. After comprehensive consideration, select the sheave roping method with traction ratio 8:1.

The deadweight of the car is 14 tons, the deadweight of counterweight is 21 tons, the traction machine is 1 ton, the rated capacity is 15 tons, and the size of the car is 4000 x 6000 x 3500 according to the standard. The machine supporting beam system is the focus of this design, including the counterweight return sheave beam, diverting pulley beam, the auxiliary machine supporting beam, the middle supporting beam, and the main machine supporting beam. The whole machine supporting beam system is shown in Fig. 1. A schematic showing the roping arrangement of traction wire is shown in Fig. 2.

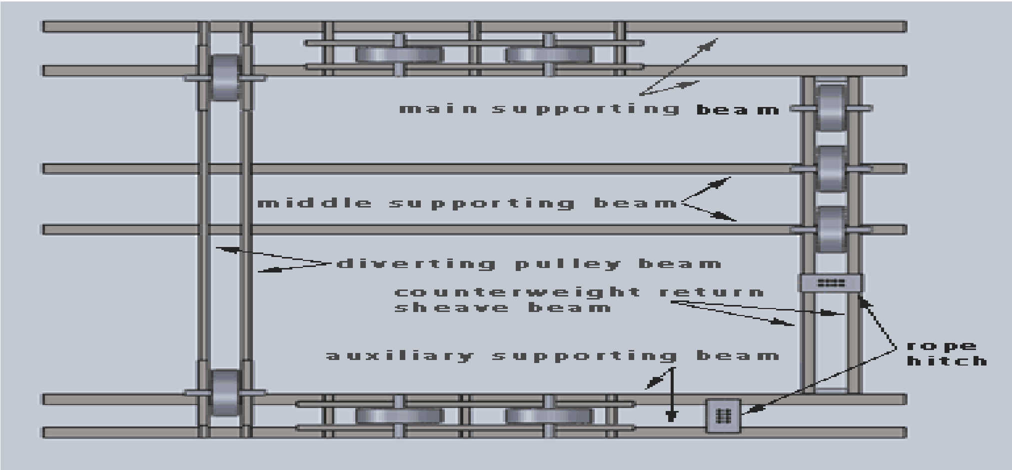

Figure 1 Layout of whole machine supporting beam system

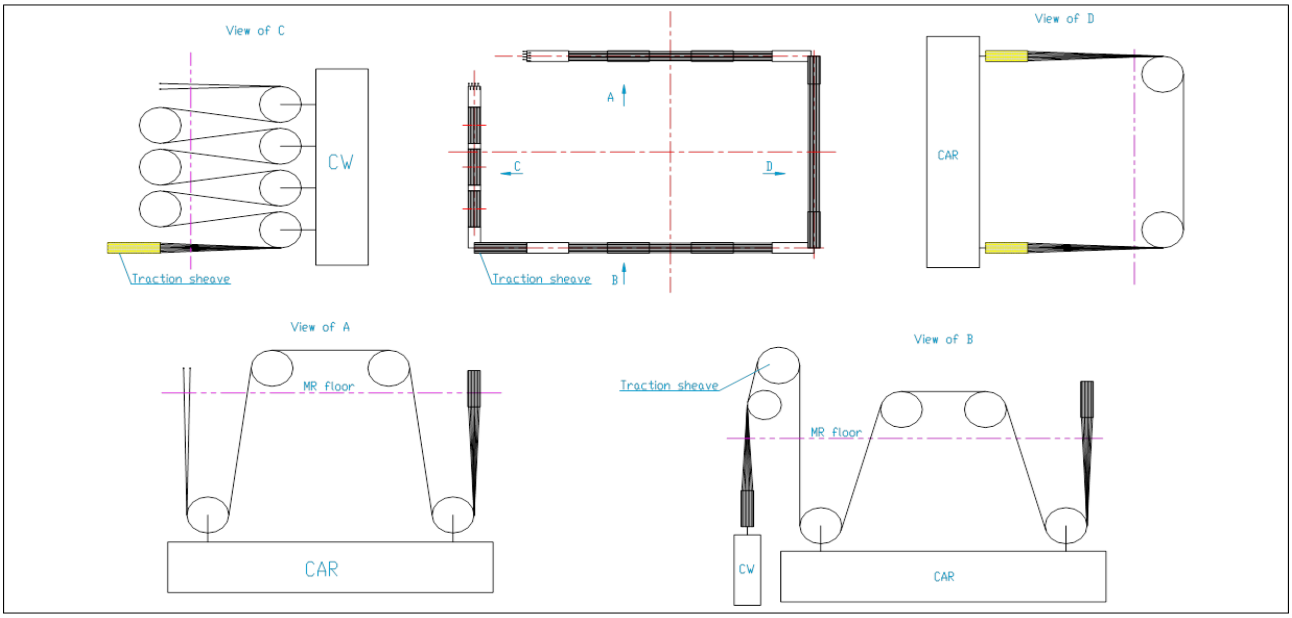

Figure 2 Schematic showing the roping arrangement

3 DETERMINATION OF BEAM SYSTEM PLANE POSITION AND INSTALLATION

Depending on the position for steel wire rope hole in the machine room, the location of the machine supporting beam system can be determined. The position of the traction machine's girder is determined according to the established standard line of the well plane layout, connecting the line of the car center to the counterweight center and the position of the bolt hole of the machine chassis.

