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Design and Development of a Pillar-Mounted Jib Crane with 180-Degree Rotation for Industrial Material Handling

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Abstract *– This paper presents the design, structural analysis, fabrication, and experimental testing of a 1-ton capacity pillar-mounted jib crane with 180-degree controlled rotation, developed to address material handling challenges in small and medium-scale industrial environments. Conventional jib cranes providing 360-degree rotation impose safety risks in confined workspaces. The proposed crane employs an ISMB 250 structural steel boom as a cantilever beam, supported by a hollow circular steel mast of 225 mm outer diameter. Analytical load calculations incorporating hoist, impact, dead, and inertia factors yielded a total design load of 19.71 kN and a test load of 24.63 kN. Bending stress was computed at 75.91 MPa, well below the 250 MPa yield strength. Combined column stress reached 186.33 MPa against an allowable 208.33 MPa. Euler critical buckling load was 6302.4 kN, vastly exceeding the applied axial load of 25.38 kN. Experimental validation confirmed safe lifting of the rated 1-ton load and passage of the 125% overload test without permanent deformation. Boom deflection remained within serviceability limits (L/250). Smooth 180-degree rotation was achieved through a bearing-based pivot mechanism. This work demonstrates a complete engineering workflow from conceptualization to fabrication, yielding an economical and space-efficient lifting solution for confined industrial applications.*

Keywords– Jib Crane; ISMB 250; Structural Analysis; Material Handling; Cantilever Beam; Buckling; Fabrication

I. INTRODUCTION

Material handling is a critical function in manufacturing, assembly, and warehousing environments where loads must be lifted, transported, and positioned efficiently. Industries have long relied on manual labor or large overhead cranes, each presenting distinct drawbacks: manual handling leads to operator fatigue and safety hazards, while overhead cranes involve high installation and maintenance costs unsuitable for small-scale operations.

Among the range of available lifting devices, the jib crane stands out for its compact footprint, straightforward construction, and suitability for medium-weight repetitive lifting tasks at fixed workstations. A typical jib crane consists of a vertical column (mast) and a horizontal boom carrying a hoist and trolley mechanism. While many commercial jib cranes offer 360-degree rotation, this becomes a liability in congested industrial setups, causing potential collisions with machinery and inefficient space utilization.

This paper presents the design, fabrication, and validation of a pillar-mounted jib crane with a restricted 180-degree rotational range for a 1-ton rated capacity with a 2.5 m boom span, developed in collaboration with Turn Tech Automation Pvt. Ltd., Satara. The crane is manually operated and incorporates mechanical rotation limiters to ensure operator safety. The objectives are: (1) to perform comprehensive structural design and load analysis; (2) to fabricate a functional working model; (3) to validate structural safety through staged load testing; and (4) to demonstrate the feasibility of a space-efficient 180-degree jib crane for confined industrial environments.

II. LITERATURE REVIEW

Khetre et al. [1] performed static analysis of an I-section boom under lifting loads, confirming maximum bending stress occurs at the fixed support, validating I-section beams for crane applications. Kumar and Singh [2] developed a CAD model and applied FEM to identify critical stress concentration zones near base joints. Sharma et al. [3] optimized welded I-beam structures by varying flange thickness, web thickness, and beam height, achieving improved strength-to-weight ratios. Reddy and Rao [4] conducted a comparative study of I-beam profiles under identical loading to identify optimal cross-sections.

Chen et al. [5] developed theoretical vibration models to study dynamic response during lifting, highlighting that sudden loading induces oscillations requiring structural mitigation. Gupta and Patel [6] compared structural steel grades under FEM loading conditions, finding that higher-strength steels significantly improve performance. Li et al. [7] applied computational optimization to reduce crane superstructure weight while preserving structural integrity. Joshi and Kulkarni [8] specifically analyzed jib cranes with 180-degree rotation, performing stress and safety factor evaluations, confirming that constrained-rotation designs remain structurally stable.

Singh and Gupta [9] investigated dynamic stability during slewing motion, identifying conditions that lead to tipping and providing recommendations. Pavlovic et al. [10] performed topological optimization of welded joints in pillar jib cranes, reducing stress concentration and improving fatigue life. Collectively, this literature confirms the structural viability of ISMB-section jib cranes and emphasizes the importance of analytical validation before fabrication.

