# Research of telescopic variable Boom length system for flat Boom tower crane

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**Abstract.** The telescopic principle of its boom section is investigated using the luffing system of the horizontal lifting boom with telescopic operation as the aim. In order to ensure that the normal lifting and luffing work of the trolley can be ensured when the horizontal boom is telescoped and retracted, the support method of the rope system on the horizontal boom, including the lifting rope system, the luffing rope system, and the telescopic rope system, is studied. The procedure for locating the supporting pulley of the three rope systems is investigated, and the alteration in the length of the three ropes caused by the extension or contraction of the horizontal boom is examined. The boom system's force analysis is conducted, and the force expressions of each force member with the expansion and contraction of the boom are obtained, and the force state diagram of each force member is drawn by MATLAB software.

**Keywords:** Horizontal Boom; Telescoping principle; Rope system; Boom system.

## 1. Introduction

Under normal circumstances, tower cranes operate at full amplitude, but when there is not enough room, the Boom joint two can be retracted to reduce the radius of rotation, avoid interference with nearby structures, and other circumstances. The boom of the lifting boom can be retracted, and the luffing trolley can retain normal lifting and luffing operation when retracted to any length, as shown in Fig. 1 for the retractable horizontal Boom tower crane.

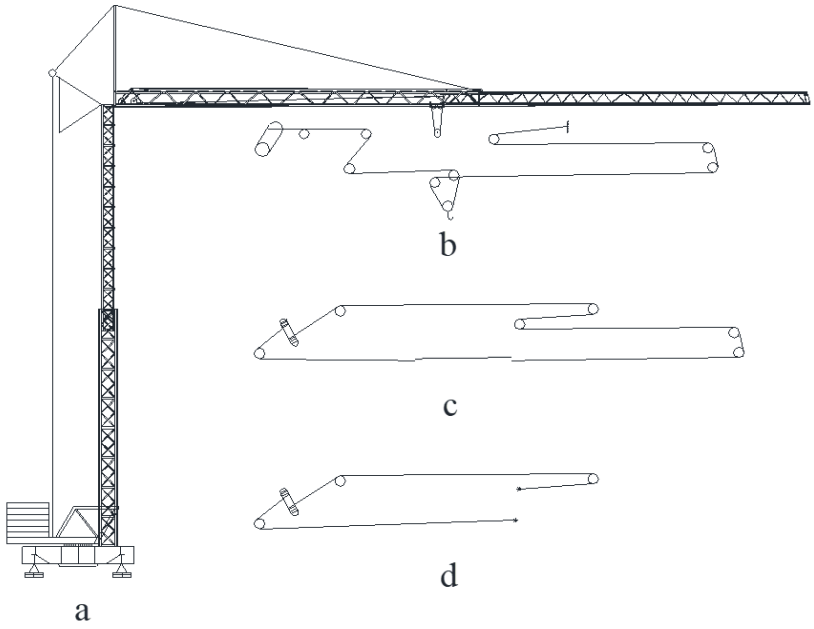



**Fig 1.** Diagram of a tower crane's horizontal boom in its fully extended state.

This essay focuses mostly on the boom telescoping principle and the rope system's support mode. The boom's telescoping principle is comprised of the trolley track's design, the boom section's structural form, and its supporting concept. The hoisting rope system, the luffing rope system, and the telescopic rope system must be specially constructed in order to ensure that they can function normally when the boom is extended or retracted without the need for readjustment. In order to ensure

that the three rope systems can be adjusted automatically under any length of the boom in its luffing range and operate normally, this paper conducts research on the arrangement of the supporting pulley of the rope system, including the working principle of the supporting pulley layout and the positioning method of the pulley [2].

In Fig. 1, (a) is the tower crane horizontal boom full extension state, (b) is the full extension state hoisting rope winding mode, (c) is the full extension state luffing rope winding mode, (d) is the full extension state telescopic rope winding mode.

