Stress Analysis of Boom of Special Mobile Crane for Plain Region in Transmission Line

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Abstract. Basis of the boom force analysis of special mobile crane for plain region in transmission line, the load type of boom design is confirmed. According to the different combinations of boom sections, the composite pattern of the different boom length is obtained to suit the actual conditions of boom overlapping. The large deformation model is employed with FEM to simulate the stress distribution of boom, and the calculation results are checked. The performance curves of rated load with different arm length and different working range are obtained, which ensures the lifting capacity of special mobile crane meeting the requirement of tower erection of transmission line. The proposed FEM of boom of mobile crane would provide certain guiding and reference to the boom design.

1. Preface
The mobile crane is the important equipment of tower erection in transmission line, which can reduce the labor intensity, increase the erection efficiency and improve the economic and social benefit [1]. The normal mobile crane of construction industry can’t meet the requirement of tower erection. For example, the body size and weight of normal crane is too large to use in small working site [2]. So, it needs a new type mobile crane for tower crane in transmission line with smaller size and weight and enough lifting height.

Therefore, the research of the special mobile crane for plain region in transmission line is carried out. The main technical requirement is proposed as 70m lifting height and 2.7t lifting weight at the maximum height [2].

The boom, as the main load bearing part of crane, should be paid more attention for its design. Its bearing capacity directly affects the lifting level of crane [3-6]. In this paper, through the typological analysis of calculation load, the FEA model of boom of mobile crane for plain region in transmission line is set and simulated. Based of strength and stiffness control criteria, the performance curves of rated load with different arm length and different working range are obtained.

2. Design parameter of boom
The cylinder section of boom is oval shape. The boom head is single-sheet structure, and boom end is vertical plate reinforcement structure. The boom structure is shown as figure 1.

The boom of special mobile crane has 7 sections. The full-retracting length is 13.4m, and the full-extending length is 72m.
3. Calculation loads
The actual loads of boom, such as self-weight, hoisting load, rotary inertia load, deflection load, wind load and the wire tension, are considered in the FEM model.

3.1. Self-weight
Self-weight is the total weight of all sections of boom.

3.2. Hoisting Load
Hoisting load is the gravity of the lifting substances, includes goods, banding device and the hoisting rope. When the goods are lifted off the ground, or braked during descending suddenly, a dynamic load is generated due to inertia. The dynamic load is expressed as the product of lifting quality \( Q \) and dynamic coefficient \( \phi \), which is exceed 1. So the hoisting load \( P_Q \) is obtained:

\[
P_Q = \phi \cdot Q \cdot g .
\]

3.3. Rotary Inertia Load
The horizontal tangential inertia force caused by boom dead weight when starting and braking around rotation, is called rotary inertia load. The rotary inertia load \( P_d \) is obtained:

\[
P_d = 0.002 \cdot R \cdot G_b .
\]

In which, \( R \) is working range; \( G_b \) is dead weight of boom.

3.4. Deflection Load
Deflection load refers to the horizontal force caused by lifting quality when rotating or varying amplitude, includes wind force, inertia force and centrifugal force. The deflection load is:

\[
P_H = P_Q \cdot \tan \alpha .
\]

In which, \( \alpha \) is swing angle of rope, 3°–6° generally.

3.5. Wind Load
Wind load refers to the wind force worked on the boom:

\[
P_w = C \cdot Q_f \cdot \sum A_i .
\]

In which, \( C \) is wind shape coefficient; \( Q_f \) is wind pressure (125N/m\(^2\) when boom length less than 50m, 150 N/m\(^2\) when boom length more than 50m); \( \sum A_i \) is the sum of areas windward of all sections.

3.6. Wire Tension
During the cargo hoisting, the weight is balanced by the tension of rope. In the FEA model, the tension is replaced by addition load, the value is equal to the weight of cargo.

4. Model of FEA
4.1. Geometrically nonlinear analysis
4.1.1. Model building.

(a) Actual Model  
(b) FEA Model

Figure 2. Shape of boom section.

