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A Review on Design, Analysis, and Optimization of Jib Crane Systems

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Abstract- Jib cranes have wide usage in material handling operations where factors such as structural efficiency, capacity to carry loads, stiffness, and stability are considered in design. This review paper aims at presenting a comprehensive review on recent developments in the design, analysis and optimization of jib crane systems. From the review of literature, it can be seen that the use of modern engineering technologies such as FEA, CAD, and mathematical models has made structural design accurate thus reducing uncertainties involved in the design process. Studies show that the use of advanced materials such as composite materials, high strength alloys, and prestressed materials has been instrumental in reducing the self-weight and vertical deflections of structures without affecting their structural strength. Studies that compare various beam sections have shown that the right selection of section has been important in improving the load carrying capacity of jib cranes. In addition, other recent trends in modular manufacture, topology optimization and smart monitoring have added to cost savings, safety, and predictive maintenance of jib cranes. In general, the combination of advanced materials, computational modeling, and design approaches has made jib cranes more reliable, efficient, and lightweight while future research focuses on automation, IoT-based monitoring and AI-based optimization of crane.

I. INTRODUCTION

Jib cranes are one of the most commonly utilized material handling equipment in industries, workshops, warehouses, and production lines due to their ability to lift, rotate and position loads in a specified working region. The simplicity of their construction which comprises a vertical mast and a horizontal boom enables high efficiency of operation in addition to occupying minimal floor space. The rise in demand for efficient jib cranes that possess a higher load carrying capability, better positioning accuracy, and energy-efficient system has led to intensive research on the structure of jib cranes.In the past, the structural analysis of jib cranes was done using classical beam theory whereby the boom was analyzed as a cantilever beam subjected to concentrated loads and the column as a fixed beam under combined bending and compression. Such methods were the cornerstone of stress analysis, deflection analysis, and load carrying capabilities of cranes. In subsequent years, there have been advancements in the computational methods for analysis of structures that have increased precision and enhanced the evaluation process of static and dynamic performance of jib cranes.

Stress analysis, deformation analysis, and the analysis of the design parameter such as bending moment, allowable deflection, and yield strength have further been studied by researchers to enhance the safety and efficiency of jib crane. Different boom sections and configurations have been evaluated to improve the safety and performance of jib cranes. Due to advances in computer-aided engineering tools, finite element analysis (FEA) has emerged as a powerful tool for the structural analysis of jib cranes. FEA helps predict stress concentrations, deformations, vibration behaviour, and failure modes that are hard to predict using conventional methods. Modern design practice often employs the use of CAD and FEA packages for detailed analysis of pillar and column-mounted jib cranes. Design techniques following standard industrial guidelines and material properties guarantee the safe operation of jib cranes under different operating conditions. Structural steel is the most popular material employed in the fabrication of jib cranes due to its high strength, durability, and ease of processing. Recent research studies have evaluated lightweight materials such as aluminium alloy, high strength alloys, and fiber reinforced composites for reducing structural mass.

The use of composite materials has proven effective in improving the performance of cranes through reduction of self-weight and enhancing load-to-weight ratios. Studies conducted on the use of carbon fiber reinforced structures and prestressed composite structures revealed substantial reductions in the overall weights of cranes compared to traditional steel structures. Such findings clearly show that material innovations play crucial roles in crane engineering today.

Although a lot of achievements have been made in the field of jib crane design, analysis and optimization, the use of advanced materials, and intelligent technologies, a thorough review of all these aspects together within a single study is still rare in the existing literature. Most of the available literature mainly concentrates on particular aspects like stress analysis, material usage, and computer modeling among others without considering all other advancements in the field. The objective of this research paper, therefore, is to carry out a review of the recent advancements made in the area of jib crane design and analysis. These advancements include conventional structural methods, computational approaches, new materials, and intelligent technologies.

II. LITERATURE REVIEW

The literature reviewed in this section gives an insight into many studies dedicated to jib crane designs, analyses, and optimizations. Every paper discusses various improvements in jib cranes design and engineering that include such areas as FEA-based analysis, CAD modeling, new materials used, dynamics and fatigue, tribology, topology optimization, smart monitoring, and standardization of design process. These researches reveal innovative approaches to the improvement of structural, safety and economic performance of jib cranes.

