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SLEWING PORT JIB CRANES

ABSTRACT

The paper presents slewing port cranes with a luffing jib. The advantages of slewing port jib cranes are high lifting capacities, high speeds of re-loading and excellent mobility since they are capable of load lifting, travelling, luffing and slewing. The paper gives a detailed description of their characteristics such as the highest reached load-carrying capacities, speeds of motion and accelerations. It also presents the crane assembly, driving mechanisms, loads and load cases, transport by ships and testing of lifting capacity. As a practical example the paper presents the slewing port jib crane with the capacity of 25/15/5 t at a 27/37/40 m radius made by the Slovenian company Metalna Maribor for the shipyard 3. Maj, Rijeka, Croatia.

KEY WORDS

cranes, port, port cranes, slewing port jib cranes

1. INTRODUCTION

In modern ports up-to-date technologies of re-loading are used for the loading and unloading cargo from ships onto land transport vehicles or storehouses. These technologies are oriented towards continuous and discretized systems of re-loading. The continuous systems of re-loading are used for the re-loading of bulk cargo. They use rotational grabbing of materials or the transport of material by conveying belts. The discretized systems of re-loading are intended for re-loading large piece materials, containers or bulk cargo. The re-loading operations are carried out by cranes. Grabs and other special gripping devices such as hooks, spreaders or ropes with a hook and/or lifting eye are used for grabbing material. Modern technologies and large quantities of materials to be re-loaded in the fastest possible manner require the manufacturing of cranes with high lifting capacities and speeds. Cranes are special types of steel structures and therefore, in addition to the structural analysis for the state of standstill, the dynamic and kinematic analyses for the state of operation must also be carried out. The group of discretized systems of re-loading also includes slewing port jib cranes. With respect to the main supporting structure slewing port jib cranes are designed as tower, portal, semi-portal or gantry cranes. The paper presents in detail the slewing port cranes with a luffing jib.

2. THE CHARACTERISTICS OF SLEWING PORT JIB CRANES

The advantages of slewing port jib cranes are particularly in their pleasant appearance, high lifting capacity, fast speed of re-loading and excellent mobility providing load lifting, travelling, luffing and slewing. The load carrying capacity of these cranes is up to 1000 kN (100 t of mass) with the horizontal jib lever radius ranging from 5.5 m to 60 m and the height of the lift reaching 60 m. The crane speeds for different work operations are different:

- jib luffing speed: up to 150 m/min,
- load lifting speed: up to 120 m/min,
- crane travel speed: up to 100 m/min,
- slewing speed: up to 4 revolutions/min.

The accelerations and decelerations depend on the anticipated time necessary for the accelerating or the braking of the crane. The time the crane needs to accelerate or brake is usually 2.5 sec to 10 sec, therefore, accelerations vary between 0.16 m/s^2 to 1.0 m/s^2.

3. ASSEMBLY AND DRIVING MECHANISMS

The slewing port jib cranes (see Figure 1) consist of the luffing jibs, the tower, the slewing part with a machinery house, a slowly moving slewing ring bearing, a column, a travelling portal, the driving mechanisms and the ballast.

The upper part of the crane consists of a luffing jib, a tower and a slewing superstructure. Cranes of this type are designed with a single or double luffing jib. The single luffing jib is luffed by means of a rope reev-