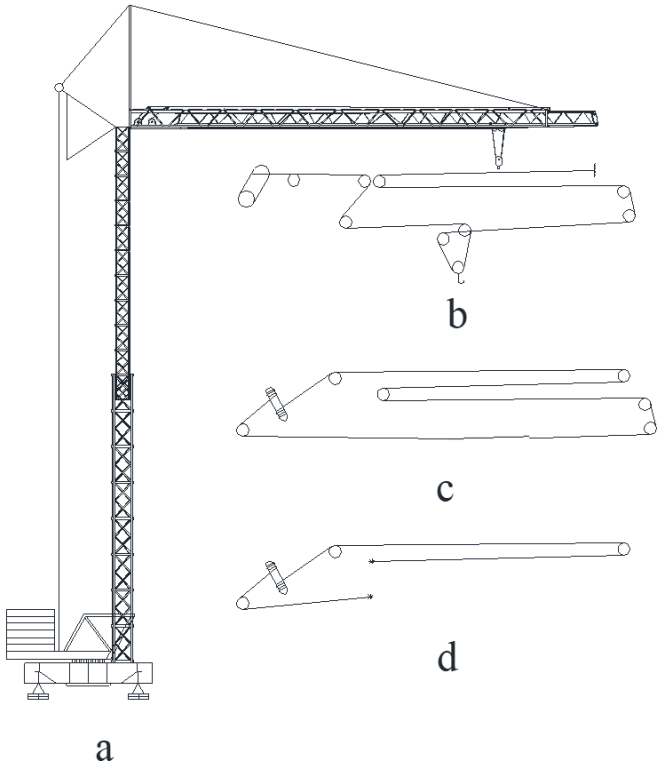



**Fig 2.** Diagram of a tower crane's horizontal boom in its fully retracted state.

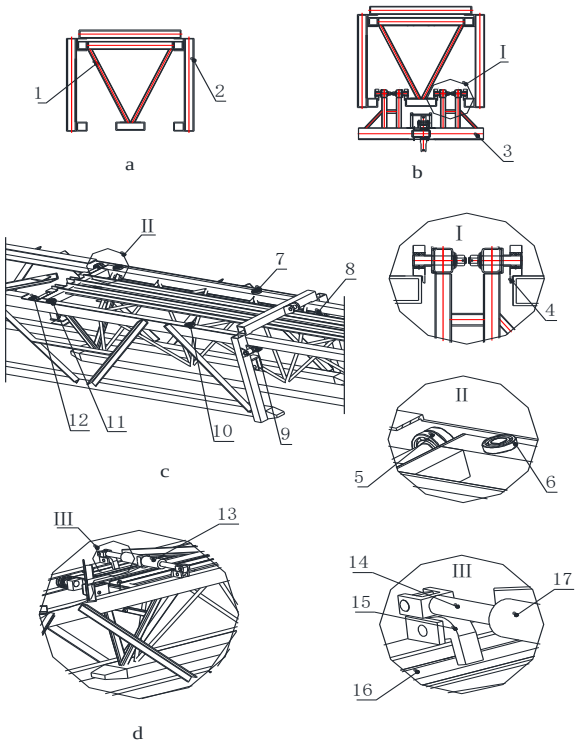
In Fig. 2, (a) is the full retracted state of the horizontal boom of the tower crane, (b) is the full retracted state of the hoisting rope winding mode, (c) is the full retracted state of the luffing rope winding mode, (d) is the full retracted state of the telescopic rope winding mode

## 2. Telescoping principle of the boom

### 2.1. Components of the telescoping boom system

In Fig. 1 and 2, (a) depicts the two states of a fully expanded and fully retracted horizontal boom during the operation of the entire machine, (b) depicts the configuration of the hoisting rope system corresponding to the fully expanded and fully retracted boom, (c) depicts the configuration of the luffing rope system corresponding to the fully expanded and fully retracted boom, and (d) depicts the configuration of the telescopic rope system corresponding to the fully expanded and fully retracted boom.

The telescoping boom system is depicted in Fig. 3, along with the precise design of each telescoping system mechanism. The structural shape of the Boom may be seen in Fig. 3(a). The telescopic horizontal Boom under study in this paper primarily consists of two lifting Booms, with the First boom installed on the outside of The second boom, which is installed at the top of the tower and has a rectangular cross-section to ensure adequate strength while providing The second boom with room for relative movement. The interface between booms two and one is shaped like an inverted triangle, which can help the lifting boom be lighter overall while maintaining its strength. The second boom is placed on First boom by the support device.




1-Lifting boom joints; 2-Lifting boom joints; 3-Trolley; 4-Wheel rim; 5~12-Support wheel; 13-Locking mechanism; 14-Piston rod; 15-Z-block; 16-Anti-slip gasket; 17-Bidirectional linear motor.

**Fig 3.** Boom telescoping system.

In Fig. 3, (a) is the cross-sectional structure of the boom, (b) is the schematic of the small wheel and track, (c) is the support principle of the boom, (d) is the locking principle of the boom.

The trolley track's layout is seen in Fig. 3(b). In the telescopic horizontal boom that was the subject of this study, the trolley has the ability to change the amplitude along the lifting boom, and this variation is unaffected by the lifting boom's telescoping motion. On booms one and two, the trolley is outfitted with various tracks, accordingly. The trolley track is installed on the first boom's two lower chords, which are on each side of the lifting boom. Each lower chord is supported by a row of tiny wheels that are symmetrically positioned on the lifting boom. On boom two, the trolley track is installed on the lower chord bar, which is positioned on the lifting boom's central axis and carries two rows of tiny wheels simultaneously. The two rows of small wheels are symmetrically arranged. It is important to note that the trolley has a total of four rows of wheels, and each row of wheels has a protruding "rim" on the side to prevent lateral movement of the trolley as it is being lifted by the boom.