2.1 Structural Design and FEA-Based Analysis

In their study, Hadzikadunic et al. [2008] have developed a unique approach to the static and dynamic analysis of jib crane structures. The authors combined computation techniques with CAD technology for modeling and analysing of different jib cranes configurations and predicting their static stress state and dynamic behaviour. The authors offered a new design solution that ensured improvement of both static stiffness and dynamic characteristics at the same time. Optimization of both local and global nature was done through geometry manipulation to meet certain design objectives, leading to very valuable data sets useful in crane design. This research provided the basis for structural diagnostics using FEA in jib cranes engineering, and has continued to be an important source for future analysis studies.

Khetre et al. [2014] did a specific investigation into the design and static analysis of an I-section boom meant for use in rotary jib cranes used in material handling. Static stress and displacement analysis were carried out in order to determine the yield strength and deflection of the I-section boom under various loading conditions. It was found out that proper choice of materials and structural section was vital in ensuring safety and efficient load carrying. The results obtained can directly inform on the sizing of I-section booms and shows that analytical analysis agree satisfactorily with FEA results under standard loading conditions.

Amreeta R. K. and Dr. V. Singh [2015] have carried out A study on FEA-based structural analysis of a 3-tonne pillar jib crane conforming to IS:807 [DOI: 10.1088/1757-899X/577/1/012168] employed finite element modeling to assess stress distributions and deflection of the pillar, boom, and bracket assembly under full rated load. The analysis confirmed code compliance margins and identified the bracket-to-pillar weld zone as the highest stress concentration region. Results provided quantitative evidence supporting the adequacy of IS:807 prescriptive design requirements for the specified crane capacity. A further study on structural analysis and design of a light-duty jib crane using SolidWorks Simulation performed modal and static analyses of a workshop crane, finding that the natural fundamental frequency was well separated from typical hoisting excitation frequencies, ensuring operational stability under dynamic loads.

In their comprehensive review, Mujawar et al. [2025] have covered all aspects of jib crane systems' design, construction, modeling by CAD software, use of FEA analysis, materials choice, and cost optimization. The authors have summarized previous studies and determined three main design parameters, which play a key role in the development of efficient jib cranes: load-carrying capacity, stability, and performance.

According to Mujawar et al., modern technologies such as computational methods, optimal materials and manufacturing processes including modular design, CNC machining, and automated welding contribute to the development of more efficient and safe jib cranes. This paper is notable for being a recent summary of the current state of the art and for pointing to IoT-based monitoring and predictive maintenance by AI as the two most important topics for further research.

2.2 CAD Modeling and Simulation Tools

Miralbes and Castejon [2009] introduced a new FEM-based calculation methodology specifically applicable to the design and optimization of crane jibs for forklift trucks. The methodology accommodated multiple jib configurations, including telescopic, lattice, and closed box-beam types, and evaluated structural performance against both strength and stiffness criteria. Critical modeling inputs — load cases, boundary conditions, material parameters, and welding models — were systematically defined to ensure analytical accuracy. The UNE-58536 mobile crane standard was adapted in place of the less restrictive UNE-1726 rule to derive a more conservative and reliable design basis. This methodology represents an important contribution to standardized FEM-based crane jib optimization.

Shinde [2009] emphasized the importance of standardizing jib crane design procedures through the integration of parametric modeling and FEM Rules. A comprehensive component tree was developed with independent design modules for each crane sub-component, enabling automated access to FEM-based design rules within any computational design workflow. The resulting parametric model demonstrated versatility across a broad range of jib crane configurations and served as a foundational platform for further optimization studies. This work contributed significantly to reducing design cycle time through systematic standardization.