Because the traction machine beam is the main bearing part of the lift, the length of the beam should be long enough to avoid the on-site welding.

The installation of the traction machine beam will depend on the different running speeds, the traction mode, the top layer height of the shaft, the sound insulation layer, machine room height, and the plane layout of all parts inside the machine room. Then, consider the specification and interaction distance of the machine supporting beam. Different installation methods can be determined according to these factors. After installation, the traction rope and machine supporting beam are not allowed to have friction when the lift is running. It is necessary to ensure that the traction rope operates smoothly to ensure the safe operation of the lift.

When installing the traction machine beam system, China GB/T10060-2011 "lift installation and acceptance specification"[3] must be followed: the traction machine supporting beam imbedded in the load-bearing wall, its supporting length should exceed the center of wall thickness 20mm, and should not be less than 75mm. For a brick wall, a reinforced concrete or metal beam, which can bear its load, should be placed under the beam to prevent the insufficiency, such as concrete and brick cracking and fragmentation under the support of the traction machine girder (I-beam), as this would not effectively guarantee the long-term safe operation of the lift.

The unevenness of each beam should not be more than 0.5/1000mm. The allowable height difference of two adjacent machine supporting beams should not be greater than 0.5mm, and the parallel deviation between them should not be greater than 6mm. The total equality is based on the connection line between the car and the counterweight center, to avoid causing the verticality of the traction sheave to not meet design requirements, as if the traction rope tension is improperly adjusted, it can result in traction rope groove jumping[4,5].

The common I-steel machine supporting beam is not directly placed on the floors or brick walls. This is to prevent mechanical and electromagnetic vibrations caused by the traction machine, which would lead to floor vibrations, affecting the residents nearby [6].

The loader beam embedded into the load-bearing wall is a hidden project. Before plugging, the quality of the beam installation is checked according to the requirements of GB50310-2002 "acceptance specification for construction quality of Lift Engineering"[7].

4 STRESS ANALYSIS AND CHECK

The whole machine supporting beam system includes the counterweight beam stress calculation, the diverting pulley beam stress calculation, the auxiliary machine supporting beam stress calculation, the middle supporting beam stress calculation, the main machine girder stress calculation.

4.1 Stress calculation of counterweight beam

First, take the counterweight return sheave beam as the simply supported beam; consider the most unfavorable conditions, namely all stress points being in the central span of girder [8].As shown in Fig.3, F_M: Support reaction force of the CW beam on the supporting point of the main supporting beam; F_V: Support reaction force of the CW beam on the supporting point of the auxiliary supporting beam; F_{CC}: Support reaction force of the CW beam on the 1# middle supporting beam; F_{CD}: Support reaction force of the CW beam on the 2# middle supporting beam; F_{C1}: Load force on the 1# pulley block on the CW beam5250kg=the weight of CW/4; F_{C2}: Load force on the 2# pulley block on the CW beam5250kg=the weight of CW/4; F_{C3}: Load force on the 3# pulley block on the CW beam5250kg=the weight of CW/4; F_{C4}: Load force on CW rope head 2625kg=the weight of CW/8；Lc: The CW beam spacing between the supporting points on the main supporting beam and the auxiliary supporting beam4550mm; Lc1: The CW beam spacing between the supporting points on the main supporting beam and the 1# pulley block on the CW beam 520mm；Lc2: The CW beam spacing between the supporting points on the main supporting beam and the 2# pulley block on the CW beam 1360mm; Lc3: The CW beam spacing between the supporting points on the main supporting beam and the 3# pulley block on the CW beam 2200mm ; Lc4: The CW beam spacing between the supporting points on the main supporting beam and the rope head plate on the CW beam 2940mm.

The supporting point of the CW beam on the 1# middle supporting beam coincides with the 2# pulley block on the CW beam. The supporting point of the CW beam on the 2# middle support beam coincides with the 3# pulley block on the CW beam.

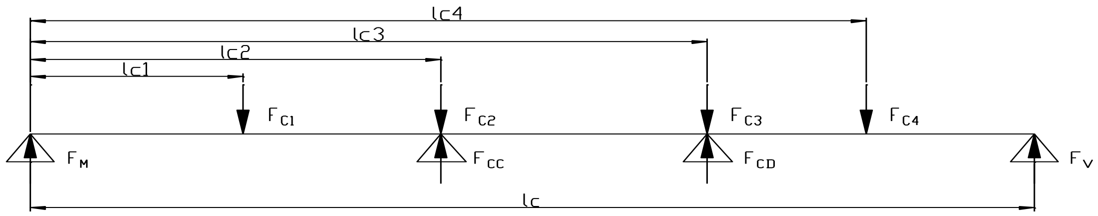

Figure 3 Force diagram of counterweight beam

From the force equilibrium equation,

$$F_{C1} + F_{C2} + F_{C3} + F_{C4} = F_M + F_V + F_{CC} + F_{CD}$$

From the moment equilibrium equation,

$$F_{C1} \times lc1 + F_{C2} \times lc2 + F_{C3} \times lc3 + F_{C4} \times lc4 = F_V \times lc + F_{CC} \times lc2 + F_{CD} \times lc3$$

$$v_{AB}(F_{C1}, lc2) + v_{AB}(F_{C2}, lc2) + v_{AB}(F_{C3}, lc2) + v_{AB}(F_{C4}, lc2) + v_{AB}(F_{CC}, lc2) + v_{AB}(F_{CD}, lc2) = 0$$

$$v_{AB}(F_{C1}, lc3) + v_{AB}(F_{C2}, lc3) + v_{AB}(F_{C3}, lc3) + v_{AB}(F_{C4}, lc3) + v_{AB}(F_{CC}, lc3) + v_{AB}(F_{CD}, lc3) = 0$$