According to the boom joint support concept shown in Fig. 3, (c), boom joint two is supported by the rolling bearing set housed inside common boom one. This rolling bearing set makes it possible for boom joint two and boom joint one to move relative to one another. Among them, rolling bearings with the numbers 8 and 9 are put on the end of First boom, bearings with the numbers 5 and 12 are fixed on the end of the second boom, and other bearings with the numbers 8 and 9 are mounted on the upper plane of the second boom. The Numbers 8, Numbers 9, and Numbers 12 rolling bearings are mounted in the same manner as the Numbers 5 rolling bearings, all of which are mounted in the vertical plane, and this rolling bearing set can prevent boom joint two from shaking up and down on boom joint one. Different rolling bearings work together to achieve different effects. Similar to Numbers 6, Numbers 7, Numbers 10, and Numbers 11, rolling bearings are placed in the top horizontal plane of joint boom two. This rolling bearing set may stop the lateral movement of the second boom on the First boom.

The boom joint's locking concept is depicted in Fig. 3(d). The locking mechanism 13, primarily made up of the bi-directional linear motor 17, the piston rod 14, the Z-shaped block 15, and the anti-slip gasket 16, completes the locking and unlocking of the boom joint.

### 2.2. How the telescoping boom system operates

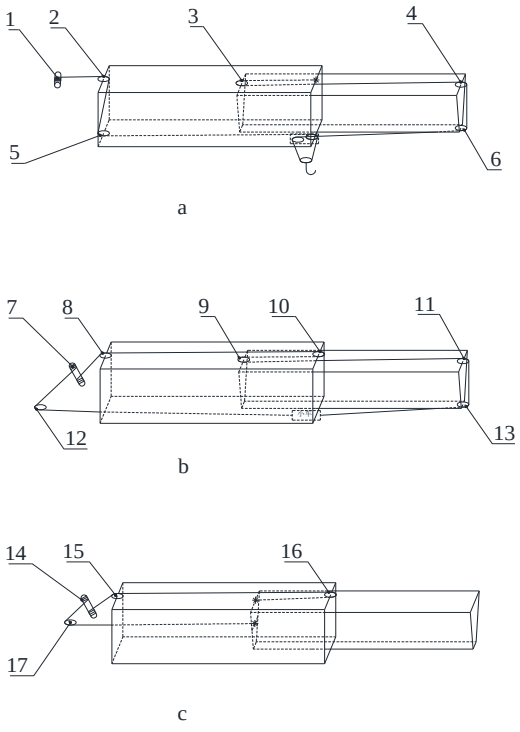
Fig. 1 depicts the beginning state of the telescopic horizontal boom under study while the tower crane is in full amplitude operation. The lifting boom discussed in this paper can be accomplished by retracting the Boom portion when the tower crane has to operate at a reduced amplitude or when there are obstructions like buildings in its operating range.

The locking mechanism's linear motor 17 is turned on during the lifting boom's retraction to unlock the boom portion. The traction force of the wire rope is used to extend and retract the telescopic horizontal boom. Boom section two retracts once the traction force has released the boom section. In this study, boom joint two may lock and unlock at any place along boom joint one's length. When boom joint two reaches the ideal length position for the operating situation, the locking mechanism locks the boom joint. Similarly, there are three motion stages involved in the lifting boom's extension process: unlocking of the boom joint, relative motion between the boom joints, and locking of the boom joint.

## 3. Design of three types of rope systems

The lifting rope system and the luffing rope system are the two types of rope systems present on conventional tower cranes' lifting boom. This research includes a third rope system in addition to the first two rope systems mentioned above since the wire rope traction force in this study drives the telescopic horizontal Boom telescoping.

The second boom and first boom move to one another while the boom is in telescopic motion, and the guiding pulley linked to The second boom also moves in relation to First boom. The typical tower crane rope system's wire rope will become slack or over-tensioned when the guiding pulley relative movement occurs, which will impact the tower crane's ability to perform its regular tasks. The hoisting rope system, luffing rope system, and telescopic rope system are modified in this study to meet the goal of maintaining the total rope length of the three rope systems during the hoisting and telescoping processes.




1-Lifting reel; 2~6-Lifting rope guide pulley; 7-Variable width reel; 8~13-Variable width rope guide pulley; 14-Telescoping reel; 15~17-Telescoping rope guide pulley.

