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CRANE SELECTION FOR ADVANCED MATERIAL HANDLING SYSTEMS

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Abstract: *The expectations of today's industrial processes require not only the continuous development of the handling equipment, but also the modernization of the methods used in their design, operation and maintenance, which a logistics engineer encounters every day. The selection of material handling equipment is a traditional process, but the individual steps and the methods used are always aligned with current industrial expectations. This article reviews the main types and application characteristics of cranes, as well as the steps used during crane selection and their relationship, covering the most significant changes that have occurred during the transformation of the selection process.*

Key words: *advanced material handling systems, cranes, crane selection*

1. INTRODUCTION

Cranes are lifting devices operating above ground level that are capable of moving bulk materials or piece goods between points in different vertical and horizontal positions by combining vertical lifting and horizontal movement [1]. The characteristic features of cranes are the upside access to the goods, the vertical lifting device and the movement above ground level.

In terms of the history of cranes, we have to go back to the appearance of simple lifting equipment, because the ancestors of each crane type developed from rope lifting equipment, and the vast majority of cranes used today also apply modern versions of this. The first high-performance, efficient lifting equipment were certainly rope lifting equipment, the use of which appeared in ancient times, where they were used to lift large loads (e.g. on construction sites). However, these were only used to lift goods, they did not allow horizontal movement. The next important element in the operation of cranes is the rope drum, which is used to wind the rope, allowing the load to be fixed in a given position and the lifting height to be increased. The basics of the operation of cranes on wheels (travelling cranes) have been known since the Middle Ages (drawing by Leonardo da Vinci, 1500), but their application only took place after the Industrial Revolution, primarily in connection with increasing production output [2].

The design and operation of cranes used in today's modern industrial processes are adapted to the specifics of the application environment and material handling tasks.

2. MAIN TYPES OF CRANES

In material handling, various cranes are basically used for lifting, but special lifting structures can also be used for simpler lifting tasks (Fig. 1). Based on the operating mode and the characteristics of the space served, we distinguish between traveling and rotating cranes [3]. In traveling cranes, the movement of goods is carried out by linear displacement, on one or more fixed paths, so that the serviceable points are located along a given line or in a cuboid

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space. In the case of rotating cranes, the movement of goods is carried out by rotation around a given axis, so that the serviceable points are located along a contour or in a cylindrical space.

Certain types of cranes (e.g. portal cranes) combine the characteristics of the two versions, thus adapting to the special needs of the service tasks. According to the operating mode, we can talk about manual and automated cranes, and according to the location of handling, there are also installed and mobile cranes.

a) Chain lifter. Source [4] *b) Lifting table. Source [5]* *c) Portable lifter. Source [6]*

Figure 1. Simple lifting equipment

2.1. Rotary cranes

A jib crane performs loading tasks using a lifting device placed on an arm rotating around a given axis and an attached gripping device [7]. Jib cranes are used to perform loading tasks in the vicinity of a given location, and the horizontal movement of goods is performed by the rotation of the arm around the axis, or in some types, by the lifting mechanism or the radial movement of the arm (Figure 2).

There are two basic types of cranes in terms of their structure: rotating cantilever and jib cranes. In the case of rotary cantilever cranes, the crane arm is a horizontally positioned console, on which a suspended trolley usually moves, so the horizontal movement of the goods is achieved by the rotation of the console and the radial movement of the trolley. In the case of jib cranes, the crane arm is a simple or complex boom structure, one end of which (or a given point) is fixed on the axis of rotation, and a rope pulley is located at the other end. The lifting is carried out by the rope of the lifting device placed near the axis of rotation, which runs through the rope pulley. Consequently, the goods are always suspended at the end of the boom structure, and the movement and rotation of the boom perform the horizontal movement.

Due to the rotary motion, the points accessible by rotary cranes are always located within an area delimited by a circular arc, but in some versions this may be further narrowed (circle, circular arc, circular ring, circular segment, etc.).