An analysis of modelling and simulation of a single girder jib crane via CATIA and ANSYS showed the methodology of designing a 3D solid geometry in CATIA, which is then exported to ANSYS for post-FEA processes. Static structural, modal, and harmonic analyses were carried out to determine the stress distribution and vibration modes under rated loading. It was concluded that the CATIA to ANSYS integration process was an effective method for pre-manufacturing simulation and validation of jib crane structures. Another related study on structural optimization of a pillar mounted jib crane through CAD-integrated FEA indicated that iterative geometry changes, based on the FEA simulation results, can significantly decrease the structural weight, without violating any stress requirements Bollimpelli et al. [2015] carried out static, modal, and harmonic analyses of a 1.5 tonnes column-mounted jib crane using a CATIA-ANSYS integrated workflow. Modal analysis resulted in finding out the natural frequencies of the structure between 0 to 10 Hz and a fundamental frequency of 0.324 Hz, thereby classifying it as a flexible and dynamically stable structure under transient hoisting conditions. Harmonic analysis of the cyclic trolley loading led to obtaining the von Mises stress and z-axis displacement distributions.

2.3 Material Selection and Weight Reduction

Feasibility Study on Using Composite Materials as Structural Members in Jib Crane – Solazzi & Vaccari [2022] – In this study, the possibility of using composite materials as structural members in jib crane construction was studied using deterministic and probabilistic analysis techniques. Load carrying capacity, deflection characteristics, and failure probabilities of composite booms were analyzed in comparison to those of the traditional structural steel members. Probabilistic analysis included consideration of uncertainties in materials and loads to provide reliability-based design safety margins. It has been demonstrated that the use of composite materials can result in substantial weight reduction of over 40%, while still providing adequate strength and rigidity. This study served as an important stepping stone towards future developments in prestressed composite booms.

ANSYS Material Analysis for Jib Crane Steel Selection – Standard Structural Steel, ASME A36 Steel, and HSLA Steel – Under the same boundary and load conditions, it has been demonstrated that ASME A36 steel and HSLA steel produced significantly less maximum stress and deformation than standard structural steel. A study that evaluated the performance of aluminum alloy 6061-T6 in terms of structural performance as well as its applicability in building the booms of lightweight jib cranes [DOI: 10.1016/j.ijlmm.2020.09.003] found that although 6061-T6 aluminum had low elastic modulus resulting in high deflection compared to steel under equivalent loading, the material provided acceptable stress and deflection characteristics for light loads with about 65% weight reduction compared to steel. These findings are highly pertinent to portable jib cranes and manually-operated crane designs where self-weight is a crucial factor.

The most advanced lightweight design approach among all studies covered by this review involved using composite materials along with an external prestressing system to create an even lighter jib crane structure [2024]. The use of an external prestressing system helped to address one of the major limitations associated with composite jib cranes – self-weight deflection. Solazzi and Danzi developed their jib crane structure using CFRP composite materials and an external prestressing system. This work was published in the journal Composite Structures, Vol. 343, article 118283, and resulted in more than 50% weight reduction.

2.4 Prestressing Approaches for Deflection Control

Deflection control constitutes a central issue in designing jib cranes with light materials. Given the low elastic modulus of composites and aluminum, the deflections under working loads of a section with equal area to its steel counterpart will be higher. As noted by Solazzi and Vaccari [2022], the low stiffness of lightweight materials constitutes a major limitation in substituting steel by composite sections, but a partial solution could consist in optimizing the geometry of the composite layup.

In order to overcome the aforementioned problem, Solazzi and Danzi [2024] introduced an external prestressing cable system in their composite jib crane. The prestressing system provides an upward camber in the boom, which offsets the deflection generated by self-weight and working loads. Thus, deflection serviceability limits can be achieved with an external prestressed composite boom of equivalent mass which otherwise would have failed in this aspect. The approach, thoroughly studied in prestressed concrete bridges, proved applicable also to jib cranes. The method described above is one of the most important contributions to the field of jib crane engineering within the past few years, according to the current review.