**Fig 4.** Three types of rope systems.

In Fig. 4, (a) is the lifting rope system, (b) is the luffing rope system, and (c) is the telescopic rope system.

In contrast to the conventional tower crane rope system, this study rope goes around the lifting boom's end, around the head of The second boom, and then is fixed in the end of First boom position or returned to the reel, as opposed to the conventional tower crane rope system, which fixes the hoist rope or luffing rope directly to the lifting boom's end or back to the lifting boom reel [1]. The wire rope moves at a speed of 2 in the head position of the second boom of the revised rope system. By using this technique, the overlap between booms one and two is converted into what is known as a "rope length compensator," and a portion of the wire rope is kept in this compensator.

To prevent the wire rope in the lifting boom from becoming too tense and interfering with the machine's regular operation, the "rope length compensator" overlap section is designed to release the rope when the lifting boom is in the process of extending.

To prevent the wire rope in the lifting boom from becoming too slack or coming off the rope and impairing the machine's ability to function normally, the "rope length compensator" is rejoined with the lifting boom when it is in the process of retracting.

As an illustration, consider the luffing rope system in Fig. 4(b), where the luffing reel 7 is installed in the head position of the first boom, close to the tower. The luffing wire rope emerges from reel 7 in the direction of the tower, and after passing through the lower support of the guide pulley 12, it is wound to the tight rope ratchet device of the luffing trolley and fixed. The wire rope from the trolley is immediately linked to pulley 11 and guide pulley 13 at the end position of The second boom, after the top support of pulley 11, and then it is luffed via the First boom and The second boom overlap section of the "rope length compensator," following the compensator The wire rope returns to the luffing reel 7 after being linked to the guide pulley 10 fixed to boom section one and after receiving the upper support from the guide pulley 8. The guide pulleys 11 and 13 are placed at the end of the The second boom position increasingly further from the luffing reel fixed to the First boom when the lifting boom is extended, winding the guide pulleys 11 and 13 on the wire rope tensioning. In order to prevent the luffing steel wire rope in the lifting boom from being under excessive stress and interfering with the machine's regular operation, the boom section and the boom section two joined sections of the "rope length compensator" release rope at this time. The guiding pulleys 11 and 13 were wound in on the slack in the wire rope when the lifting boom was retracted, moving them from their fixed positions at the end of booms two to the First boom of the luffing reel. At this point, the "rope length compensator booms" one and two overlap to collect the rope, preventing the lifting boom's rope from becoming too slack or detached from the rope and interfering with the machine's regular operation.

## 4. Rope system rope length variation analysis

The three rope systems in the telescopic horizontal boom investigated in this research have a special design that keeps the total rope length wrapped around the boom constant regardless of whether the horizontal boom is extended or retracted. The "rope length compensator" of the overlap between boom sections one and two is the solution.

Consider the luffing rope system as an illustration. Fig. 5 depicts the system's sketch, and (b) it shows the luffing wire rope in the boom section while expanding the winding schematic design on the lifting boom. At this point, boom, section two is fully expanded. The lifting boom schematic design in Fig. 5(c) shows the boom retracted state variable amplitude wire rope winding at this point, with the second boom in the first boom being fully retracted. The overall rope length of the luffing wire rope is left unaltered, but each portion of the boom section's rope is adjusted to be in either an expanded or contracted condition, as illustrated in Fig. 5(b), in order to more intuitively portray the process of lifting boom expansion and contraction (c).

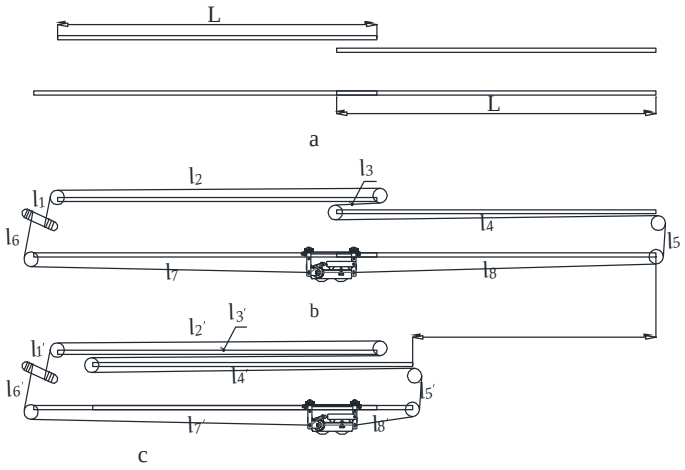



**Fig 5.** Sketch of variable rope system.

In Fig. 5, (a) shows the boom length preset, (b) shows the boom fully extended, and (c) shows the boom fully retracted.