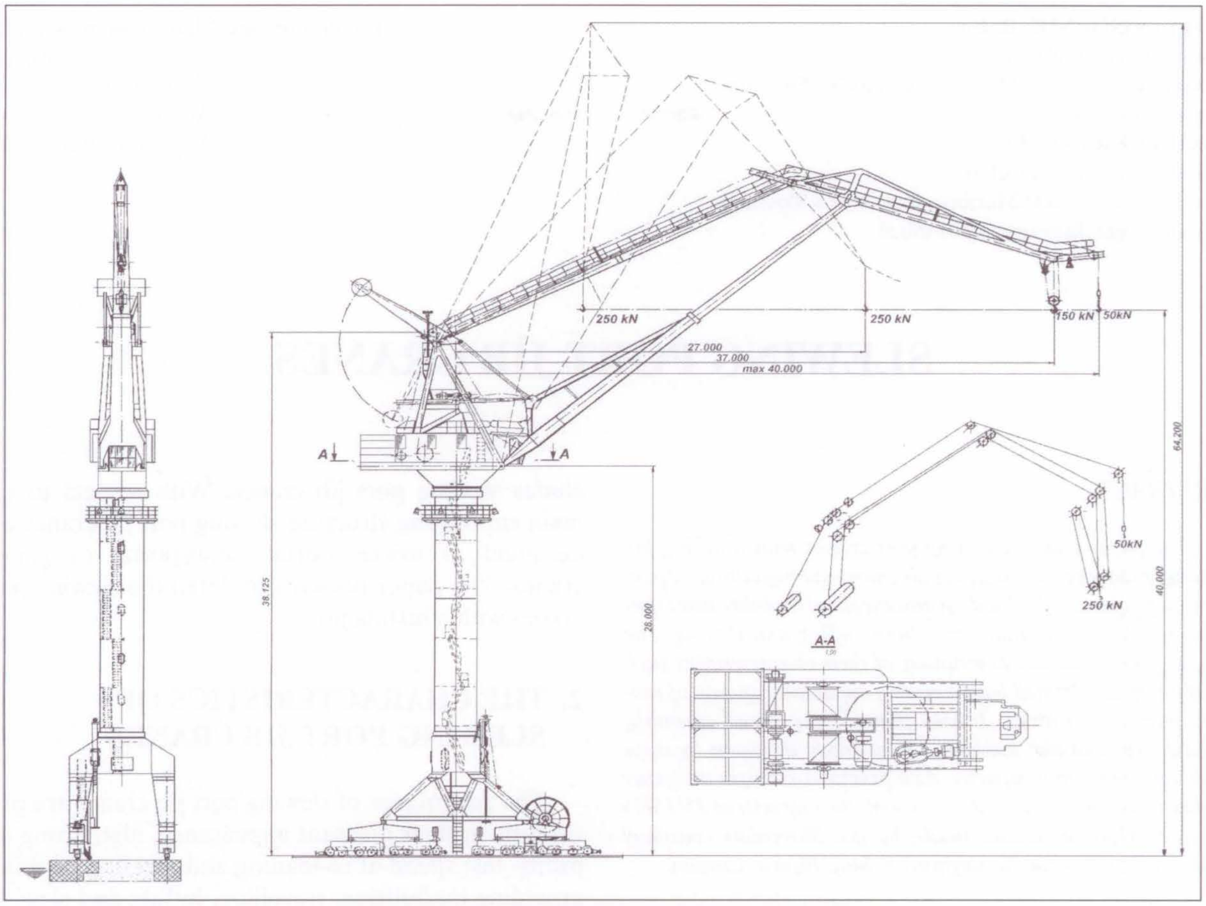

Figure 1 - Assembly of the slewing port jib crane

ing around one rotation point only. The luffing changes the radius, the jib tip elevation and the crane lifting height. The double luffing jib is designed as a four-hinge mechanism. The double jib's changing of radius does not change the crane's lifting height. Most modern slewing port jib cranes are designed with the double luffing jib. The desired position of the jib lever top and its greatest possible radius are obtained by changing the jib inclination and by rotating the threaded nut round the spindle. When carrying the load the jib and crane structure are elastically deformed, therefore, the jib kinematics must be designed in such a manner that during horizontal movement of the load away the jib lever top describes a smooth sine curve with the smallest possible deviation from the horizontal [1], see Figure 2.