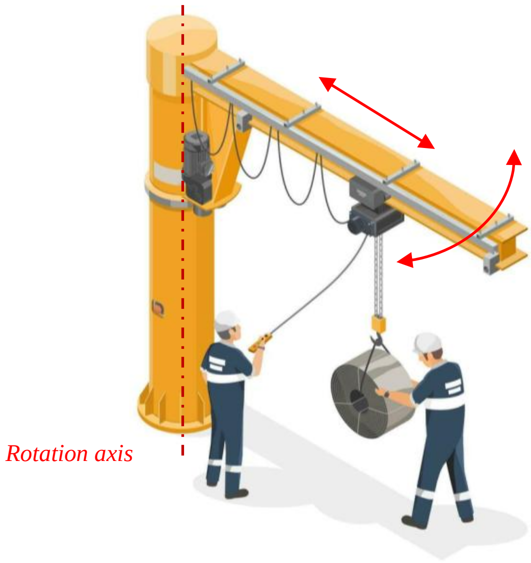

Figure 2. Operation of rotary cranes. Based on [8]

The main application area of rotary cranes is in the workplace and loading area service (ports, warehouses, etc.), the biggest advantage is that their design can be perfectly adapted to the requirements of the handling location. Most slewing cranes can be used to move both piece goods and bulk materials (with the appropriate gripping device).

The types of jib cranes are shown in Fig. 3, the most important difference is the design of the crane arm (cantilever or boom), but there is also a significant group of variable-position jib cranes, which are able to change the loading location. Further differences basically arise from the design of the boom or cantilever structures, typically simple, complex and counterweight versions are used.

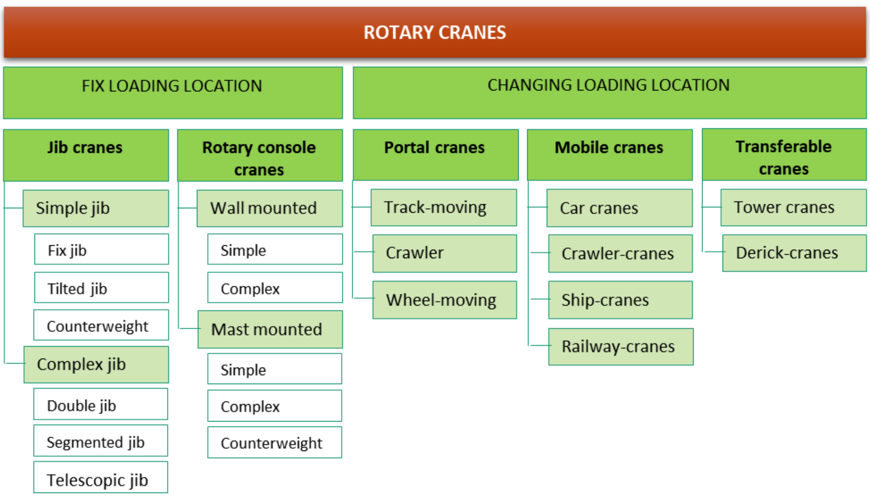

Figure 3. Main types of rotary cranes. [Own edition]

In the case of the simplest jib cranes, lifting is done using a single arm, which can be fixed, tiltable or counterweighted. In the case of a low-mass crane structure or a large boom extension, the load weight can be increased by using a counterweight crane. In the case of a compound jib structure, the crane arm contains several connected elements. There are three basic versions: double-jib, segmented jib and extendable jib. Regarding the crane structure, the jib structure can be placed on the crane body, on a column or on a hall wall. Regarding the application of compound jib cranes, double-jib cranes play an important role in port loading, and as fixed-position or portal cranes, they are indispensable elements of modern port service systems. Segmented jib cranes are relatively new players in material handling, but they are appearing in more and more places during plant service. The extendable boom is mainly found on mobile cranes (truck cranes) and various lifting platform equipment.