The length of joint boom II is equal to the length of boom joint I, expressed as L, as indicated in (a) in Fig. 5, to enable joint boom II to retract at its maximum length on boom joint I. The length difference between the unfurled condition and the retracted state is set to L, as illustrated in Fig. 5, to indicate the length of the Boom extension or retraction.

The boom unfolding condition luffing wire rope's overall length may now be stated as:

$$L_z = \sum_{i=1}^{8} l_i \tag{1}$$

In the boom deployment state, the luffing wire rope's overall length may be stated as follows:

$$L_z' = \sum_{i=1}^{8} l_i' \tag{2}$$

Where.

*Lz*--The total length of the luffing wire rope in the boom deployment state.

*Lz'*--The total length of luffing wire rope in the retracted state of the boom.

From (b) and (c) in Fig. 5, it can be seen that:

$$l_i = l_i'(i = 1,2,3,4,5,6,7) \tag{3}$$

When the length of the lifting boom varies, the overall length of the wire rope wound on it does not vary. However, the length of the rope in the extended state of the boom section and the length of the rope in the retracted state of the boom section differ.

$$L_z - L_z' = \sum_{i=1}^{8} l_i - \sum_{i=1}^{8} l_i' = l_3 + l_8 - (l_3' + l_8') \tag{4}$$

It is possible to deduce from Fig. 5 that there is a length difference of l between the boom in its unfurled and retracted states.

$$l_3' = l_3 + l \tag{5}$$

$$l_8' = l_8 - l \tag{6}$$

Then

$$\begin{aligned} L_z - L_z' &= l_3 + l_8 - (l_3' + l_8') \\ &= l_3 + l_8 - (l_3 + l + l_8 - l) = 0 \end{aligned} \tag{7}$$

The rope system designed in this paper takes into account the total rope length of the boom section's expansion state and its retraction state, so in the event that the total rope length changes before and after the boom section's expansion without taking into account the different pulley radius, two adjacent horizontal guide pulleys, and other factors, the total rope length of the luffing wire rope will change. It implies that the "rope length compensator" effectively contributes to the boom's section and the second overlap of the boom's section. This example shows that the hoisting rope system and the luffing rope system both have components known as "rope length compensators" that work to maintain the total length of the hoisting rope and the telescopic rope that is wrapped around the hoisting boom regardless of how far the boom extends or retracts.

## 5. Force Analysis

### 5.1. Evaluation of the wire rope's resistance around the pulley

The wire rope must overcome the stiff resistance it creates on its own plus the friction resistance the pulley bearing creates when it rotates around the pulley, which will result in certain consumption.

The reason why wire rope is stiffness resistant is that when the radius of curvature of the rope is changed, friction is created between the wires inside the rope and between the rope strands, which prevents the curvature from changing. As a result, as seen in Fig. 6(a), when a wire rope is wrapped around a pulley and does not quickly adapt to the pulley's curvature, internal friction, and the wire rope's elasticity from working together to prevent the wire rope from bending along the pulley, producing a deviation value of e1. When the pulley is out, it is impossible to rapidly restore to a straight position; this results in the production of the deviation value $e_2$. However, when the wire rope is wound out, internal friction prevents it from straightening and increases its elasticity; thus, $e_1 > e_2$ [3]. The stiff resistance of the wire rope causes the force boom of the winding into the wire rope to grow, the force boom of the winding out of the wire rope to drop, the pulley rotation to be required, and the winding out of the wire rope tension to be increased.

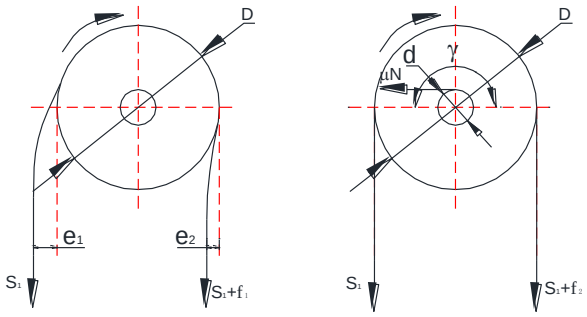



**Fig 6.** Wire rope around the pulley resistance analysis diagram.

In Fig. 6, (a) is the stiff resistance of the wire rope and (b) is the frictional resistance of the pulley bearing.

We may determine the equilibrium condition by setting the tension difference between the two branches to be.

$$S_1 \cdot (R+e_1) = (S_1 + F_{f1}) \cdot (R-e_2) \tag{8}$$

From this we can get the wire rope stiffness resistance as

$$F_{f1} = \frac{e_1 + e_2}{R - e_1} \cdot S_1 = \lambda \cdot S_1 \tag{9}$$

Where.

$F_{f1}$ -- the stiffness resistance of the wire rope.