$v_{AB}(F_{Cx}, lcx)$ denotes: simply supported beam AB, under the action of force F_{Cx}, the deflection of beam at L_{CX} point. In order to simplify the calculation, it is assumed that the deflection displacement of the CW beam is 0 on the supporting points of the 1# and the 2# middle supporting beam.

M_{C1}=F_M*lc1

M_{C2}=F_M*lc2-F_{C1}*(lc2-lc1)

M_{C3}=F_M*lc3-F_{C1}*(lc3-lc1)- F_{C2}*(lc3-lc2)+ F_{CC}*(lc3-lc2)

M_{C4}=F_M*lc4-F_{C1}*(lc4-lc1)- F_{C2}*(lc4-lc2)- F_{C3}*(lc4-lc3)+ F_{CC}*(lc4-lc2)+ F_{CD}*(lc4-lc3)

These support reaction forces can be obtained: F_M=-2819kg, F_V=-507.5kg, F_{CC}=-7474.7kg, F_{CD}=-7573.9kg, similar method can be used to solve the bending moment at other supporting points. M_{C1}= 1465804.81 kg*mm, M_{C2}= -576357 kg*mm , M_{C3}= -749770.12kg*mm , M_{C4}= 0.00008kg*mm. Generally, I-beam or channel steel is chosen for this kind of beam, and the cross section can be selected by comparing the parameter table of channel steel or I-beam. Select the material Q235 first, its yield strength is 235Mpa, choose allowable safety factor, general 3 ~ 4, according to the maximum bending moment and safety factor, the minimum section bending coefficient required by the beam can be obtained. Due to the installation space of pulley, 32a# channel steel is used for CW beam. The cross section coefficient of the beam is 950cm^3; the maximum stress of the beam is 15.43Mpa. We can obtain the bending moment diagram on the CW beam as shown in Fig.4, deflection of CW beam as shown in Fig.5, the minimum deflection of CW beam is -0.1mm.