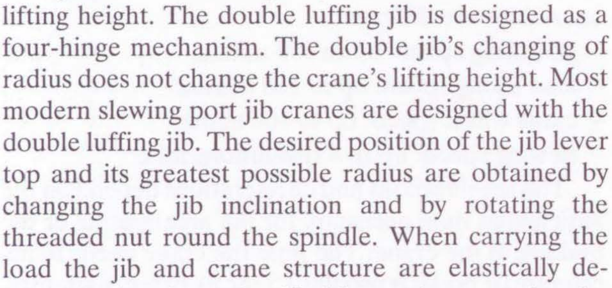

Figure 2 - The smooth sine deformation curve of the jib lever top in case of horizontal movement of the load away

The crane superstructure accommodates the machinery house with driving mechanisms serving for load lifting, crane slewing and jib luffing. The crane superstructure is arranged on slowly moving ball or roller bearings of high capacities. The bearings must withstand considerable forces in the axial and radial direction and bending moments. They are located on top of the columns, their diameters ranging from 2000 to 5000 mm. The middle part of the crane is the crane column usually consisting of a solid wall beam of box cross-section or a pipe with a diameter as large as 2000 to 5000 mm.

The bottom part of the crane consists of the travelling portal shown in Figure 3. The portal comprises a sill beam on which the column stands, two legs and a movable travelling structure. Each bottom leg is designed with at least two movable travelling structures. Further, each movable travelling structure consists of two or more bogies, a travelling wheel and a driving mechanism. The latter drives the travelling wheel and ensures the crane travel on rails. By means of systems of hinge-connected primary and secondary beams (balancing teams) the bogies suitably adapt themselves to the crane runway rails to ensure smooth and

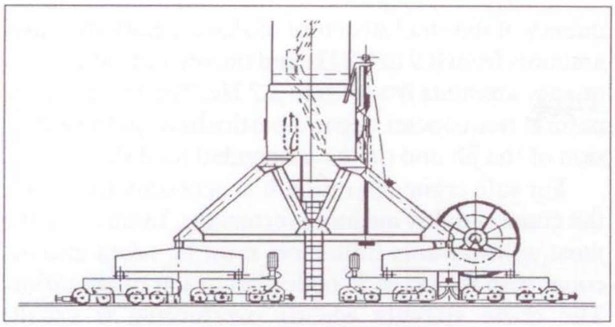

Figure 3 - Travelling portal

safe crane travel. The bogie consists of a housing and one or two travelling wheels. Usually, an even number of bogies is mounted into the movable travelling structure.

As far as the travelling wheels are concerned, driven and idle wheels are distinguished. They are designed with straight rolling surfaces and with or without guide rims (flanges). If the wheels without the guide rims are used, it is necessary to use horizontal guide wheels for safe guiding of the crane on the crane runway. On small and medium-sized cranes 3 to 6 wheels are used in the movable travelling structure and on large cranes 6 to 8. This means that in total 12 to 24 travelling wheels are installed on small and medium-sized cranes and 24 to 32 travelling wheels on large ones. For greater load-carrying capacities travelling wheels made of quenched and tempered steel materials with the tensile strength of f_u = 500 - 1000 N/mm^2 are used. The travelling wheel diameter is usually between 500 and 1000 mm, depending on the crane loading and speed.

Most frequently cross lay steel ropes with plastic cores are used as load-carrying ropes on the cranes. The load carrying capacity of the ropes is determined with respect to resistance to breaking with the safety factor $v \geq 5$. The hooks with bottom blocks (housing, rope pulleys) and other special gripping devices (grab, spreader) are installed into cranes as finished products of renowned makers. The safety factors in the calculation of their load carrying capacities should be $v \geq 5$. The ballast for balancing the double luffing jib is usually placed onto the tower on the side opposite to the jib bearing arrangement. The ballast is made of concrete with the addition of small or larger pieces of steel sections.

The carrying structure of slewing port jib cranes is made of steel materials of the tensile strength fu=360-630 N/mm^2. The excessively loaded structural components are made of fine-grained steel with an increased strength of f_u = 560 - 940 N/mm^2.