The simplest version of the rotating console cranes is a smaller and more load-bearing loading device that can be attached to the wall of the hall structure or to the supporting columns, with which a semicircular or smaller floor area can be served. Thanks to the trolley, every point of the floor area is easily accessible. In terms of its variants, they differ primarily in the suspension of the console or the method of attachment to the wall, which depends on the local conditions and the weight that can be lifted. In terms of its application, simplicity and easy placement are the most important aspects, thanks to which it can be well adapted to workplace handling and loading tasks. If the rotating console is placed on a column structure, it is possible for the crane to turn completely around, which can significantly increase the size of the serviced area and the complexity of the service task. The main application areas of slewing jib cranes are also workplace handling and loading tasks, but due to the larger available area, they can also be used for transfers between workplaces.

a) Double-jib crane. Source [9]

b) Wall mounted cantilever crane. Source [10]

Figure 4. Cranes with fix loading location.

Portal cranes are boom cranes used primarily in ports and are capable of changing their loading location (e.g. moving on a rail). To do this, a moving unit is placed under the boom crane structure (column or crane body) (Fig. 5.a). Portal cranes always perform loading activities in a fixed position, but they can change position between loading tasks. This is particularly important for loading and unloading cargo ships with long loading bays. Their application is basically related to port services, but they can also be used for loading large goods (e.g. containers) and bulk materials into storage spaces.

Mobile cranes are boom cranes that are mounted on a moving unit and, as a result, can perform loading tasks in remote locations. Mobile cranes (Fig. 5.b), like portal cranes, can only lift in a stationary (fixed) position. Its variants are primarily distinguished or defined by the transport method used to move them. We can basically distinguish between truck cranes, crawler cranes, ship cranes and railway mobile cranes. Extendable support arms are used to increase lifting stability.

The most important feature of transferable rotary cranes is that their operating location is temporary, and they must be moved to another loading location from time to time. As a result, their structure allows for quick disassembly and assembly, and the size of the individual components is adjusted to the transportation possibilities and conditions. They occur in two basic versions: tower cranes and Derick-cranes. Tower cranes were basically created to serve construction sites, and accordingly they have a large column height and a long boom structure (Fig. 5.c). A Derick-crane (or mast crane) is a jib crane whose boom is connected to a base structure placed on the ground [11]. The boom is supported and moved by a column structure (mast), which is also connected to the base of the crane and is tensioned with stiffening ropes. The most important application area of Derick-cranes is the implementation of temporary lifting tasks that arise during the construction of large structures (e.g. tower cranes).

a) Portal-crane. Source [12] *b) Mobile crane. Source [13]* *c) Tower crane. Source [14]*

Figure 5. Transferable rotary cranes

2.2. Traveling cranes

A traveling crane is a linearly moving overhead crane that performs loading tasks using a gripping device attached to it [15]. Traveling cranes use linear movements to move goods horizontally. Each type of traveling crane includes a mobile moving unit (trolley) on which the lifting device (usually a rope drum) is placed. The trolley moves along a given track or on a mobile bridge structure (Fig. 6).

The application areas of traveling cranes are basically related to plant service, and their greatest advantages are when moving large masses of goods. Most overhead cranes can be used for moving both piece goods and bulk materials (using an appropriate gripping structure). Over time, some types of overhead cranes have become suitable for off-plant service (e.g. gantry cranes) and have even specialized for certain tasks (e.g. outdoor storage). Their variants are shown in Fig. 7, the most important difference between the types is the location of the track, which can be suspended, running at ground level, or a combination of the two [17]. Most of the variants are bridge-structure solutions, the only exception being the trolley hoist.

