Abstract

On large construction sites, cranes are the most visible equipment used to place objects at specific locations. Due to the increased cost of on-site construction labor, owners are forced to look for off-site options where controlled environment, reasonable labor cost, time, and quality workmanship are less expensive. This growing trend has resulted in the necessity to transport and lift larger and heavier objects for on-site assembly operations. Consequently, the demand for larger cranes and higher capacity of rigging is ever increasing. The number of crane rigging components depends on the size of the object, which is required to be lifted vertically to keep the total weight (amount of bracing for compensate lateral forces) within certain limits. In the heavy oil industry, process modules of 120-140 feet in length are common and traditional rigging requires many types of specific components including adequate shackles, turnbuckles, slings, spreader bars, etc. Rigging engineers and practitioners perform careful and diligent analysis for every lift. Some crane rental and construction management enterprises are developing lift frames for heavy oil process modules to reduce the crane head-room and minimize the rigging modification time due to the object center of gravity offset. The iRigging application algorithm presented in this paper captures expert knowledge of calculating rigging line acting force and assigning proper line components with adequate capacity. For traditional riggings, the proposed algorithm with predefined minimum triangle angles automatically outputs required slings length, number of shackles, or spreader bars. For lift frames, the algorithm identifies modules for lifting, position under the hook (center of gravity offset), and approximate time for each lift. iRigging algorithm is part of a more complex program known as iCrane with assembly site identification, crane selection, location, mat design, object lift trajectory, and visualization options.

Keywords: Algorithm; Crane lift; Lift frame; Rigging

1. Introduction

On remote heavy oil construction projects, on-site construction is the most expensive activity. The necessity to reduce on-site work has created the trend to prepare ready process equipment packed in the steel module off-site, and then transport and assemble on-site like a puzzle. This “modular construction” method is not new to the industry. However, with the constant growth of the industry, the increasing size and weight of the modules pose challenges that required an “out-of-the-box” approach. This paper illustrates concerns related to crane rigging design and its associated equipment selection. While, rigging has existed as long as cranes have been used to lift objects, its complexity and importance are not always properly addressed. Although the industry has produced some books [6] and manuals [8], there is limited research information that teaches readers the basics of rigging techniques. Some rigging equipment producers release instructional pamphlets containing information to properly assess, calculate, and assemble simple
rigging. At first glance, rigging calculations may appear simple, but that assumed simplicity may cause practitioners to overlook specific issues which may place an entire lift in danger, as was reported a few years ago in USA [9]. Rigging equipment not only reduces crane head-room (maximum distance between crane hook and ground for particular crane capacity) [3, 5] but also increase the weight, which must be taken into account while analyzing crane configuration and lifting capacity. In some cases, this can be critical for the lift. Rigging components are subject to periodic inspections for the wear factor, marking, and structural damage, and must be sent back for repair to qualified repair shop. In some cases, maintaining and storing the large number of rigging parts poses problems at a construction site, and requires dedicated personnel to maintain proper inventory. The rigging price in only a fraction of the entire crane rental cost, and some crane rental companies provide their rigging equipment at no-charge for the project or performed lift. From the perspective of a project owner, the rental of rigging equipment for an unknown period of time (project duration maybe longer than initially planned) could be more costly that purchasing sets of rigging components and donating to the crane renting enterprises at the end of the project. This situation is very common in most heavy oil construction sites, which creates an overstock of shackles and slings that are not properly utilized. The proposed algorithm will have options to identify the individual rigging components and their testing time status.

2. Challenges

Crane or construction companies are reluctant to share or rent their rigging inventory due to several reasons: they required exclusive use during a project, bidding competitive advantages for project, possible damage and costly replacement, etc. This particular situation refers to components for traditional rigging items. In the case of lift frames, however, the scenario is different. Lift frames [1] are designed for repetitive lifts of similar objects. Heavy oil industry companies build their processing plants from modules, which are similar in size and weight. Figure 1 represents the lifting of a typical pipe rack module and Figure 2 depicts the assembled modules at the processing plant.

2.1. Lifting and transportation rules

Engineering bureaus, which are responsible for the proper design of processing plants, must consider the direct process equipment and by what method this equipment will be supported, transported, and lifted to the final destination. They must understand the procedures for transporting and lifting the modules in order to design the module frame, columns and braces accordingly. Figure 3 shows a typical module structure and an undesired method of lifting (red arrows). This incorrect lifting method creates additional horizontal compressive forces, which are usually compensated for by additional bracing components in the frame structure. Figure 4 shows the same module where bracings (green arrows) are used only to maintain the structural integrity of the assembly, but not to compensate for the lifting operation. Small loading force diagrams are embedded in each lifting method. The lifting operation is rarely a driving factor for designing structural frame and bracing, while the transportation is a more demanding factor due to the cyclic loads acting on the structure. However, transportation speed has a large influence on the cyclic load forces, therefore, it cannot be too slow since such operations are performed during night time hours and cannot be performed during rush hour.
Other additionally important aspects of delivering modules to the construction site are the total module weight and height, planners must consider designing transportation routes to avoid unsuitable bridge capacity and overpasses with inadequate clearances. Module lifting lugs are designed to be loaded with vertical loads, minimal side loads, and are the responsibility of a module structure designer.