The driving mechanisms serve for crane/portal travel, jib luffing, crane tower slewing and load lifting. The driving mechanisms consist of an induction gear motor with one or several reduction steps. For softer starting of travel and braking a frequency controller is used to regulate the rotating speed and the starting torque of the induction motors. The D.C. electric motors are more expensive than induction motors, which is why they are rather seldom installed on cranes. All driving motors have solenoid brakes. The crane can be operated from the driver's cabin or from a remote wireless control station. The cabin is usually located on the crane's slewing part beside the jib or on the travelling portal.

4. LOADS ACTING ON THE CRANE

4.1. Types of loads

Static as well as dynamic loads act on slewing port jib cranes. The former act on the crane in the state of standstill and the latter act particularly in the state of operation. For the sake of economical selection and safe dimensioning of the load-carrying structure it is important that the loads are defined as realistically as possible: the design load should be closest possible to the actual load acting on the crane.

In addition to the dead and imposed load, the dynamic loads due to inertia forces also act on the crane. These forces arise because of accelerating and braking during the crane travel, jib luffing, crane slewing, load lifting, lowering or shaking; they further occur because of unevenness of runways and guides, clearances in bearings, hinges and gears. Additional inertia forces act on the crane in case of earthquakes and wind during operation, standstill and transport of the crane.

The loads for such type of structure are specified in the relevant standards. In Europe mostly the FEM 1.001 [2], BS 2573 Part 1 [3], Lloyd's Register of Shipping [4], DIN 15018 [5], DIN 15019 [6], Det Norske Veritas [7] and USSR Register [8] are used. It is characteristic of all these standards that the static replacement load is specified for the action of the dynamic forces. The static loads are multiplied by the prescribed dynamic coefficients and the service class coefficients. In most cases the specified coefficients correspond to the conditions of operation of the overhead travelling crane and portal cranes, whereas they are not sufficient in the case of large slewing port jib cranes. In such cases one should rely on the findings of the researches from literature [9, 10] and particularly on one's own experience.

4.2. Types of load cases

Most standards classify loads into three different load cases (load cases I, II and III).

Load case I defines the load during normal crane operation without taking the wind load into consideration. This load case includes:

- dead weight of the steel structure, ballasts and bulk material,
- lift weight such as the weight of the gripping device, the weight of unwound rope and the rated load,
- inertia forces during acceleration and braking,
- centrifugal forces during slewing,
- shocks of bulk material.

Load case II defines the load during normal crane operation taking the wind load into consideration. This load case includes:

- all loads listed in load case I,
- wind load during the crane operation w = 250 N/m^2,
- the load due to oblique pulling of load,
- the load due to climatic influences (temperature, snow and ice).

Load case III defines the load during the testing of the crane load-carrying capacity, the load due to the crane striking the bumper and the load of the storm wind acting on the crane in the state of standstill of the crane. This load case includes:

- dead weight,
- load during testing of the crane load-carrying capacity,
- lift weight,
- inertia forces due to the crane striking the bumper,
- the load of storm wind during crane standstill.

Within the frame of each load case the individual loads are combined into load combinations. Each load case usually contains several different load combinations. In most cases the crane structure is in motion, therefore, the influence of the temperature load acting on the crane is smaller than otherwise. The crane is dimensioned for the temperature load only in cases when the influence of the temperature load is important (i.e. the predominant local influence). Particularly in the stage of operation, the cranes of this type are continuously loaded by a repeating dynamic load causing cyclic change of stresses in the steel structure. Therefore, the structural components with the number of changes of loadings and/or oscillations equal to $N \geq 2.\ 10^4$ must be designed for the permissible permanent strength during fatiguing.

