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Increasing the Degree of Freedom in a Tower/Jib Crane

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***Abstract*: The tower/Jib cranes are extensively used to construct super high-rise buildings with a multi-degree-of-freedom system. Jib cranes are used for industrial purposes, whereas the Tower cranes are used in heavy-duty lifting. This paper presents a new approach of utilizing a Jib crane with features of a tower crane based on many interrelated factors such as site constraints, shape and size of the buildings, types, and quantity of required materials, crane configurations, crane type, and construction site layout thereby increasing its degree-of-freedom. These factors range from one project to another, resulting in complicated site layout strategies and approaches. Jib cranes have motion, translational, and rotational constraints, which restrict its functionality. By utilizing the design characteristics of a Tower crane, constraints in the Jib crane are overcome. The elongation of the Jib crane design aims to make it more economical by increasing its efficiency and bridging the gap between a Jib and a tower crane.**

***Keywords*: Automation, Degree of freedom, Jib crane, Lifting mechanism, Rotating arm, Tower crane.**

1. Introduction

A crane is a machine that utilizes the power of a motor to lift and convey loads. Among different types of cranes, those with engines enabling them to move around freely are called mobile cranes. Cranes having one arm are called a boom, and tower cranes with a second arm are called a Jib. Crawler cranes have recently shifted their area of appeal to infrastructure development and plant construction, essentially in emerging economies. In such job sites, flexible loading performance is required to lift and place a large component hung from under the Jib and convey a component into a building. Furthermore, the recent trend of large, modularized loads intended to reduce construction periods urges an increase in cranes' hoisting capacity.

A. Jib Crane Structure

Jib cranes are mostly of a fundamental design and construction. They are simple to operate than workstation cranes and bridge or gantry cranes and demand less maintenance because they have more limited parts that could potentially break down or fail.

Reach/Boom: The horizontal beam on which the trolley travels in and out.

Mast/pillar: The vertical beam used in freestanding and mast systems to support the boom

Movable hoist: the hoist is employed to lift, position, and lower a load.

Trolley: Trolley movement may be manual, motorized, or pneumatic. The trolley carries the hoist, wire rope or chain, and the hook all along the boom's entire length.

Rotation: On freestanding and mast type Jib cranes, 360° of boom rotation can be achieved. 180-200° of rotation on the wall and column-mounted Jib cranes can be achieved.

Controls: On motorized or air-powered Jib systems, a push-button controller can be used to control the boom's rotation, as well as the trolley's motion and the hoist lift and lower motion. The hoist and trolley have multi-speed or variable speed controls.

Rotation stop: If the crane is near a wall or other obstruction, a rotation stop will limit the crane's movement before it collides with a nearby object.

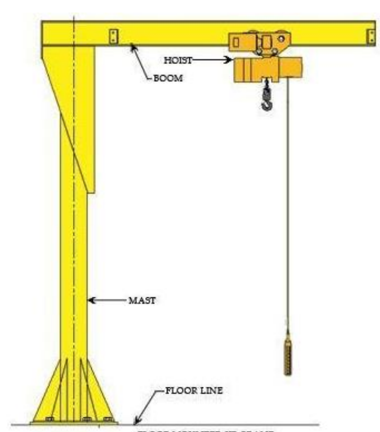

Fig. 1. Jib crane anatomy

B. Tower Crane Structure

Tower cranes are a modern design of balance cranes. Attached to the ground on a concrete slab, it is sometimes linked to the structures' sides. Tower cranes often give the best blend of height and lifting capacity and are used in constructing tall buildings.

Base: The base is the crane's principal support. It is connected to a broad concrete foundation carrying all of the weight.

Mast or tower: The mast is attached to the base, and the supporting structure gives the height of the crane. The mast has a massive structure of triangulated lattice, which provides the crane with its strength.

Slewing unit: The slewing unit consists of a gear and motor attached to the top of the mast and facilitates the crane to rotate along its axis.

The slewing unit is composed of three parts, in turn:

Jib or working arm: A horizontal element carrying the load, with a trolley running along its length in and out to move the load in.

Machinery arm: A shorter horizontal element that holds the load-lifting motor. It also includes electronic controls, a cable drum, and concrete counterweights to maintain balance.

Operator's cabin: Consists of the space where the operator handles all of the crane's functions.