3. Traditional rigging

Traditional rigging contains several components that transfer loads from object lift lugs to the crane hook. If module weight analysis is available, forces are transferred to the lift lug and then through shackles and lines to the spreader bar where compressive forces are eliminated. Figure 5 shows a typical traditional rigging arrangement for a 14 point pick. This configuration contains following: Level I: 7 spreader bars, 20 slings, 36 shackles; Level II: 2 spreader bars, 12 slings, 12 shackles; Level III: 1 spreader bar, 6 slings, 5 shackles. This 14 point pick configuration requires a total of 10 spreader bars, 38 slings and 53 shackles. Each level has a different capacity and spreader bar, slings, or shackle, must have larger capacity than the predecessor level. The situation may change when the center of gravity (CoG) of the lifted object is offset from its geometrical center. Ideally, a rigging engineer has the information about an object’s CoG offset prior to performing lift calculations, and can adequately compensate for the difference by adding additional shackles above the specific spreader bar. In some cases, riggers encounter an alternate situation at the performed lift. To modify the sling arrangement in short direction CoG, riggers required half of a working day to perform the adjustments, which then requires several tryouts at the job site before the rigging is acceptable for the lift. Long direction CoG adjustments may require as much as one full working day of tryout operations. These times may vary when proper information is available prior to performing a lift. More complicated situations may arise when a module's CoG is in vertical-alignment with the geometrical center, but the loads vary depending on different pick-points. In these cases, the forces exerted by the lifted object may be unevenly distributed and may cause damage to either the structure or the attached components. In some critical lifts, and for the purpose of the research line load cells may be used to confirm line load calculations. Figure 6 shows forces travelling through the lifted object.

Traditional rigging inventory depends on the number of module lift points (4 to 16) and may include: spreader bars from 7 to 15, slings from 22 to 34 or more, shackles from 36 to 56 or more, where the total number of inventory items may be more than 270. In the most advanced configurations (16 point pick), total rigging height may vary from 75 to 165 feet.

4. Lift frames

As an alternative to the traditional rigging, construction contractors and crane rigging companies have developed lift frames. A lift frame is specially designed rigging equipment that can handle sling compressive forces. In the lift
frame, object lift principles are maintained for vertical lift but only to level I of traditional rigging configuration. There are a number of additional components that may be required alongside frame bars such as lift ears or sling plates, but the overall configuration significantly reduces the crane head-room height. There are other advantages associated with employing a lift frame for heavy oil module lifts such as requiring only 20 to 30 minutes to change rigging for short direction, and 10 minutes for long direction CoG offset. In the short direction, special adjusters are designed and attached to the line components to compensate for line length increase or decrease. In the long direction, there are lift sliders or lift windows that can freely move alongside the bar components. The most important aspect of using lift frames is that it can completely eliminate the forces traveling through the lifted object, thus eliminating the necessity for additional bracings and reducing the total weight of the lifted object. Figure 7 shows a module lift frame concept where two sets of sling walls transfer loads to the crane hook. Figure 8 shows a side view of the lift frame where the arrows represent the actual force distribution. In each set of walls, two slings are directly connected to the frame lugs and they are in the middle of each side. The remaining four slings are connected to the frame lugs by turnbuckles which can be adjusted for proper line tension. This eliminates the imperfection of the manufactured sling length and prevents overload to the directly connected middle slings. Top spreader bar function, as mentioned before, is a main component that compensates compressive forces resulting from the object lifted width size and keeps the sling walls vertical with respect to each bar. Such position allows the bar lift lugs and the line components to act in line where these items have more strength. Side-loaded forces would increase line force and at the same time reduce the capacity of the line components. There are two different lift frames presented where they follow the same principle but have different long direction sliding parts. One can have more functionality, addressing folding and unfolding operations by dividing the line into three different sling lengths, while the other is a single line. The three-part line section is designed to fold like a scissor, but in a real scenario it is sling are curved in different direction due to the its’ flexibility. Changing the sling connection from shackles to a more controlled sling plate links does not solve the problem but improves control of sling flexing action. A one-sling line during folding operation simply folds down as it flexes, but it does not have any additional connecting items like a three part line and the unfolding operation is much less complicated.