Although the standards do not specify the requirement for checking the natural frequencies of the crane structure, the checking of natural frequencies is useful for safe operation of the slewing port jib cranes. Particularly, it is important to compare the natural frequencies of the steel structure with the frequencies of the operating dynamic loads and the work motion in order to prevent resonance influences and premature failure of the steel structure or of some vital part. The crane natural frequencies are obtained experimentally by measurements or by analytical-numerical procedures [11, 12, 13, 14, 15]. Usually, the first natural frequency of the steel structure of slewing port jib cranes amounts from 0.9 to 1.2 Hz and the second natural frequency amounts from 1.6 to 2.2 Hz. The values of the natural frequencies depend particularly on the extension of the jib and on the suspended load size.

For safe crane operation it is necessary to analyse the crane stability against overturning. In this case the most unfavourable influences must be taken into account with the crane in operation or out of operation. The crane stability against overturning is usually reached by adding ballast.

4.3. Transport of crane by ship as a special load case

A special case of loads is the load acting on the crane structure due to the transport of the crane by ship. Usually, these loads are considerably greater than the loads during crane operation or standstill. The accelerations during the crane transport by ship can be great due to the ship's pitching, rolling and heeling. They depend on the characteristics of the ship transporting the crane. The acceleration values in the case of transport by medium-sized ships which are 12 to 16 m wide and 125 to 150 m long are given as an example [16, 17]:

- during pitching: from 0.1 to 0.45g,
- during heeling in the middle of the ship on the deck (h = 0 m): up to 0.07g,
- during heeling in the middle of the ship above the deck (h = 20 m): up to 0.57g,
- during rolling on the deck (h = 0 m): up to 0.2g,
- during rolling on the deck (h = 20 m): up to 0.3g.

5. TRANSPORT AND TESTING OF CRANE LOAD-CARRYING CAPACITY

Crane steel structures are usually made by companies with long-standing tradition and experience in constructing of such equipment. In manufacturing a crane structure great attention must be paid to the inspection of the quality of materials, equipment and workmanship. Due to great dimensions slewing port jib cranes cannot be assembled in workshops, but are rather built together in ports. Road and railway vehicles transport the crane structure to the place of erection. In cases when the location (port) of the crane's end user is too far away from the place of manufacturing, the crane is assembled in a nearby port and then transported by a cargo ship of high load-carrying capacity. Transport by ship is the cheapest type of transport, but it requires additional fixing of the crane structure to the ship in order to support high inertia forces due to rolling, heeling and pitching of the ship [16, 17].

After the final erection of the crane in the user's port it is necessary to carry out the tests of the crane load-carrying capacity, i.e. the static and dynamic tests of the load-carrying capacity.

The static test of the load-carrying capacity for this type of crane is carried out with 40% overloading. It is to be carried out when there is no wind and when the crane is in the state of standstill. The crane must lift the overload, placed in the extreme position, 10 cm above the ground.

The dynamic test for this type of crane comprises the test of the load-carrying capacity with a 20% to 25% overload. The crane must be in service and all the crane operations must be carried out. The suspended load is to be lifted in the most unfavourable position. The wind pressure on the steel structure must be smaller than 400 N/m^2. The dynamic test must be carried out slowly and with greatest care. Most crane accidents occur particularly in the stage of the dynamic test due to lack of care.

6. SLEWING PORT JIB CRANE 25/15/5 T X 27/37/40 M FOR THE RIJEKA SHIPYARD, CROATIA

The paper presents a practical example of a slewing port jib crane with the capacity of 25/15/5 t at the radius of 27/37/40 m (see Figure 4). The crane was made by the Slovenian company Metalna Maribor for the shipyard 3. Maj, Rijeka, Croatia [18]. The crane is used for the re-loading of piece materials in the shipyard during the manufacturing and renovation of ships. In addition to the main lifting of loads Q=25 t (15 t), auxiliary lifting of loads Q=5 t is anticipated at the end of the crane jib lever. The main and auxiliary lifting can take place simultaneously. The crane is designed with a double luffing jib. In its highest possible position (correction of pull rod and jib lever) it can reach the height of 64 m. The basic technical data on the crane are given in Table 1.