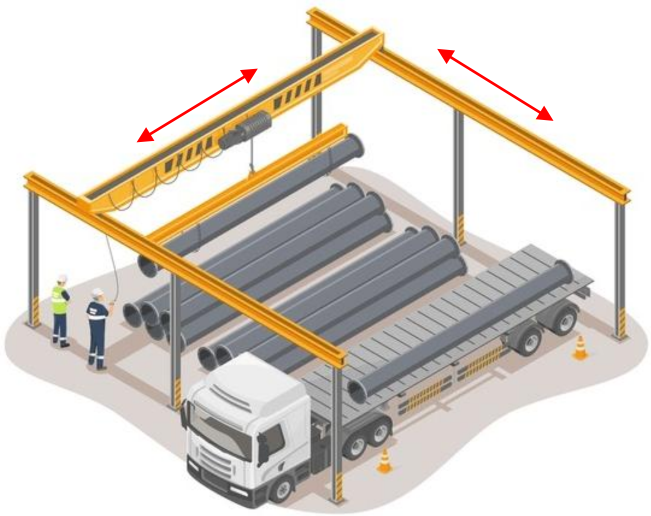

Figure 6. Operation of traveling cranes. Based on [16]

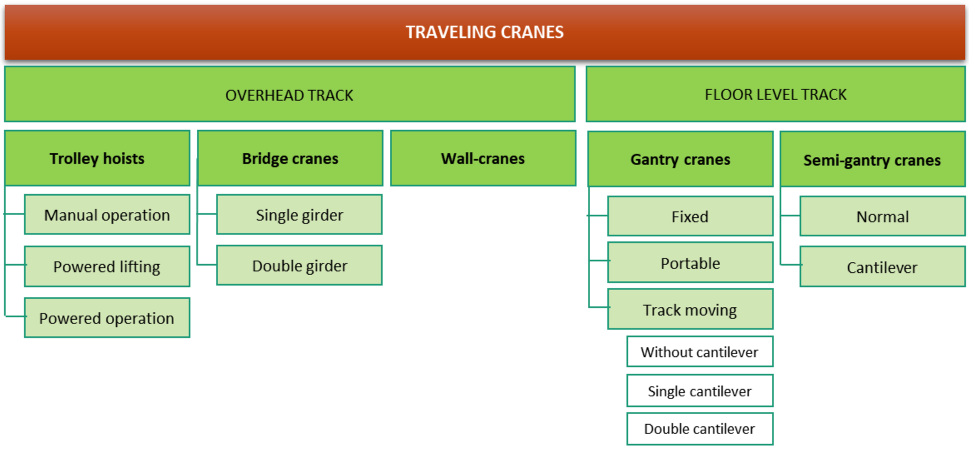

Figure 7. Versions of travelling cranes. Source [17]

A trolley hoist is a simple carriage structure to which a lifting mechanism is attached and suspended from a rail track, moved horizontally manually or electrically. The crane track usually consists of homogeneous steel beams, which can be straight or curved. The lifting mechanism can be a rope drum or a sprocket, in the latter case manual lifting can also be implemented (chain winch). It is typically used to lift and move piece goods, most often with a crane hook. For smaller loads, manual movement is also possible (using a drag chain), but it is usually moved electrically via a suspended switch panel, with a pedestrian solution (Fig.

8.a.). An important feature of trolley hoists is the location of the track, because it is only suitable for serving objects directly below the track.

In the case of bridge cranes, the lifting trolley is placed on a bridge structure, which moves on a pair of tracks fixed to the hall structure or supporting columns, above ground level (Fig. 8.b). Since the bridge structure and the track are both straight and perpendicular to each other, the goods can reach any point in the area delimited by the pair of rails by moving the trolley and the crane bridge simultaneously [20]. The smallest bridge cranes, with a single main girder and suspended trolley, are used for smaller loads. For heavier goods, a more robust structure and usually a double girder design with an overhead trolley are used. In modern manufacturing plants, the bridge crane is the most commonly used loading device for lifting heavy goods. The upside access and movement of goods does not interfere with ground-level traffic and objects located anywhere in the space under the crane can be quickly accessed.

a) Trolley hoist. Source [18] *b) Bridge crane. Source [19]*

Figure 8. Overhead traveling cranes.