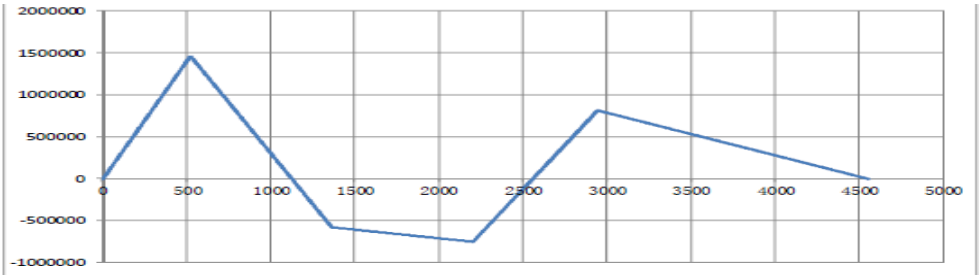

Figure 4Bending moment diagram of counterweight beam

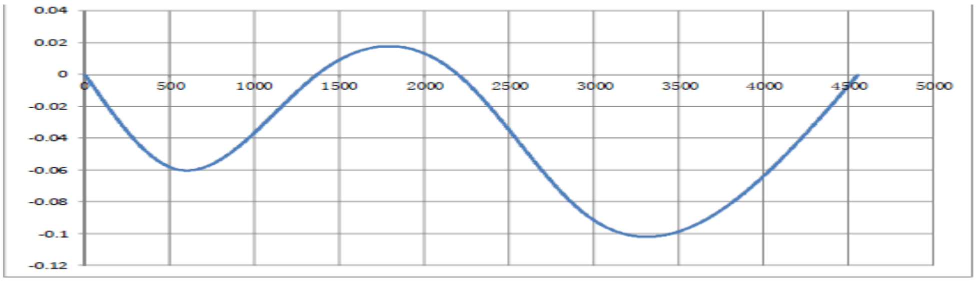

Figure 5 Deflection of counterweight beam

4.2 Stress calculation of middle support beam

Figure 6 Force diagram of middle support beam

The middle supporting beam is simplified as a simply supported beam.
F_{ZA}: support reaction force of the left support of the middle support beam ;
F_{ZB}: support reaction force of the right support of the middle support beam ;
F_{Z1}: Load force of CW beam applied to the middle support beam 7575kg（calculate the maximum of two loads） ;
lA: The length between the left and right support points of the middle support beam, 6300mm ;
lz1: The length between the support point of the middle support beam on the CW beam and the middle support beam left support, 5850mm ;
lz2: The length between the support point of the middle support beam on the CW beam and the middle support beam right support, 450mm。
$F_{ZA}=F_{Z1}*lz2/lA$
$F_{ZB}=F_{Z1}*lz1/lA$
$M_{Z1}=F_{ZB}*lz2$
These support reaction forces can be obtained: F_{ZA}=-541.1kg, F_{ZB} =-7034 kg, the bending moment at the supporting point be solved: M_{Z1}= 3165267.69 kg*mm. Select the material Q235 first, its yield strength is 235Mpa, choose allowable safety factor, general 3 ~ 4, according to the maximum bending moment and safety factor, the minimum section bending coefficient required by the beam can be obtained. 32a# I-steel is used for the middle support beam. The cross section coefficient of the beam is 692 cm^3; the maximum stress of the beam is 45.74Mpa. We can obtain the bending moment diagram on the middle support beam as shown in Fig.7, the deflection of middle support beam as shown in Fig.8, the minimum deflection of middle support beam is -3.7mm.

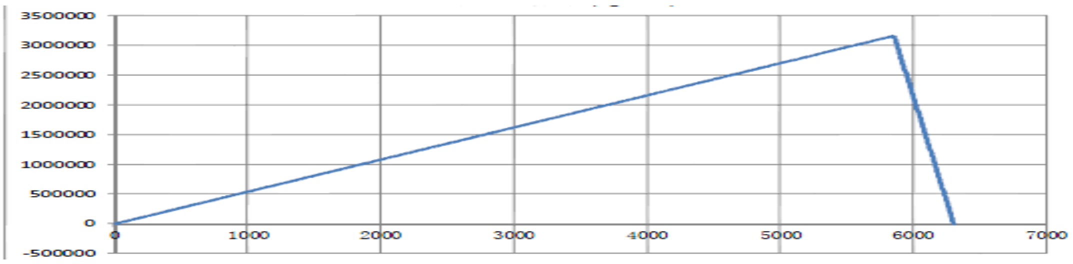

Figure 7Bending moment diagram of middle support beam

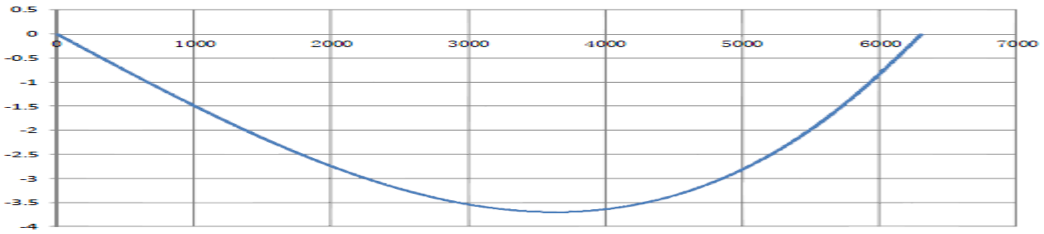

Figure 8 Deflection of middle support beam

4.3 Stress calculation of main supporting beam

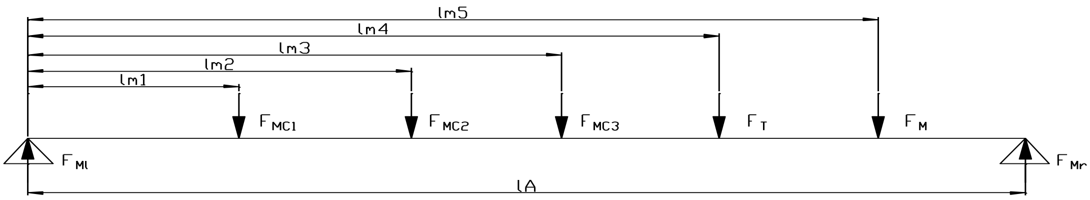

Figure 9 Force diagram of main support beam

F_{Ml}: support reaction force of the left support of the main support beam；
F_{Mr}: support reaction force of the right support of the main support beam；
F_{MC1}: Loading of diverting pulley beam on the main support beam, 3625kg；
F_{MC2}: loading of diverting pulley frame left support point on the main support beam, 2360kg；
F_{MC3}: loading of diverting pulley frame right support point on the main support beam, 2360kg；
F_T: Loading of traction machine on the main support beam, 5000kg；
F_M: Load of CW beam applied to the main support beam, 2820kg；
lA: The length between the left and right support points of the main support beam, 6300mm；
lm1: The length between the support point of the diverting pulley beam on the main support beam and the main support beam left support, 1350mm；
lm2: The length between the left support point of the diverting pulley frame on the main support beam and the main support beam left support, 2410mm；
lm3: The length between the right support point of the diverting pulley frame on the main support beam and the main support beam left support, 3990mm；
lm4: The length between traction machine center and main girder left support, 5450mm；
lm5: The length between the support point of the CW beam on the main support beam and the main support beam left support, 5850mm；
In the two main support beams, the 1# main girder is close to the car center, the 2# main girder is far from the car center. Among them, the 1# main girder is subjected to greater force, and the above parameters and the following checking calculations are for the 1# main girder.