Table 1 - Basic technical data on the crane

Crane capacity at the radius of 8.5 - 27 m		Q=25 t
Crane capacity at the radius of 27 - 37 m		Q=15 t
Auxiliary lifting at the radius of 40 m		Q=5 t
Main load lifting speed (25, 15 t)	m/min	10/1
Auxiliary load lifting speed (5 t)	m/min	35/3.5
Luffing speed of luffing jib	m/min	30
Speed of crane travel on rails	m/min	30
Crane slewing speed	rev/min	1
Height of lift on hook		(40+8) m
Maximal force on wheel		F=20 kN

Figure 4 - The slewing port jib crane in the 3. Maj shipyard, Rijeka, Croatia

The mass of the slewing port jib crane operating in the shipyard 3. Maj is 184.1 t without the ballast, while the mass with the ballast is 316.1 t, see Table 2. The total mass of ballast placed on the slewing part of the crane is 132 t, 14 t on the arm of the counterweight for balancing four-hinge luffing jibs, 14 t on the side opposite the jib bearing arrangement and 22 t in the base of the slewing part.

Table 2 - Mass of crane components

Crane component	Mass
Luffing jib	31.56 t
Crane slewing part with tower	31.77 t
Column with travelling portal	51.91 t
Driving mechanisms for travel	36.75 t
Mechanisms for slewing, luffing, lifting	16.81 t
Accessories: rope pulleys, bases	7.30 t
Ballast	132.00 t
In total	316.10 t

In the computation analysis of the crane structure 15 different load combinations for three standard load cases were accounted for. The computation model of the crane is a spatial line structure. The inside static quantities and deformations were calculated by computer according to the finite element method.

The crane structure was designed according to standards JUS M. D1. 050 and JUS M. D1. 051 [19, 20]. The checking of the crane stability against overturning was effected for four different load cases and the different outreaches of the hook on top of the jib lever (8.5m, 27m, 37m). In the computational checking of the crane against overturning the load cases are defined as follows:

- load case I, normal crane operation with 10% overload by taking the in-service wind into account (wind pressure w = 250 N/m^2) and by accounting for the highest horizontal loads due to inertia forces in normal crane operation (travel, luffing, slewing, suspended load swinging, oblique pulling of load),
- load case II, crane operation with 45% overload without considering the in-service wind and the horizontal load,
- load case III, crane out of operation, the storm wind load is taken into account (wind pressure w = 1100 N/m^2 - 1500 N/m^2),
- load case IV, sudden loading of crane (breakage of lifting rope, F = - 0.3 Q).

The resulting rated safety factors against the crane's overturning are indicated in Table 3. They are defined with the ratio of the stable moment of the crane $\sum Mg$ (moment of dead weight of crane and ballast) and of the crane overturning moment $\sum Mp$ (moment of the individual load combination) around the most unfavourable overturning point of the crane: $\nu = \sum Mg / \sum Mp$.

Table 3 - Calculated safety factors against crane overturning

Load case	Safety factor n with hook outreach on the jib lever		
	L = 8.5 m	L = 27 m	L = 37 m
Load case I	1.36	1.18	2.22
Load case II	1.57	1.47	7.38
Load case III	1.15	0.82	0.54
Load case IV	1.57	1.47	7.38

When checking the overturning of the crane for the load case II with a jib lever outreach of L ≥ 27 m, the safety factor $\nu < 1$ was calculated. Nevertheless, to make the crane stable for this case (the crane was out of operation) we anticipated crane anchoring by rail clips taking over the remaining overturning moment. The rail clips are fixed to the travelling portal leg and their jaws embrace the crane rail. For dimensioning the crane rail this load was also taken into account.