III. METHODOLOGY

A. Industrial Requirement Study

The design commenced with an industrial visit to Turn Tech Automation Pvt. Ltd. to study real-world material handling requirements. Parameters recorded included rated load (1000 kg), working radius (2.5 m), column height (4 m), rotation clearance (180 degrees), and mounting constraints. Operator interactions identified safety concerns and operational frequency shaping the design specifications.

B. Design Parameters and Standards

Key design parameters: Rated Capacity = 1000 kg; Boom Length = 2.5 m; Column Height = 4 m; Column Outer Diameter = 225 mm (wall thickness 10 mm); Beam Section = ISMB 250; Yield Strength = 250 MPa; Factor of Safety = 1.2; Trolley Weight = 75 kg; Hoist Load Factor = 0.5; Impact Factor = 0.25; Dead Load Factor = 1.2; Drive Inertia = 2.5% of vertical load. Design standards followed: IS 807 (crane design), IS 800:2007 (general steel construction), and IS 3177 (jib cranes).

C. Load Calculations

The primary lifted load was 9.81 kN (1000 kg x 9.81 m/s^2). Hoist load = 0.5 x 9.81 = 4.905 kN; Impact load = 0.25 x 9.81 = 2.4525 kN; Total lifted load = 17.168 kN. Factored trolley dead load = 0.883 kN; beam self-weight contribution = 1.177 kN. Including inertia forces (2.5% x vertical load = 0.481 kN), the total design load was 19.71 kN. The test load was set at 125% = 24.64 kN as per IS 807. Side thrust per wheel = 1.805 kN, and the maximum wheel vertical load = 12.318 kN.

D. Boom Design – ISMB 250 Section

The jib boom was modeled as a cantilever beam of 2.5 m span. ISMB 250 properties: overall depth h = 250 mm, flange width bf = 125 mm, flange thickness tf = 12.5 mm, web thickness tw = 6.9 mm. Total cross-sectional area A = 4.4642 x 10^{-3} m^2. Second moment of area I = 4.2446 x 10^{-6} m^4 (combined flange and web, using parallel axis theorem). Elastic section modulus Z = I/c = 3.396 x 10^{-5} m^3, where c = h/2 = 0.125 m.

Fixed-end shear: Vfix = P + wL = 9.81 + (0.3659 x 2.5) = 10.725 kN. Fixed-end bending moment: Mfix = PL + wL^2/2 = (9.81 x 2.5) + (0.3659 x 2.5^2/2) = 25.668 kN.m. Maximum bending stress: σ = Mc/I = (25668 x 0.125) / (4.2446 x 10^{-6}) = 75.91 MPa. Since 75.91 MPa is far less than 250 MPa (yield strength), the beam design is confirmed safe in elastic bending.

E. Column Design – Hollow Circular Section

Mast design as hollow circular section: D = 225 mm, d = 205 mm. Cross-sectional area A = π/4 x (D^2 - d^2) = 6754.42 mm^2. Moment of inertia I = π/64 x (D^4 - d^4) = 3.9112 x 10^7 mm^4. Radius of gyration r = $\sqrt{(I/A)}$ = 76.1 mm. Axial compressive stress σa = Cf/A = 25389.5/6754.42 = 3.759 MPa. Bending moment at column base Mbase = Cf x L = 63.474 kN.m. Section modulus S = I/c = 3.9112 x 10^7/112.5 = 347,660 mm^3. Bending stress σb = Mbase/S = 182.57 MPa. Combined stress = 186.33 MPa < allowable stress (fy/FOS) = 208.33 MPa. Design is safe.

Euler critical buckling load: Pcr = π^2EI/(KL)^2 = π^2 x 200,000 x 3.9112 x 10^7 / (1.0 x 3500)^2 = 6302.4 kN. Applied axial load Cf = 25.38 kN. Stability ratio = Cf/Pcr = 0.004. Since the applied load is negligible relative to the critical buckling load, buckling is not a governing failure mode.