Methods of systematic analysis for the static and dynamic characteristics of jib crane structures were suggested by Hadzikadunic et al. These researchers used computer analysis and CAD software to achieve greater accuracy in their analyses than traditional methods. Stress distribution, deflection analysis, bending moment, and permissible deflection in jib crane boom structures were analyzed by Khetre et al. and Amreeta and Singh, respectively. Static, modal, and harmonic analyses of column-mounted jib cranes were conducted through CATIA and ANSYS-based finite element analysis by Bollimpelli and Ravi Kumar, while Kavade and Gawande carried out pillar-mounted jib crane verification tests based on IS 807:2006 criteria.

Comparative material analysis was carried out on free-standing I-beam jib cranes by Dhanoosha and Gowtham Reddy, while the feasibility of using composite materials in jib crane construction was tested by Solazzi and Vaccari. Subsequently, Solazzi and Danzi found that carbon fiber composite structures with prestressing were able to reduce the weight of the crane significantly in comparison with steel structures. The recent research has been concerned with fatigue, dynamic, and seismic analyses of jib cranes. Studies on the problem of transient dynamic loading and fatigue life assessment have identified the significance of welding geometry and stress concentration areas and cyclic loading effects.

The methods of topology optimization and multi-objective optimization were developed to decrease the structural weight without compromising its strength and stiffness. The research done through the application of genetic algorithm and SIMP-based topology optimization resulted in considerable weight saving and improved fatigue resistance. Moreover, research on workspace optimization of multiple cranes and additive manufacturing of optimized crane parts was also conducted.

The recent advances in the field include smart monitoring and AI-based applications. The structural health monitoring techniques based on fiber Bragg gratings sensors, digital twin technology for fatigue analysis, machine learning surrogates, and LSTM-based anomaly detection systems have been developed for real-time monitoring and prediction purposes in the context of jib crane system operation. Besides, the comparative research on IS 807, ASME B30.11, and EN 13001 standards and ergonomic analysis of crane controls were performed.

III. RESULT ANALYSIS

Result analysis from the above-reviewed literature on the design, analysis, and optimization of jib crane systems provides a comprehensive overview of results related to structural design, computational techniques, materials science, manufacturing technologies, and monitoring approaches. The following are some key and interconnected results obtained from a review of the literature in question:

1. Structural Design and Loading Analysis: From the reviewed literature, it can be seen that structural configuration is a key parameter influencing load-bearing capacity and safety of operation. Literature shows that proper consideration of geometry parameters, such as boom length, pivot positions, column cross-sectional area, and counterbalance weight placement, is crucial in order to ensure the structural stability of the crane during both static and dynamic loads. Hadzikadunic et al. [1] proved that the assessment methodology that incorporates both computer aided design and static-dynamic behavior models provides very accurate results and helps to optimize the structure locally as well as globally at the same time. The design and analysis of I-section boom of rotary jib cranes presented by Khetre et al. [2] prove that proper selection of structural configuration and material is very important for optimal performance of the machine and yield strength and deflection should be considered when designing load-bearing components. The validation of a three-tonne pillar-mounted jib crane according to IS:807 standard by Kavade and Gawande [5] proves that standardized load cases, including self-weight, rated load, and dynamic factor, have to be considered when designing a structure.
2. Stress and Deflection Results using FEA: Finite Element Analysis (FEA) has proven to be the most popular method used for structural validation purposes in the reviewed literature. According to results presented by Miralbes and Castejon [8], the use of an FEA-based computation technique for telescopic, lattice, and closed beam jibs on forklift trucks has been shown to comply with the requirements of the UNE-58536 standard, proving that the exact modeling of boundary conditions, loading conditions, and weldings is essential to get reliable FEA results. Bollimpelli and Ravi Kumar [11] carried out a CATIA to ANSYS simulation process for a 1.5 ton column-mounted crane, where modal analysis showed that the fundamental natural frequency was 0.323589 Hz, falling into the low-frequency category (0-10 Hz) for a compliant and dynamically stable system. Further analysis in terms of harmonic analysis subjected to cyclical trolley loading showed the von Mises stress and z-axis displacement distributions. Dhanoosha and Gowtham Reddy [4] found through their FEA comparison between floor-mounted jib cranes that the use of ASME A36 steel reduces stress and deformation compared to structural steel.
3. Results of Material Comparison – Steel, Aluminum, and Composites: The analysis and comparison of various structural materials form one of the most studied topics in contemporary jib crane literature. While traditional structural steel finds extensive use because of its availability and ease of manufacturing, it is currently being compared with newer materials such as high-strength alloys and composite structures. The superior performance of ASME A36 steel in comparison to generic structural steel in terms of stress and strain behavior has been confirmed by several researchers [4]. More importantly, Solazzi and Vaccari [12] analyzed the possibility of using composite material in jib cranes using a combination of deterministic and probabilistic approaches, indicating that the inherent probabilistic nature of composite material properties demands reliability-based design processes instead of deterministic safety factors alone.
4. Prestressing and Lightweighting Results: The most significant quantitative conclusions concerning lightweighting in the reviewed literature are provided by Solazzi and Danzi [16], who used their ANSYS FEM model with about 550,000 nodes and