The individual structural components of the crane structure were designed to be made from hot rolled beams of open compound sections, a closed box and round sections of different thickness. The jib 30.5 m of length and the pull rod 26.65 m of length have a box cross-section, whereas the crane column is made of a pipe with a ϕ 2910 mm in diameter and 17.485 m of height. The jibs, the crane slewing part with the tower and the bottom part of the travelling portal are made of steel RSt 37-2 and St 52-3, whereas the column is made of steel St 52-3. The pins, axles, wheels, rope pulleys and other mechanical components are made of quenched and tempered material Ck 45. The bearing arrangement of the crane slewing part above the column consists of a slowly moving slewing ring ball bearing with an internal gear rim. The designation of the bearing is: Standard series KD 320, Drawing number 012.35.2690.000.11.1503. The outside diameter of the bearing is 2820 mm, its inside diameter is 2432 mm and its mass is 1225 kg. The maximum permissible load-carrying capacity of the bearing is determined from the catalogue. In our case the permissible axial force was N = 2550 kN and the permissible resulting bending moment M = 5500 kNm. For the main auxiliary load lifting steel wire ropes B 24 x 160 were selected in accordance with DIN 6895. The rope for the auxiliary load lifting is 115 m long.

The crane travelling part consists of four driving units. Each driving unit consists of an inclining structure with 8 wheels with a diameter of 500 mm. The crane has a total of 32 wheels out of which 8 are driven and 24 are idle wheels.

The driving mechanisms for the main and auxiliary lifting and slewing of the crane's upper part is placed in the machinery house in the crane slewing part, whereas the mechanisms for luffing the four-hinge jibs are located on the tower structure. The major part of the electrical equipment and controls is installed in the machinery house and in the driver's cabin. The power supply to the crane is effected with electric cable. The driver's cabin is located on the front side of the slewing port jib crane close to the jib bearing arrangement. The access from the ground to the driver's cabin is ensured by the access stairs of the travelling portal over the access ladders, placed inside the tubular column. The access walkways and platforms are provided on all places where the rope pulleys and bearing arrangements are located.

7. CONCLUSION

The paper presents slewing port jib cranes serving to re-load large piece materials, containers and bulk cargo. The advantages of these slewing port jib cranes are their pleasant appearance, high load-carrying capacities, high speed of re-loading and excellent movability ensuring load lifting, travel, luffing and slewing. Characteristics such as highest load-carrying capacities, sizes, moving speeds and accelerations are described in detail. The assembly, the crane driving mechanisms, the acting loads, the load cases, transport by ships and testing of load-carrying capacities are also presented. As an example the slewing port jib crane with the capacity of 25/15/5 t at the radius of 27/37/40 m, made by Metalna Maribor for the 3. Maj, a shipyard from Rijeka is introduced. This crane has been successfully in operation as much as for a decade. The crane has been regularly maintained and inspected and no serious defects have been traced so far. Due to its slender and pleasant appearance and its reliability it can be considered a modern slewing port jib crane design.

IZVLEČEK

VRTLJIVI PRISTANIŠKI ŽERJAVI Z NAGIBNO ROČICO

V članku so predstavljeni vrtljivi pristaniški žerjavi z nagibno ročico. Odličnost vrtljivih pristaniških žerjavov se kaže predvsem v njihovih velikih nosilnostih in hitrostih pretovarjanja ter izredni gibljivosti, saj omogočajo dvigovanje bremen, vožnjo, nagibanje in vrtenje. V članku je podrobneje podan opis njihovih značilnosti kot so največje dosežene nosilnosti, hitrosti gibanja in pospeški. Prikazani so tudi sestava in pogonski mehanizmi žerjavov, delujoče obtežbe in obtežni primeri, ladijski transport in preizkus nosilnosti. Kot praktični primer smo predstavili vrtljivi pristaniški žerjav nosilnosti 25/15/5 t pri dosegu 27/37/40 m, ki ga je slovenska firma Metalna Maribor izdelala za ladjedelnico 3. Maj, Rijeka, Hrvatska.

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