Fig. 2. Tower Crane Anatomy

C. *Degree of Freedom*

The Degree-of-freedom of a general mechanical system is defined as the minimum number of independent variables required to completely describe its configuration. For a mechanism, these can be either Cartesian coordinates of specific points on the mechanism, the links' joint angles, or both. There are three active degrees of freedom in a Jib crane [Translatory, rotational: x-axis (trolley), y-axis (upward, downward), and x-z]. Trolley's rope and pulley system allow upward and downward motion; this motion is the first degree of freedom. Trolley's rotation about the boom is the second degree of freedom. The boom can move left-right/circular (sometimes complete circular motion and semi-circular motion, depending on how the Jib crane is designed) gives the third degree of freedom.

Motion constraints

Translation Constraint:

No Constraint: The body is unconstrained to move in any direction. Point: The body is fixed to one point of reference.

Line: Body motions are limited along the line specified.

Plane: Body movement is limited in a plane. Its normal vector specifies the plane.

Rotational Constraint:

No Constraint: The body is unconstrained to rotate.

Fixed Orientation: No rotation is permitted. The body is translated in a fixed direction. Axis: The body can rotate only about a fixed axis.

2. System Description

Idea: The basic idea is to enhance a Jib crane's utility by manipulating its design with reference to a tower crane and overcoming the motion constraints. Jib crane has a boom, a mast, and a trolley in its basic structure. A tower crane has an additional counter Jib and a counterweight.

By increasing the boom supported by a pneumatic shock absorber and a spring system, we can enhance a Jib crane's mechanism to give it the functionalities of a tower crane.

Features:

The boom would be extended from the shorter side like a tower crane to form the counter boom, which would provide stability. A pneumatic shock absorber would be attached to the mast and the counter boom to enable the boom's vertical motion and increase the torque.

Spring system attachment is placed between the boom and the mast to provide support to the extended length.

Design Changes:

The traditional design of the crane has not been altered. There is no removal of parts from the crane; instead, there are design enhancements that will promote the crane's functionality. Apart from the existing design, the new modifications will help in an amplified motion.

New Additions: There are three additions to the conventional Jib crane design

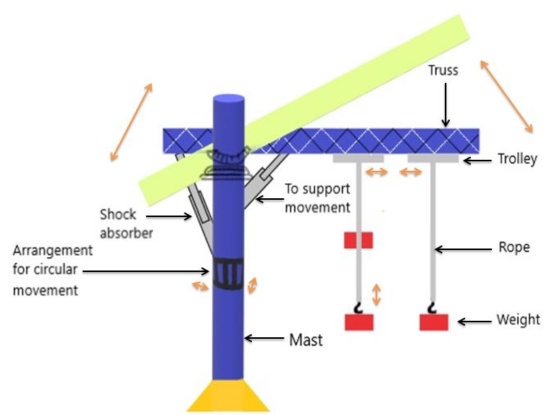

Fig. 3. Modified jib crane anatomy

- The existing boom is elongated from the rear end of the nonworking end. Jib crane has an arm on the head of a rotating mast at a fixed angle. A floor-mounted mast providing 360° boom rotation or an existing building column or cantilever Jib providing 180° boom rotation supports the pivoting head. This elongation would provide support and balance, reducing the strain developed in the boom, which would be necessary when an additional degree of motion will be introduced in the X-Y plane.

- A pneumatic shocker system attached to the rear end of the extended boom is introduced to support the load as shock loading can occur in any situation where the load on the crane suddenly increases. It would also provide a torsional push comprehending a rotational motion such that the load-bearing tip of the boom can move downward in the X-Y plane. A similar pneumatic shocker would be introduced on the other side of the mast, supporting the load-bearing side of the boom, which would also provide a torsional push comprehending a rotational motion, such that the load-bearing tip of the boom can move upward in the X-Y plane. The crane and accessories are designed to take up the weight of loads slowly and unwaveringly. They are not intended to withstand sudden increases or decreases in the apparent weight of the load. In our new design, pneumatic shock absorbers are used in conjunction with cushions and springs. Shocker will be deployed on the hinge-section of the boom to achieve maximum torque.
- Where the mast connects on the boom, we employ a spring (leaf or any other spring), allowing the rotational displacement at the junction of boom and mast and to provide support to the extended length of the boom - derived from the level luffing method. A level-luffing mechanism is where the hook remains at the same level whilst luffing; moving the Jib up and down to move the hook inwards and outwards relative to the base. Usually, the description is only implemented to those with a luffing Jib with some additional mechanism implemented to keep the hook level when luffing. Level-luffing is most important when the careful movement of a load near ground level is required, such as in construction or shipbuilding. This partially explains the prevalence of fixed horizontal Jibs in these fields. Stress in the spring would help in deciding the load capacity in the future.