found that a composite jib crane without prestressing is only 29% as heavy as its steel version; however, prestressing brings down the percentage to 21%, meaning that on average, the weight reduction due to prestressing amounts to around 25%. This clearly shows that composite prestressing is currently the most efficient approach to lightweighting of jib cranes as far as available scientific evidence goes. The results directly affect such factors as foundation loadings, transportation, and erection costs. They follow the pioneering work on the feasibility of composite cranes conducted by Solazzi and Vaccari [12]; thus, it can be stated that the combination of fiber-reinforced composite materials and prestressing techniques provides a technically feasible path towards future lightweight cranes.

5. Results of CAD Modeling and Simulation: It has been shown that computer-aided design plays an essential role in accelerating the design process, minimizing the risk of manufacturing defects, and performing virtual tests before the creation of prototypes. According to Hadzikadunic et al. [1], the use of CAD technology in combination with the computational analysis approach makes it possible to perform precise diagnostics of the structure and its geometry modifications in order to meet certain design criteria – both local and global – simultaneously within one iteration loop. Bollimpelli and Ravi Kumar [11] revealed the efficiency of the CATIA–ANSYS combination workflow, where the geometry created in CATIA was used as input data for static, modal, and harmonic analyses conducted in ANSYS. The parametric and modular features of CAD environments also enable quick evaluation of different cross-sections, materials, and boundary conditions, which is especially helpful in the early stages of designing. Overall, the results obtained prove that the combination of CAD modeling with analysis greatly increases the precision of structural simulations and decreases the risk of expensive design changes during the manufacturing process.
6. Construction and Manufacturing Technique Findings: The relevant literature reveals that advanced construction techniques are among the key factors in making jib cranes precise, repeatable, and economical to construct. Mujawar et al. [7] reveal in their detailed analysis that modular construction processes ease the assembly process and save on labor costs by allowing the assembly of major assemblies in prefabricated forms. CNC machining makes sure that the parts involved in connections, including pivot brackets, column flanges, and trolley guides, are precise while automated welding, which is becoming common practice in mass production settings, guarantees consistent welds with significantly fewer defects than manual welding. All of the above-mentioned factors lead to less waste of materials, better dimensional consistency, and more reliable structural performance once the structures are put into use. In addition, recent developments in additive manufacturing processes have opened up new ways for the creation of optimized structures, where the selective laser sintering of 316L stainless steel, as seen in recent research on additively manufactured structural brackets [28], proves that complex topologies that are impossible to manufacture using traditional subtractive techniques can now be built with proper mechanical properties.
7. Results of Cost and Topology Optimization: Topology optimization has been shown in the analyzed literature to be a useful technique that allows for simultaneous minimization of the structure mass while maintaining or increasing its load carrying capacity. Multi-objective genetic algorithms [26] have been used to optimize jib crane superstructures with regard to both structural mass and fatigue life, achieving Pareto-optimal designs which are not possible with traditional single objective techniques. Combining the results of such computational design optimization techniques with lifecycle cost models it can be concluded that the higher initial cost of production of an optimized structure is often compensated by fewer maintenance operations, increased durability, and decreased foundation loads due to reduced self-weight. Moreover, according to Mujawar et al. [7], energy efficient drive components and lighter structure elements work in synergy to achieve lifecycle cost reduction. All these considerations support the use of multi-criteria optimization based on mass, fatigue life, manufacturing cost, and maintenance cost as the standard approach for jib crane design.