$F_{Ml}=(F_{MC1}*lm1+ F_{MC2}*lm2+ F_{MC3}*lm3+ F_T*lm4+F_M*lm5)/lA$

$F_{Mr}=F_{MC1} + F_{MC2} + F_{MC3} + F_T +F_M- F_{Ml}$

$M_{MC1}=F_{Ml}*lm1$
$M_{MC2}=F_{Ml}*lm2-F_{MC1}*(lm2-lm1)$
$M_{MC3}=F_{Ml}*lm3-F_{MC1}*(lm3-lm1)-F_{MC2}*(lm3-lm2)$
$M_T=F_{Ml}*lm4-F_{MC1}*(lm4-lm1)-F_{MC2}*(lm4-lm2)-F_{MC3}*(lm4-lm3)$
$M_M=F_{Ml}*lm5-F_{MC1}*(lm5-lm1)-F_{MC2}*(lm5-lm2)-F_{MC3}*(lm5-lm3)-F_T*(lm5-lm4)$

These support reaction forces can be obtained: F_{Ml} = -6047kg, F_{Mr} = -10118kg, the bending moment at the supporting points be solved: M_{MC1}=8163160.7kg*mm, M_{MC2}=10730254kg*mm, M_{MC3}= 10827874.94kg*mm, M_T=7000000kg*mm, M_M= 4553196.345kg*mm. Select the material Q345 first, its yield strength is 345Mpa, choose allowable safety factor, general 3~4, according to the maximum bending moment and safety factor, the minimum section bending coefficient required by the beam can be obtained. 40a# I-steel is used for the main support beam. The cross section coefficient of the beam is 1090cm^3; the maximum stress of the beam is 99.34Mpa. We can obtain the bending moment diagram on the main support beam as shown in Fig.10, the deflection of main support beam as shown in Fig.11; the minimum deflection of main support beam is -10.37 mm.

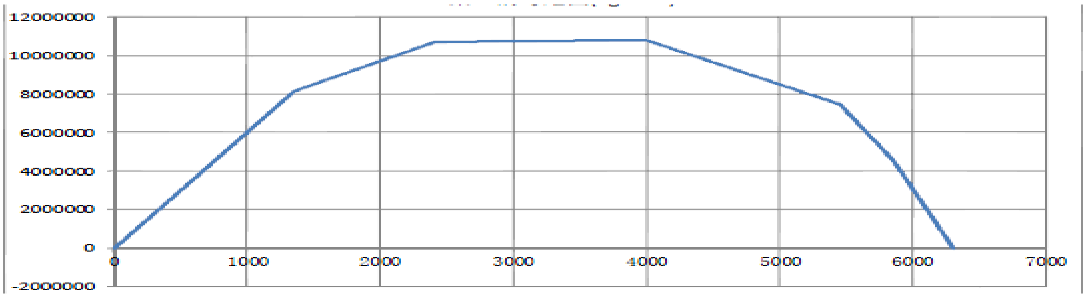

Figure 10 Bending moment diagram of main support beam

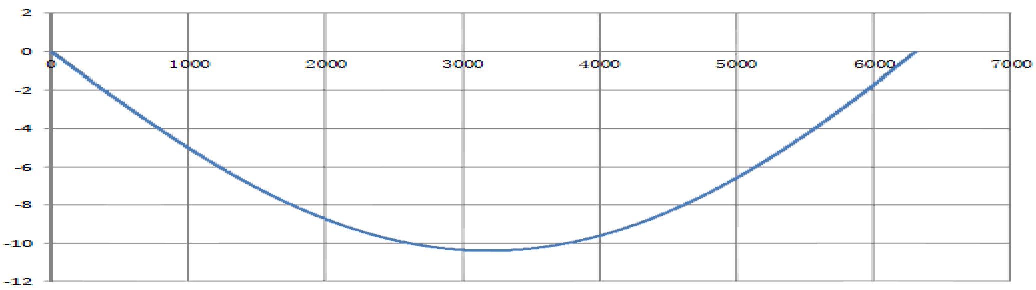

Figure 11 Deflection of main support beam

4.4 Stress calculation of auxiliary support beam

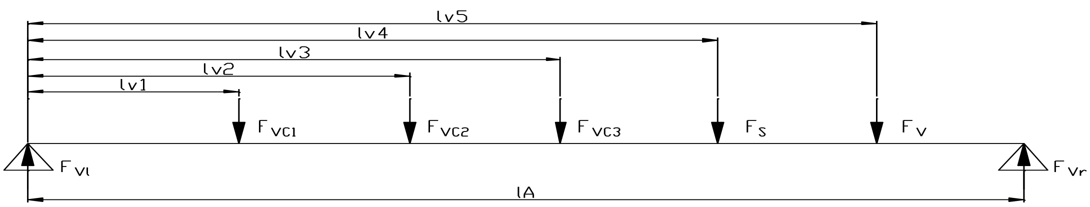

Figure 12 Force diagram of auxiliary support beam

F_{Vl}: Support reaction force of the left support of the auxiliary support beam;
F_{Vr}: Support reaction force of the right support of the auxiliary support beam；
F_{VC1}: Loading of diverting pulley beam on the auxiliary support beam, 3625kg；
F_{VC2}: Loading of left support point of diverting pulley frame on the auxiliary support beam, 1815kg；
F_{VC3}: Loading of right support point of diverting pulley frame on the auxiliary support beam,1815kg；
F_S: Load of the car rope head plate applied to the auxiliary beam, 1815kg；
F_V: Load of the CW beam applied to the auxiliary beam, 510kg；