A special version of the bridge crane is the cantilever crane (wall crane), which is used when it is not possible to place a pair of rails. Cantilever cranes can move along a wall, using a pair of rails placed on the wall. They are typically used in cases where the distance between the hall walls is too large, or where it is not possible to place intermediate columns, but it is important to reach all points of the area accessible by the cantilever, or to provide fast service. An important feature of this type of crane is that it can also be installed on the outside of the hall walls.

Gantry cranes consist of a bridge structure on a pair of rails placed at ground level, linearly moving legs, and a trolley equipped with a cable-operated lifting device running on it. They are actually off-duty versions of bridge cranes. Since it is more complicated and expensive to create a track above ground level outdoors (there are no hall walls or columns), it is easier to place the rails on the ground and install legs on the crane bridge. The most important factor in terms of its variants is the possibility of a cantilever design. Since the crane track is not connected to a hall wall, the bridge structure can extend beyond the area delimited by the legs (Fig. 9.a). The operating principle of a gantry crane can be used not only for loading large loads, but also for solving smaller, occasional lifting tasks. Small mobile gantry cranes are a solution to this, which can be easily moved to the lifting location in the form of rolling racks on rubber wheels. Gantry cranes are used primarily in outdoor storage areas, when handling bulk materials and large unit loads (e.g. containers), and at various terminals.

In their structure, semi-gantry cranes combine the characteristics of bridge cranes and gantry cranes, which consist of a bridge structure with legs on one side, moving linearly on a ground-level steel rail and another steel rail attached to the hall structure or support columns on the other side (Fig. 9.b).

a) Gantry crane. Source [21]

b) Semi-gantry crane. Source [22]

Figure 9. Floor level traveling cranes.

2.3. Automated cranes

As the number of automated equipment in all areas of industry increases, automation also appears as a demand for cranes [23]. We can find automated cranes in more and more places, primarily when servicing large production halls and warehouses. However, automating cranes and lifting tasks is not an easy task. Three basic characteristics must be taken into account that limit the spread of automatic cranes:

- limitations in increasing loading efficiency,
- the need for human presence,
- automation problems of technical solutions applied to cranes.

Since cranes were basically developed to move large goods, loading cycle times are usually long, so the efficiency increase required to pay back the automation costs and the purchase price of automatically operating loading equipment is not always achievable. Consequently, automation must be preceded by a serious efficiency analysis. Another obstacle to automation is the need for human presence, which primarily occurs during the handling of goods (load lashing). If manual handling cannot be avoided due to the characteristics or inhomogeneity of the goods (grip difficulties), then only a semi-automatic crane can be used. The third factor comes from the characteristics of the crane components, primarily due to the properties of the gripping and lifting structures. The most commonly used piece goods gripping structure of cranes is the crane hook, which can be universally used for various goods, often using load securing ropes or chains. This requires human labour, which cannot be automated. Of course, we can replace the crane hook with various gripping devices (Fig. 10), but this reduces the universality and flexibility of the gripping.

The situation is simpler when loading bulk materials because grabs can be more easily automated, but the increase in efficiency is not self-evident there either.

Figure 10. Example for automated crane. Source [24]

The situation is similar with cable hoists, where load swing significantly complicates or slows down the gripping process. Load swing can be eliminated with certain auxiliary devices or other types of lifting equipment, but then we lose other advantages of cable hoists (e.g. high lifting height). Despite the above, we can still encounter automated cranes, but primarily in areas where high loading performance must be achieved (e.g. container terminals, ports), or where other advantages of automatic operation are decisive (e.g. hazardous working environments).