The boom of special mobile crane has 7 sections, which can be extendable. The size along extension direction is considerably larger than the size of height and width. The up cover plate of section is arc groove plate, the under plate is elliptical elbow plate. The shape of section is shown as figure 2(a). The section model of boom is established by ANASYS custom section module. The FEA section model is shown in figure 2(b).

4.1.2. Section assembly and load application. Establish the connection between boom sections. The connection of sections is shown as figure 3. Node 1, 2 and 4 simulate the slider of boom head, and node 3, 5 and 6 simulate the slider of boom end. The contact element of boom sections is established by MPC184 slide block unit.

Figure 3. The connection simulated by beam elements.

The geometrically nonlinear analysis is adopted in calculation of large deformation. The model is loaded progressively from 0 to the target weight. Take the case of 72m full-extending length as an example, the model with load is shown as figure 4.
4.2. Static analysis

4.2.1. Selection of element type. The boom is simulated by shell element basically. All sorts of axle hole are beam elements. The slide block is solid element.

4.2.2. Establishment of connection. The boom sections are connected by slide block. The influence of block at boom head is ignored. The connection of boom sections is shown as figure 5. The slide block decides the boom movement.

![Figure 5. The diagram of main boom connection.](image)

4.2.3. Mesh generation. Mesh generation is a discretization process of structure. If the mesh is too dense, the calculation accuracy is enough, but the computation time is long. Here the triangle and quadrilateral elements about 40mm in size are adopted which has short computation time and high precision.

4.2.4. Boundary conditions. There are two boundary conditions: force boundary condition and displacement condition.

Displacement condition is to constrain the model. The three translational degrees of freedom at later pivot of boom and lower pivot of derricking cylinder are constrained.

Force boundary is to load the model. The pulley at the lifting point has hoisting load, lateral load, rotation inertia load. In the centre of leading sheave is loaded by rope tension. The wind load is applied on the body of boom averagely.

5. Result of calculation
The lifting capacity of boom with different length of arm and different working range is analyzed by geometric large deformation model. And then the partial structure is checked by linear static model. At last, the rated load with different working range is obtained when arm length is 13.4m, 32.6m, 59.1m, 68.2m and 72m respectively.

There are 9 different boom combinations calculated according to the optimization and comparison of working condition, shown in Table 1. Here “0” means full-retracting section, “1” means the section expands 46% in length, “2” means 92%, and “3” means 100%.

| Boom length m | Section | 13.4 | 36.2 | 59.1 | 68.2 | 72 |
|---------------|---------|------|------|------|------|----|
| 2             | 0       | 0    | 1    | 2    | 0    | 2  |
| 3             | 0       | 0    | 1    | 1    | 2    | 1  |
| 4             | 0       | 0    | 1    | 1    | 2    | 2  |
| 5             | 0       | 1    | 1    | 1    | 2    | 2  |
| 6             | 0       | 2    | 1    | 0    | 2    | 1  |
| 7             | 0       | 2    | 0    | 0    | 2    | 1  |

The results are shown as figure 6- figure 10.
Figure 6. Lifting capacity with arm length 13.4m.  
Figure 7. Lifting capacity with arm length 36.2m.  
Figure 8. Lifting capacity with arm length 59.1m.  
Figure 9. Lifting capacity with arm length 68.2m.  
Figure 10. Lifting capacity with arm length 72m.

The results show that the capacity of crane boom with different arm length combinations at different working ranges could meet the requirement of tower erection in transmission line.

6. Summary

The boom is the key part of mobile crane in design and manufacturing. Whether or not its structure is reasonable will affect the working performance and operation stability. In this paper, firstly the load type of mobile crane for plain region in transmission line is analyzed. Then, the FEA model is established by reasonable simplification. Lastly, adopting geometric large deformation model, the working performance with different arm lengths is obtained. The results show that the designed crane
can meet the requirement of tower erection in transmission line, and the method can provide enough support for optimization and improvement of crane boom.

7. References
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