F. Fabrication and Assembly

Components fabricated: ISMB 250 boom (2.5 m, cutting + welding); MS pipe column (4 m, machining); MS base plate 500 x 500 x 25 mm with 209 mm central hole (drilling); EN8 pivot assembly (turning). Welding followed IS 816 standards with non-destructive inspection of weld joints. Assembly sequence: (1) base plate leveling and anchor bolt fixing; (2) column erection with plumb verification; (3) pivot mechanism installation and lubrication; (4) boom mounting with gusset-plate reinforcement; (5) electric hoist integration – VOLTZ VZ-MEH 1500 (1-ton, single-phase, pendant-controlled).

IV. RESULTS AND DISCUSSION

A. Summary of Analytical Results

All computed stresses remained within permissible limits with FOS = 1.2. The following table summarizes the key design outcomes.

TABLE I. Summary of Analytical Design Results

Parameter	Value	Status
Total Design Load	19.71 kN	--
Test Load (125%)	24.64 kN	--
Max Bending Stress (Boom)	75.91 MPa	Safe
Allowable Stress	208.33 MPa	--
Combined Column Stress	186.33 MPa	Safe
Euler Buckling Load (Pcr)	6302.4 kN	Safe
Applied Axial Load (Cf)	25.38 kN	--
Stability Ratio (Cf/Pcr)	0.004	Safe

B. Experimental Testing Results

Load testing was conducted in four staged increments followed by an overload test. Boom deflection was measured at the tip by dial gauges at each stage.

TABLE II. Load Testing – Deflection Observations

Load Stage	Deflection	Observation
250 kg (25%)	2 mm	Minor elastic deflection -- Safe
500 kg (50%)	4 mm	Proportional increase -- Safe
750 kg (75%)	6 mm	Within permissible limits
1000 kg (100%)	8 mm	Within L/250 serviceability limit
1250 kg (125% OL)	~8 mm (elastic)	No permanent deformation

TABLE III. Theoretical vs. Experimental Comparison

Parameter	Theoretical	Experimental
Max Bending Stress	75.91 MPa	Within elastic range
Boom Deflection	7.5 mm	8 mm
Rated Load Capacity	1 Ton	Successfully lifted
Overload (125%)	Predicted safe	Passed -- no damage
Column Buckling Load	6302.4 kN	No instability observed
Rotation Range	180 degrees	Smooth operation

C. Discussion

The ISMB 250 section proved adequate for the 2.5 m cantilever span, providing a large margin against bending failure (actual stress/yield strength ratio: 75.91/250 = 0.30). The hollow circular column exhibited very high buckling resistance; the stability ratio of 0.004 confirms the applied load is negligible relative to the critical buckling load. The overload test at 125% validated the design's conservative load factors and material selection.

The bearing-based 180-degree pivot mechanism performed without excessive friction or misalignment. The controlled rotation eliminated collision risks inherent to 360-degree systems, validating the design approach for confined workspaces. Measured boom deflection (8 mm) corresponds to L/312 – well within the L/250 serviceability limit of IS 800. Proportional deflection across all load stages confirmed elastic structural response without residual plastic deformation. Theoretical and experimental results agree within 6.7% deviation at full load.

V. CONCLUSION

This paper presented the complete engineering development of a 1-ton capacity, 180-degree rotating pillar-mounted jib crane for industrial material handling. Analytical design following IS 807, IS 800:2007, and IS 3177 confirmed structural safety: boom bending stress 75.91 MPa vs. 250 MPa yield strength; combined column stress 186.33 MPa vs. allowable 208.33 MPa; Euler buckling load 6302.4 kN vs. applied axial force 25.38 kN. Staged experimental testing from 25% to 125% overload confirmed safe lifting, deflection within L/312, smooth 180-degree rotation, and elastic structural recovery post-overload.

The crane provides an economical, compact, and safe material handling solution for confined industrial environments such as workshops, warehouses, and manufacturing units, at significantly lower cost than overhead crane systems. Future scope includes FEA optimization using ANSYS, motorized rotation drives, 360-degree rotating variants, and lightweight high-strength steel alternatives.

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