As for the automation of individual crane types, theoretically the movement of goods can be automated for most crane types; for overhead cranes, linear movement in one or two directions, for rotary cranes, rotation in one or more directions (boom), or rotation and linear movement (cantilever). The problems outlined above related to gripping and lifting occur in all types, but due to efficiency limitations, automatic bridge cranes and gantry cranes are most commonly encountered in modern industrial systems.

3. CRANE SELECTION FOR ADVANCED MATERIAL HANDLING SYSTEMS

Selecting material handling solutions or material handling equipment to serve manufacturing and service systems is usually a complex task, the implementation of which requires significant design experience [25]. In some cases, the simplicity of the tasks may result in trivial solutions.

For each type of material handling machine, a scheme can be outlined that can be used to speed up the selection process [26]. In the case of cranes, the selection process includes the following important steps:

1. Defining the lifting tasks
2. Delimiting the operational area
3. Exploring the relationships between the tasks
4. Writing down the operational parameters
5. Determining the load spectrum

6. Narrowing down the variants based on the comparison of device characteristics and task parameters
7. Examining the suitable variants
8. Selecting the structural elements
9. Determining the dimensions of the crane

Most often, handling machines are not used to solve individual tasks, but to handle different task groups in an integrated manner, which requires system thinking. The first step in selection is therefore always to explore and define the tasks involved in service [27].

Clarifying the relationships between individual service tasks (location and scheduling) is essential during selection, because one of the most important parameters of cranes is the shape and dimensions of the space served. The characteristics of the operating area clearly delimit the types of applicable tools (Fig. 11).

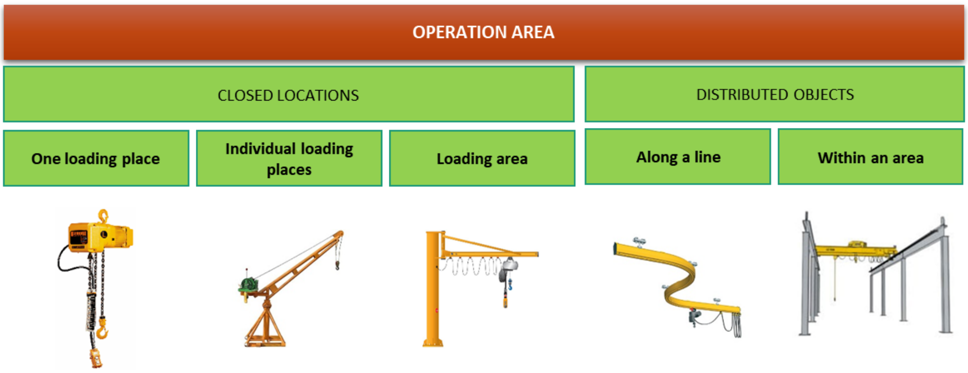

Figure 11. Handling areas for cranes. [Own edition]

Knowing the most advantageous lifting solutions, the parameters of the operations can be described and the loading characteristics of the crane (FEM group) can be determined, which is of fundamental importance for limiting the performance and maximizing the service life of the material handling device [28]. Knowing the numerical parameters, the sub-variants can be further narrowed down and the solutions that best suit the tasks can be selected. After determining the optimal device, the individual structural elements can be finalized (gripping structure, lifting structure, fastening solutions, etc.) and the exact dimensions of the cranes can be determined [29].

4. Conclusions

The expectations of today's industrial processes require not only the continuous development of the service equipment, but also the modernization of the methods used in their design, operation and maintenance, which a logistics engineer encounters every day. Every service system application begins with the design, during which the material handling equipment that best fits the needs is selected. The selection process is a traditional process, but the individual steps and the methods used are always aligned with current industrial expectations (e.g. automated service).

In this article, the main types and application characteristics of cranes are reviewed, and the steps used during crane selection and their relationship are presented. It can be seen that the most significant difference compared to the traditional selection process is the emphasis on multi-task integrated service and the preference for automated solutions during selection.

A further objective of the research is to write algorithms that can facilitate the work of logistics engineers in the design and operation of crane service systems.

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