lA: The length between the left and right support points of the auxiliary support beam,6300mm；
lv1: The length between the support point of the diverting pulley beam on the auxiliary support beam and the auxiliary support beam left support, 1350mm；
lv2: The length between the left support point of the diverting pulley frame on the auxiliary support beam and the auxiliary support beam left support, 2410mm；
lv3: The length between the right support point of the diverting pulley frame on the auxiliary support beam and the auxiliary support beam left support, 3990mm；
lv4: The length between traction machine center and auxiliary girder left support, 5050mm；
lv5: The length between the support point of the CW beam on the auxiliary support beam and the auxiliary support beam left support, 5850mm；
In the two auxiliary support beams, the 1# auxiliary girder is close to the car center, the 2# auxiliary girder is far from the car center. Among them, the 1# auxiliary girder is subjected to greater force, and the above parameters and the following checking calculations are for the 1# auxiliary girder.

$F_{Vl}=(F_{VC1}*lv1+ F_{VC2}*lv2+ F_{VC3}*lv3+ F_T*lv4+F_V*lv5)/lA$

$F_{Vr}=F_{VC1} + F_{VC2} + F_{VC3} + F_S +F_V- F_{Vl}$

$M_{VC1}=F_{Vl}*lv1$

$M_{VC2}=F_{Vl}*lv2-F_{VC1}*(lv2-lv1)$

$M_{VC3}=F_{Vl}*lv3-F_{VC1}*(lv3-lv1)- F_{VC2}*(lv3-lv2)$

$M_S=F_{Ml}*lv4-F_{VC1}*(lv4-lv1)- F_{VC2}*(lv4-lv2)- F_{VC3}*(lv4-lv3)$

$M_V=F_{Ml}*lv5-F_{VC1}*(lv5-lv1)- F_{VC2}*(lv5-lv2)- F_{VC3}*(lv5-lv3)- F_S*(lv5-lv4)$

These support reaction forces can be obtained: F_{Vl} = -5031kg, F_{Vr} = -10118kg, the bending moment at the supporting points be solved: M_{VC1}=6791785.74kg*mm, M_{VC2}=8282095kg*mm, M_{VC3}= 7635800.076kg*mm, M_S=5000000kg*mm, M_V = 2047071.54kg*mm. The material of auxiliary support beam is the same as main support beam (40a# I-steel), the allowable deflection, according to 1/500 of the beam span, the maximum stress of the beam is 75.98Mpa. We can obtain the bending moment diagram on the auxiliary support beam as shown in Fig.13, the deflection of auxiliary support beam as shown in Fig.14; the minimum deflection of auxiliary support beam is -7.59mm.