Scope of the new design:

The new design has many practical advantages and benefits. Few considerable scopes of the design changes are as follows.

- The load-bearing capacity of the Jib crane increases.
- The stability of the Jib crane increases.
- This crane is more cost-effective than a tower crane and more efficient than a Jib crane.
- Since tower cranes are very expensive and they require time, effort, and money to be shifted from one area to another, the enhanced design can be positioned like a tool.
- A significant labor-intensive effort won't be required for installation as needed in a tower crane.

3. Methodology

The idea has been derived from the level luffing method and parallel manipulator mechanism. The figure below shows the parallel manipulator.

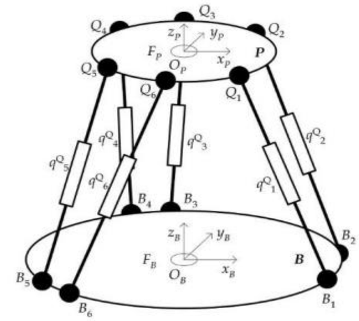

Fig. 4. Parallel manipulator

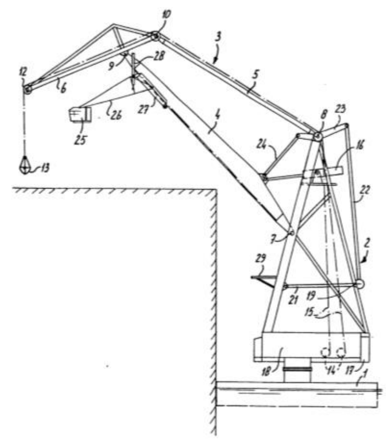

Fig. 5. Level luffing method

Calculations of the new design:

1. Stress on the leaf spring used in our enhanced model is calculated by,

$$\sigma_{max} = 6FL/bh^2$$

Where, σ =stress
F= force applied to leaf spring
L= characteristic length of the spring
b= width of spring
h= height or thickness of spring

Stress in the spring would help in deciding the load capacity in the future.

The plan of employing the Ratchet and Pawl mechanism to our model was scrapped, as it would only allow continuous linear or rotary motion in only one direction while preventing movement in the opposite direction. Due to these constraints, a gear system or bearing system is preferred over Ratchet and Pawl.

Extension on the boom is done to shift the Centre of Mass over the mast. The boom was originally a cantilever supported beam, which now is converted to a balanced/supported beam.

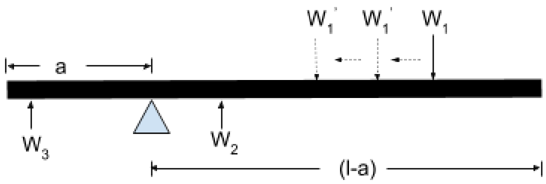

Fig. 6. Boom as a supported beam

In figure 6. The deflection of a beam under load is calculated using a Dial Gauge but may also be calculated as,

2. Deflection (Δ) of a simply supported loaded boom is given by,

$$(\Delta)= 1/48\ (WL^3)/EI$$

Where,
W = load
L = Span
E = Young's Modulus
I= Moment of Inertia

When the boom is loaded with weight, the shocker provides the reaction force so that the boom does not collapse. The following equation can calculate the effective weight of a shock absorber.

3. Effective Weight (M_e) on the shocker is,

$$(M_e)= (2W)/V^2$$

Where,
W= Total energy per cycle
V= Impact velocity at the shock absorber

4. Force and momentum in the connection of mast and boom

Momentum (torque) for the case of rotation is an essential parameter for calculating the crane's stability from overturning.

The maximum value of the resultant torque is calculated using,

$$M=M_x^2 + M_y^2 + M_z^2$$

The dynamic coefficient needs to be taken when calculating cables and the selection of safety factors for cables that will be implemented on the new crane design. It is done by,

$$F_{dynamic}/F_{static}$$

4. Conclusion

Tower cranes have complex structures with ample dimensions and mechanisms. Their working usage is high. The new design changes will help us improve the movement and utilization of the crane. Also, help in lifting loads in smaller areas with higher efficiency.

The Jib crane problem due to its motion constraints was taken care of, and the new design also increases the efficiency and mobility of the crane.

All the calculations related to the design were or will be done separately to understand the changes better. Speed of rotation should be kept as low as possible to minimize the adverse effects of load swinging, the strain on parts of the crane, and safety problems. Calculations to be made are beyond the scope of this research paper. In future extension, calculations can be made, and extensive work can be done to figure out the best possible materials for this new design crane.

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