5. Rigging analysis/calculation and selection

5.1. Traditional rigging

Traditional rigging calculation is based on transferring the loads from the lift lugs to the triangles comprising spreader bars and attached slings. Each sling must have a calculated force less than the sling capacity. Such confirmation is taken from a simple mathematical calculation applied at every node (connecting point) and transferred to the next component for checking. Spreader bars are also analyzed for compression resistance due to attached angled slings above the bar. These calculations are also designed to consider the CoG offset and provide information about any additional length to be added (number of shackles) to keep the bar as horizontal as possible. Spreader bar ends are rechecked in Finite Element Analysis (FEA) to confirm the analytical results. Figure 9 shows spreader bar end FEA results. After all the numerical values for the particular lines are calculated, a simple selection process can take place to select the proper line components such as shackles, turnbuckles, slings, or spreader bar. Each traditional rigging level provides a list of components with type, size, part number, and point to be attached.

5.2. Lift frame

Lift frame analysis is not as simple as traditional rigging. Each bar has several support points (lift lugs) and acting forces position (sliders or windows). Due to the number and configurations of the pick points and lift lugs, the bar problem is statically indeterminate in nature. Figure 10 shows lift frame graphical interpretation. Simple structural analysis approach may lead to inaccurate and less conservative estimates, which can be detrimental considering the
The dynamic nature of a lift operation. Usually, a safety factor of 3.0 is required to be maintained for each and every below the hook component of a rigging assembly. Industry practitioners cannot afford to compromise this particular specification due to the large financial (and other) risks associated with heavy modular construction projects. Consequently, each and every component needs to be meticulously analyzed before a rigging assembly can be qualified to be “safe”. Figure 11 shows bar reaction stiffness method for calculated reaction forces.

6. iRigging algorithm description

The rigging algorithm called iRigging has been developed slowly during the process of preparing a more complex program called iCrane. iCrane consists of sets of individual assignments related to a project: crane selection, position, and lift trajectory; object parameters; site associated aspects of obstruction, ground, access roads, etc; key bone application; optimization algorithms. Previously rigging information was attached to the object information without any options or written knowledge code about the selection, and optimization. However, lifted object CoG offset effect traditional rigging and practitioners compensates line length difference by adding shackles. iRigging addresses all issues beginning with the lifted object load cells weight data, through the structure of the lifted object, lift lugs, then lines, suspending at specific intervals from the spreader bars to the crane hook. Figure 12 shows the iRigging algorithm flowchart. Input parameters are collected from a database of available rigging components and lifted objects. Criteria describes the information related to area lifting codes, specific site rules, general practical rule “know-how” of rigging etc. Output shows the default parameters that are passed on to other programs for further analyses or can be generated for individual lift operation. The center frame contains six major activities driving this algorithm. Load cells collect and validate received data, depending on available information either in traditional rigging section or frame section. Line force calculation module identifies the levels of traditional rigging, then calculates the line forces depending on available data (either object load cells report, gross weight without individual cell readout, and information regarding CoG offset). It also activates the method of analyzing lines for lift frame. Line design section processes the received data and selects proper line components, such as shackles, turnbuckles, or slings based on its capacity and compare the strength of existing components in lift frames. It also checks loads in lines and assesses adjustment possibilities due to the CoG offset. Assembly optimization/selection module optimizes received data lean
on information provided by the user, such as cost (buy/rental), availability, configuration option, storage, etc. This module provides information about replacing the slings instead of using additional shackles when the CoG offset is too critical. **Final checking** module is partially automated and would only be valid when iRigging algorithm is employing as the stand-alone application. Solving only rigging issues in complex iCrane algorithm functions in this module would be employed in different form and place. **Output** section also prepares information as indicated by the client at any stage of the run and provides results as needed. At specific points, the client may require only information regarding the number of spreader bars or shackles in their own rigging components inventory to compare with information from renting, etc.

The presented iRigging concept is not only part of the iCrane program but is also a separate application for rigger engineers and rigging professionals. The application of iRigging will improve over time with the expansion of a reliable database and the assignment of appropriate criteria. It is a tool that will help individuals make informed decisions with regard to employing correct components to design a safe crane object lift operation.

If a project requires rigging analyses for several similar object lifts, as emphasized in the oil and gas industry, algorithm codes may be set for an analysis loop and the optimization module would provide the client with the amount of rigging required for the entire project.

7. **Conclusion**

Enterprises involved in heavy oil constructions operation face constant growth in complexity, size, and weight of process modules that are used to build oil extraction plants. There are many attempts to not only eliminate off-site labor but also simplify the required on-site tasks involved in the final assembly and adjustments. iRigging algorithm is part of a set of specific activities related to timely and especially safe assembly operation; there are many necessary tasks on the job site where safety are non-optional, and therefore can be improved. If this program aid in eliminating even a small amount of this additional site risk, the authors’ efforts to create this tool will be worth the effort. However, iRigging algorithm in its current form is the most effective for repetitive lifting of objects with similar size and weight, and can be modified to accommodate any potential crane lift operation. It is the authors’ intent to make rigging professionals aware of the availability and benefits of using the iRigging application.

**References**