$S_1$-- branch tension of the wire rope.

R -- Sheave radius.

λ--- wire rope stiff resistance coefficient, material elasticity, wire rope construction, and wire rope pulley true diameter. For - general steel wire rope, take take λ=0.0055~0.006.

$e_1$ and $e_2$-- winding in and out of the wire rope deviation value.

Due to the positive pressure created by the wire rope tension, as seen in Fig. 6(b), the pulley bearing will create frictional resistance. If the self-weight of the pulley is ignored and the approximate assumption of equal tension at both ends of the wire rope is used, the positive pressure produced by the wire rope tension may be represented as

$$N = 2S_1 \cdot \sin\frac{\alpha}{2} \tag{10}$$

Therefore the force $F_{f2}$ must be added to the rim of the pulley to overcome the frictional moment caused by N. Then.

$$F_{f2} \cdot \frac{D}{2} = \mu N \cdot \frac{d}{2} = \mu \cdot \frac{d}{2} \cdot 2S_1 \cdot \sin\frac{\alpha}{2} \tag{11}$$

Then

$$F_{f2} = \frac{2\mu d S_1 \cdot \sin\frac{\alpha}{2}}{D} \tag{12}$$

Generally, take the wrap angle =$180^0$, then.

$$F_{f2} = \frac{2\mu d S_1}{D} \tag{13}$$

Where.

μ--the coefficient of friction of the pulley bearing.

d--the diameter of the pulley bearing.

D--diameter of the pulley.

$S_1$--wire rope branch tension.

Therefore, the total resistance around the pulley can be obtained as follows.

$$F_f = F_{f1} + F_{f2} = \lambda \cdot S_1 + \frac{2\mu d S_1}{D} = \left(\lambda + \frac{2\mu d}{D}\right) \cdot S_1 = k \cdot S_1 \tag{14}$$

Where.

*k*--Pulley resistance coefficient; generally for sliding bearings *k=0.05*, Rolling Bearings *k=0.02*.

### 5.2. Force analysis of outward extension and retraction forces and lap reaction forces

Fig. 7 is the force sketch of the telescopic boom under full extension and lifting weight conditions. In the Fig., Qc is the calculated load; S is the hoisting rope tension; $A_1$, $A_2$ are the support reaction force at the lap; $B_1$, $B_2$ are the friction force at the lap; $G_1$, $G_2$ are the self-gravity of each section of the boom; the elevation angle of the boom at work is ; $F_1$, $F_2$ are the telescopic force or support force of the telescopic mechanism; in the Fig., when the boom is stationary or retracted, the arrows of $B_1$ and $B_2$ point to the direction of the boom head otherwise the arrow direction is opposite.

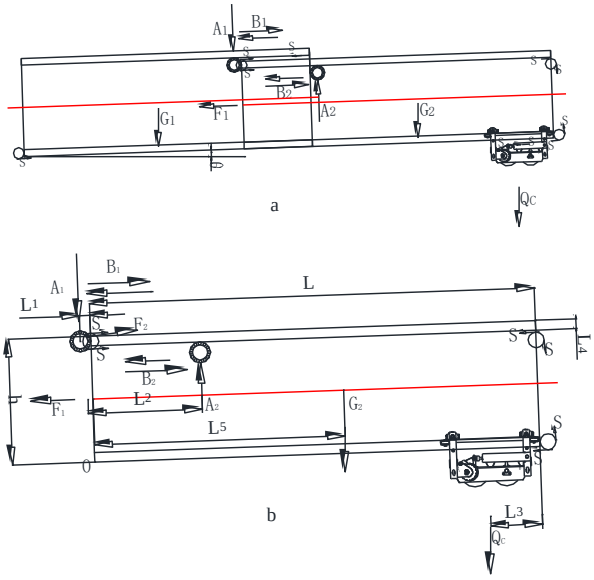



**Fig 7.** Force analysis diagram of the telescopic mechanism.

In Fig. 7, (a) shows the force analysis of the boom and (b) shows the force analysis of the second boom.

According to the force analysis of the boom joint in Fig. 7(a), joint boom two is lapped on boom joint one by a rolling bearing, and as a result, boom joint two will experience a lap response force. Fig. 7(b) depicts the force of the variable boom length system acting on the second boom joint, and the equilibrium equation is derived using the boom joint's force analysis sketch.