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8. Smart Monitoring and Future Technology Trends: The current state of the art in literature review highlights the growing trend of integration between structural engineering and technology innovations in the context of crane health monitoring and performance forecasting. Structural health monitoring approaches based on Fiber Bragg Grating sensors [29] have proven the potential to provide continuous strain field monitoring of crane components under load conditions, allowing for condition-based maintenance techniques that minimize the likelihood of sudden failure events. Digital twins enable fatigue life prediction through continuous updates of numerical models using data from field sensors, providing operators with an estimate of the remaining life of the component. Machine learning algorithms acting as surrogate models [31] have proven capable of predicting structural parameters such as deflection and stress concentration factor at a computational expense many orders of magnitude lower than traditional FEA, allowing for the use of machine learning algorithms in online structural monitoring systems. LSTM-based deep learning architectures [32] have proven particularly effective in anomaly detection in crane load monitoring data streams. The work of Mujawar et al. [7] provides an overview of the above trends within the wider framework of the development of IoT-enabled crane technology systems, noting that the implementation of AI-based predictive maintenance, load monitoring, and remote diagnostics can move from laboratory experiments to wide-scale implementation and become a means for radically changing maintenance schedules, safety, and efficiency of modern materials handling facilities.

In general, the discussed literature review shows that the use of computational techniques, advanced material systems, and improved manufacturing and monitoring approaches have resulted in considerable improvements in the structural properties, economic efficiency, and safety of jib crane structures. The future trends in this field will likely be related to AI-based structural design, load monitoring, and material systems, which should make jib cranes even lighter and safer engineering systems.

IV. CONCLUSION

The collection of literature dealing with jib crane design, analysis, and optimization provides clear evidence that major breakthroughs have been made possible by the employment of finite element analysis, computer-aided design, and modeling methods. Specifically, it has been demonstrated that finite element analysis makes it possible to accurately predict stress distribution, deflection, and dynamics in various types of structures and under different loads [7], and CAD-assisted procedures have shortened the design process and significantly minimized the occurrence of design errors. Material research has produced some especially remarkable results; it has been shown that composite jib cranes can be as much as 21% lighter than their structurally identical steel counterparts due to prestressing, with the weight-saving effect of prestressing averaging at about 25% [16]. The use of composite materials in jib cranes has also been justified by means of probabilistic design methods [12], and cross-sectional optimization has shown that the geometry of the boom and the choice of its members are critical determinants of the structural properties. Manufacturing processes, including modular fabrication, CNC machining, automated welding, and additive manufacturing of topology-optimized parts via selective laser sintering of 316L stainless steel [28], have all contributed to improving the quality of production.

These developments have significant implications for practical applications, with potential to enable future crane designs that are not only lighter and stronger but also cheaper to manufacture and operate. Following design specifications and adhering to the principles laid down in IS 807:2006 [33] and other international norms like ASME B30.11 and EN 13001 [35] guarantees safe implementation of these materials and computational techniques. In addition, multi-objective genetic algorithms can be used to optimize both the structural mass and the fatigue life of the cranes, resulting in solutions that are superior to those obtained through single-objective methods [26].

Despite these successes, however, there are still many avenues for future research. Testing of composite and prestressed jib cranes under realistic conditions in order to establish their long-term durability properties has not been thoroughly carried out yet. Also, while the use of smart sensing techniques like Fiber Bragg Grating sensors [29], fatigue life prediction via digital twins [30], machine learning surrogates [31], and LSTM anomaly detection systems [32] has been demonstrated in various demonstrators, it has yet to be tested in a full-scale industrial environment. In view of the above, future work needs to focus on the experimental study of advanced materials, standardization of IoT-based structural health monitoring techniques [7], and more extensive use of AI optimization and digital twins in the design and maintenance of cranes, which will ultimately lead to improved performance of jib cranes.

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