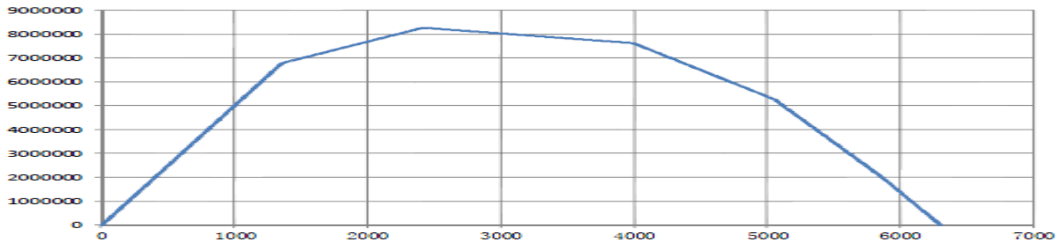

Figure 13 Bending moment diagram of auxiliary support beam

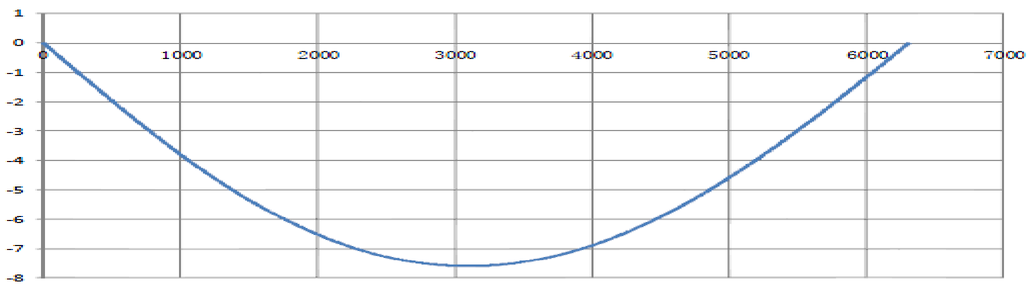

Figure 14 Deflection of auxiliary support beam

4.5 Finite element analysis results

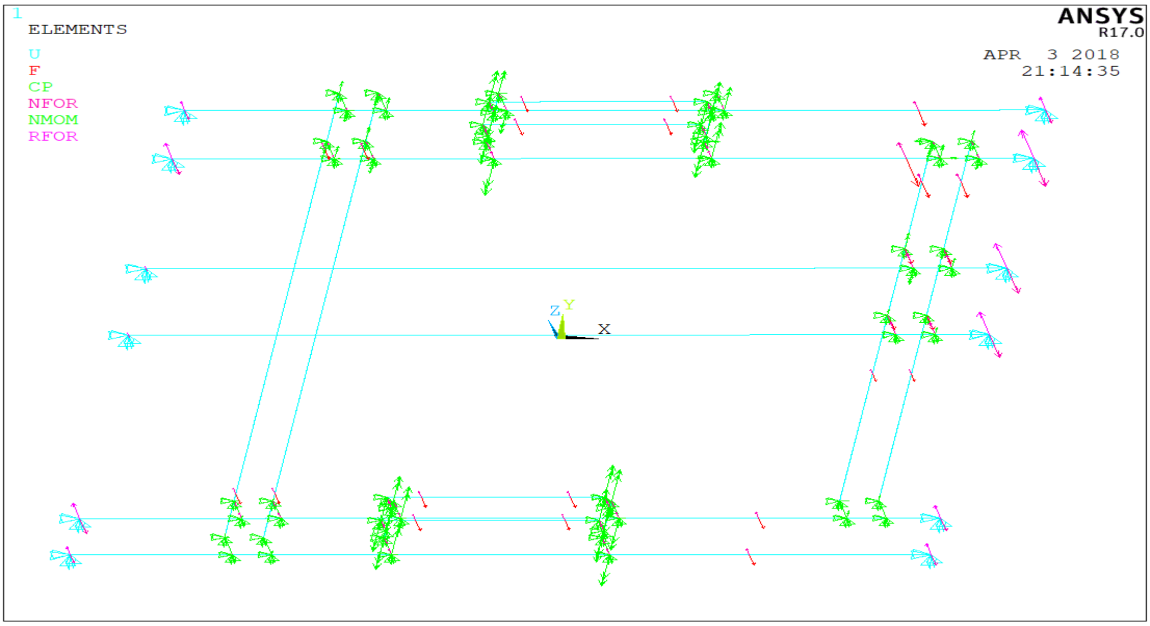

Figure 15 Simplified model of the machine supporting beam system

Figure 15 is a simplified model of the machine supporting beam. The beam is calculated by the Beam 189 element (a three-dimensional beam element in ANSYS).

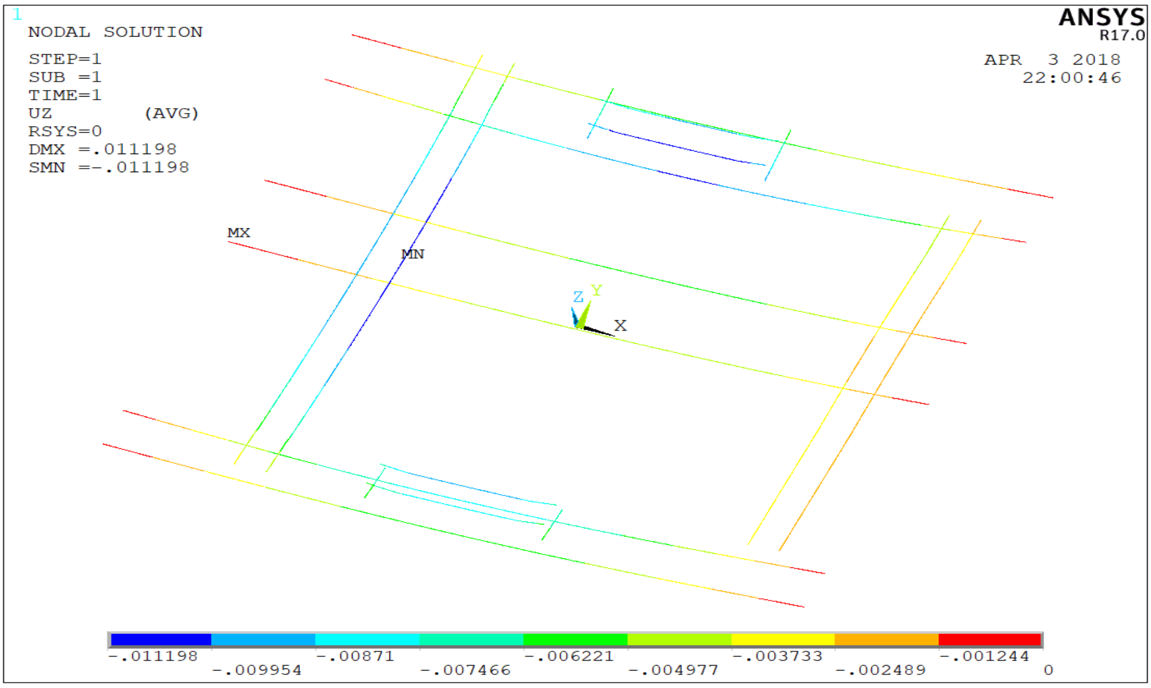

Figure 16 Deflection of Z direction

Figure 16 is the deflection of the machine supporting beam in the vertical direction when it is loaded. The maximum deflection of Z direction is 11.2mm, which occurs on the left diverting pulley beam. The maximum Z deflection on the main and auxiliary beam is 10mm.