$$\sum F = 0 \tag{15}$$

For retraction force F1

$$F_1 - B_1 - B_2 + (G_2 + Q_c) \cdot \sin\theta = 0 \tag{16}$$

Then

$$F_1 = fA_1 + fA_2 - (G_2 + Q_c) \cdot \sin\theta \tag{17}$$

For the external extension force F2

$$-F_2 + B_1 + B_2 + (G_2 + Q_c) \cdot \sin\theta + F_f = 0 \tag{18}$$

Then

$$F_2 = fA_1 + fA_2 + (G_2 + Q_c) \cdot \sin\theta + F_f \tag{19}$$

$$\sum Y = 0 \tag{20}$$

Then

$$A_1 - A_2 + (G_2 + Q_c) \cdot \cos\theta = 0 \tag{21}$$

$$\sum M_0 = 0 \tag{22}$$

For retraction force $F_1$

$$\begin{aligned} &F_1 \cdot \frac{h}{2} - B_1 \cdot h - B_2 \cdot (h - L_4) - G_2 \cdot L_5 \cos\theta \\ &-Q_c \cdot (L\cos\theta - L_3\cos\theta) + A_2 \cdot L_2 + A_1 \cdot L_1 = 0 \end{aligned} \tag{23}$$

Then

$$F_1 \cdot \frac{h}{2} = A_1 \cdot (fh + L_1) + A_2 \cdot (f(h - L_4) + L_2) + G_2 \cdot L_5 \cos\theta + Q_c \cdot (L\cos\theta - L_3\cos\theta) \tag{24}$$

For the external extension force F2

$$-F_2 \cdot h + B_1 \cdot h + B_2 \cdot (h - L_4) - G_2 \cdot L_5 \cos\theta - Q_c \cdot (L\cos\theta - L_3\cos\theta) + A_2 \cdot L_2 + A_1 \cdot L_1 = 0 \tag{25}$$

Then

$$F_2 \cdot h = A_1(fh + L_1) + A_2(f \cdot (h - L_4) + L_2) - G_2 \cdot L_5 \cos\theta - Q_c \cdot (L\cos\theta - L_3\cos\theta) \tag{26}$$

Solving for each lap reaction force and the force required to extend or retract is

$$F_1 = \frac{G_2 \sin\theta(L_1 + L_2 - L_4 f + 2fh)}{L_1 + L_2 + fh - L_4 f} + \frac{Q_C \sin\theta(L_1 + L_2 - L_4 f + 2fh)}{L_1 + L_2 + fh - L_4 f} + \frac{G_2 \cos\theta \cdot (-L_1 f + L_2 f + 2L_5 f - L_4 f^2)}{L_1 + L_2 + fh - L_4 f} + \frac{Q_C \cos\theta(2Lf - L_1 f + L_2 f - 2L_3 f - L_4 f^2)}{L_1 + L_2 + fh - L_4 f} \tag{27}$$

$$F_2 = \frac{50G_2 \sin\theta(L_1 + L_2 - L_4 f + 2fh)}{49L_1 + 49L_2 - 49L_4 f - 2fh} + \frac{50Q_C \sin\theta(L_1 + L_2 - L_4 f + 2fh)}{49L_1 + 49L_2 - 49L_4 f - 2fh} + \frac{50G_2 \cos\theta(L_1 f - L_2 f + 2L_5 f + L_4 f^2)}{49L_1 + 49L_2 - 49L_4 f - 2fh} + \frac{50Q_C \cos\theta(2Lf + L_1 F - L_2 f + L_4 f^2)}{49L_1 + 49L_2 - 49L_4 f - 2fh} \tag{28}$$

$$A_1 = \frac{G_2 \sin\theta \cdot h + Q_C \sin\theta \cdot h}{2(L_4 f - L_1 - L_2 - fh)} + \frac{G_2 \cos\theta(2L_2 + 2L_5 - 2L_4 f + fh)}{2(L_4 f - L_1 - L_2 - fh)} + \frac{Q_C \cos\theta(2L + 2L_2 - 2L_3 - 2L_4 f + fh)}{2(L_4 f - L_1 - L_2 - fh)} \tag{29}$$

$$A_2 = \frac{-Q_C \sin\theta \cdot h - G_2 \sin\theta \cdot h}{2(L_1 + L_2 - L_4 f + fh)} + \frac{G_2 \cos\theta(-2L_5 + 2L_1 + fh)}{2(L_1 + L_2 - L_4 f + fh)} + \frac{Q_C \cos\theta(-2L + 2L_1 + 2L_3 + fh)}{2(L_1 + L_2 - L_4 f + fh)} \tag{30}$$

Where: $Q_C$ is the calculated load, in the requirement with load expansion, $Q_C =$ $P_0$, $P_0$ is the self-weight of the material; f is the friction coefficient of the boom joint two laps; the rest of the symbols are shown in Fig. 7.