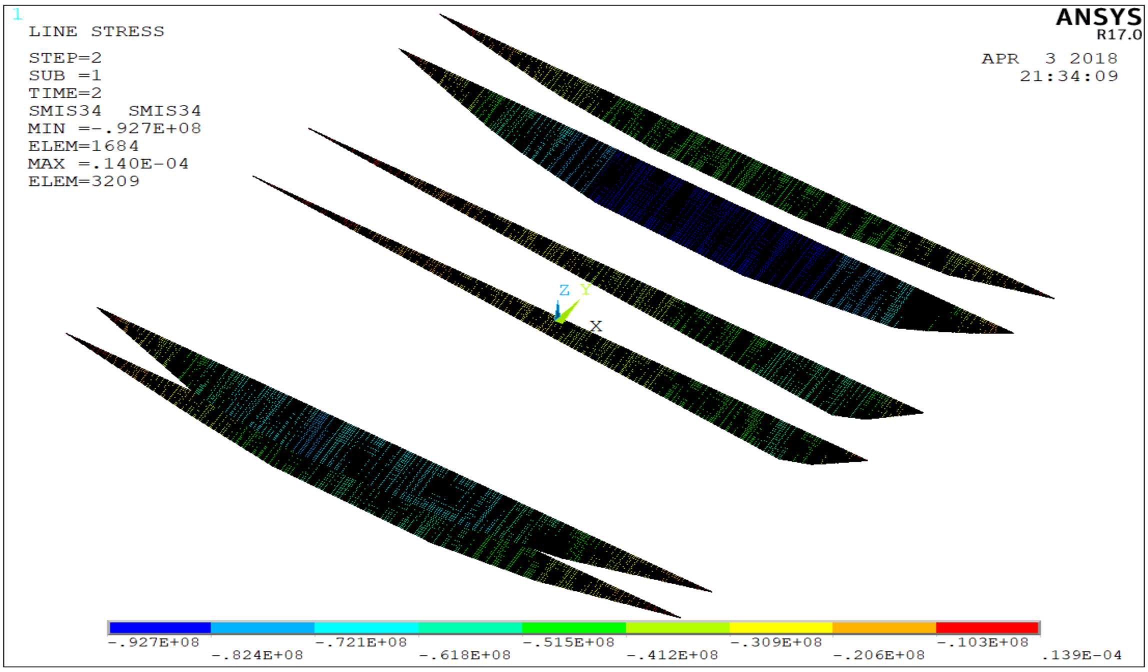

Figure 17 Bending stress on the beam system

Figure 17 is the bending stress for 3 groups of beams (main support beam, auxiliary support beam, middle support beam).

A table has been listed for comparing the key results from finite element analysis with the results obtained by theoretical calculation, including the worst stress and deflection at different locations of machine supporting beam system.

Table 1 comparison of the results of the two methods

Machine support beam system	Theoretical calculation		finite element analysis	
	Maximum bending stress	Maximum deflection	Maximum bending stress	Maximum deflection
Counterweight beam	15.43Mpa	0.1mm	20.3Mpa	2.7mm
Main support beam	99.34Mpa	10.37mm	92.7Mpa	10.04mm
Auxiliary support beam	75.98Mpa	7.59mm	73.1Mpa	7.89mm
Middle support beam	45.74Mpa	3.7mm	61Mpa	5.45mm

5 CONCLUSIONS

According to the machine supporting beam system design, the machine room layout,and the plan of hole position for wire roping, determine the position of diverting pulleys, and the position of rope fastening. The theoretical calculation is based on the actual layout size of an elevator. The main and auxiliary support beam select Q345, the other beams choose Q235, and their yield strength are 345 MPa and 235MPa respectively. The safety factor generally selects 3~4. The main and auxiliary support beam use 40a# I-steel, the counterweight beam and middle support beam use 32a# channel steel and I-steel. The stress and restriction are applied in ANSYS interface, and proven within the allowable stress range. Therefore, this can not only verify whether the material used is reasonable or not, but also can check the correctness of the theoretical calculation.

It can be seen from the table that the results obtained by the two methods are deviant. The two methods are simplified calculation methods, and there were deviations from the actual values; the deviation between the actual value and the theoretical calculation should be greater. In the calculation of the counterweight beam, the displacement of the four supporting points of the counterweight beam (the main support beam, the two middle support beams and the auxiliary support beam) is assumed to be 0, but in fact, the four supporting points of the counterweight beam will follow the displacement of the supporting points of the main support beam, the two middle support beams and the auxiliary beam and then shift. This is the biggest difference, which is the main reason for the deviation. In addition, the finite element is also calculated by a simplified model. In practice, there are total 12 constraints on both sides of the beam in addition to the constraints of the displacement (ux,uy,uz), also partial torsional deflection (rotx,roty,rotz) constraints. In addition, the traction machine and the machine support beam are in practice a surface contact, and only two force points are simplified in the theoretical calculation.

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BIOGRAPHICAL DETAILS

Dr.-Ing. Xiaomei Jiang now works for School of Mechanical Engineering, Changshu Institute of Technology & Jiangsu Key Laboratory of Elevator Intelligent Safety. She is an engineer with more than a decade of experience in engineering design. She graduated from Soochow University in 2009, received her doctorate and published more than 30 papers. She also hosts and participates in the completion of a number of scientific research projects.

Dr.-Pro. Lanzhong Guo is a professor and Dean of the school of mechanical engineering, Changshu Institute of Technology. The main research directions are fatigue fracture and reliability, friction and wear. More than 30 of their papers have been published in academic journals.