## 6. Example analysis

The second section of this paper's lifting boom size reference QTZ6013 part of the lifting boom, to get the specific force size of each force member, uses MATLAB software to graphically analyze the aforementioned force expression in order to more obviously express the force state of each member in the process of expansion and contraction. The necessary measurements are as follows: total length L=20m, total height h=1m, the height of upper chord 0.1m, rolling bearing support employed at Boom lap, the friction coefficient of 0.02, etc. Fig. 8 depicts the variance in the telescoping process' necessary tension for the telescopic wire rope, and Fig. 9 depicts the change in the boom's lap response force.

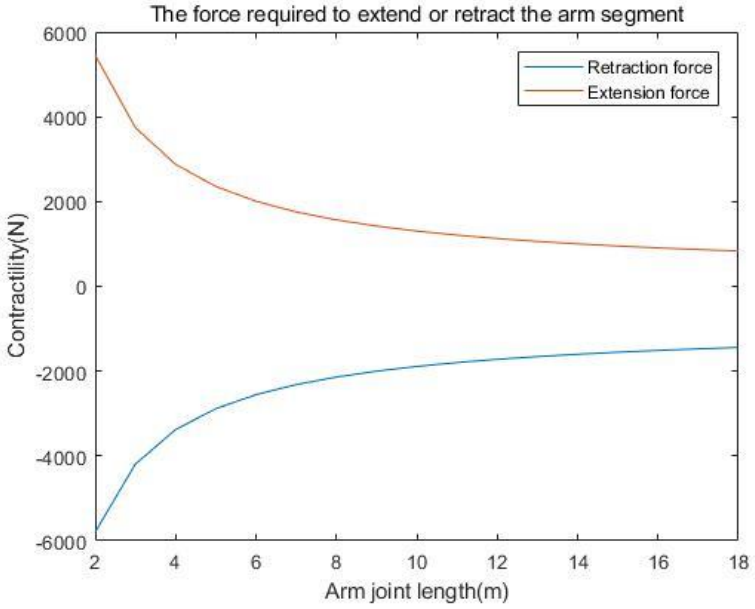



**Fig 8.** Variation of the power required to retract the wire rope.

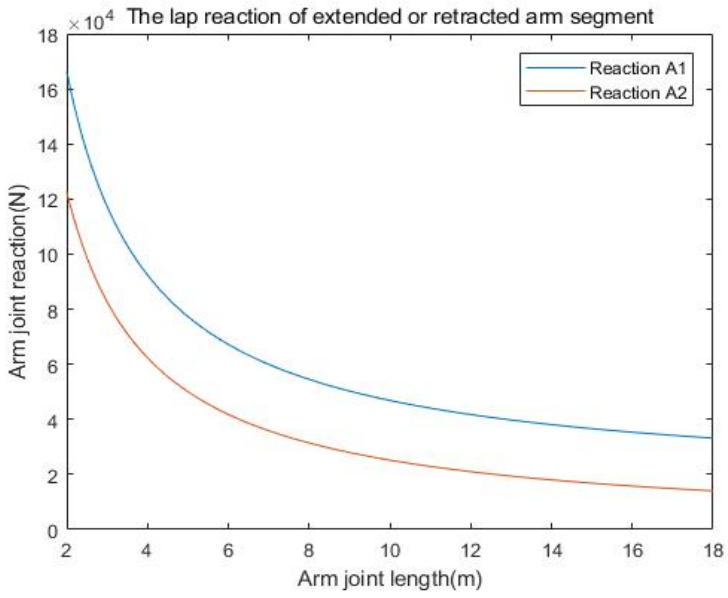



**Fig 9.** Variation of boom joint lap reaction force.

The overlap length of the boom joint is represented by the horizontal coordinate in the picture; the overlap length determines how long or how short the boom joint is when it is stretched or contracted. The tension needed for extension and retraction of the boom joint is comparable, as illustrated in Fig. 8, and the highest value of the tension is close to $6\times10^3$ N. The force on the retracting wire rope is lessened as the boom joint's overlap length increases. As seen in Fig. 9, the highest value of the magnitude of the lap response force $A_1$ is close to $17\times10^4$ N during the telescoping of the boom joint, and the maximum value of the magnitude of the lap reaction force $A_2$ is close to $12\times10^4$ N. The lap reaction force $A_2$ is somewhat less than A1 overall.

## 7. Conclusion

This essay introduces the telescoping feature and adjustable boom length technology of the flat boom tower crane. The telescoping mechanism and idea of the boom are being studied. The design plans for the hoisting rope system, luffing in the rope system, and telescopic rope system are also included, along with changes in rope length that occur throughout the whole telescoping operation. The analysis of the telescopic horizontal boom's dynamics includes the force expressions for the boom's lap response force in various stages and the power needed to extend the boom. The maximum force of each member during the telescoping of the Boom is calculated using the example after using MATLAB to plot each member's force states during the Boom's telescoping.

## References

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