Control Systems for Floating Cranes

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This paper describes a vertical lifting control and level luffing control design for newly developed, fully hydraulic-driven floating cranes. Unlike lattice boom crawler cranes for land use, the floating cranes are affected by the pitching and rolling motions of the pontoons on which the crane machinery is installed. A control algorithm was developed, taking into consideration the dynamics of the pitching and rolling motions of the pontoons, as well as the motion controls for load hoisting and boom hoisting.

Introduction

In recent port and harbor constructions, caissons and wave dissipating blocks for breakwater works have become larger. Cranes, for such construction works, are required to be multifunctional, having strong winch line pull and fast hook speed, and to have improved operationality, so that the works are performed quickly, accurately and safely, not only for heavy loads, but also for light loads. For bucket works, fast power lowering speeds and construction accuracies are also required.

KOBELCO CRANES CO. Ltd., in response to those demands, started selling all-hydraulic, multipurpose, floating cranes, F&G3106 (winch line pull 25t) and F&G3111 (winch line pull 45t, **Photo 1**). Both are capable of crane work and other work requiring strong winch line pull, such as bucket work and rock breaking work, all in one unit.

This article explains the outline of the control technologies, developed for the new series of floating cranes, and introduces their features of vertical lifting control and level luffing control.

Photo 1 Floating crane F&G3111

1. Outline of the newly developed control technologies

1.1 Hydrodynamic drive for strong line pull and high speed winding

So far, crane and grab dredging machinery of a winch line pull, having capacities higher than 25t, employ mechanical winch drives (with torque converters having modulated clutches), but suffer from lack of winching operationality and response for slow speed, inching and light loads. In contrast, the new series of floating cranes is featured by hydraulic systems in which the front and rear winches are driven by dedicated, not serially connected, independent pumps. The F&G3106 is equipped with two sets of independent hydraulic motors for front and rear winches, while the F&G3111 is equipped with four sets. The front / rear independent hydraulic circuits allow rated line pulls on both the front / rear drums and enable strong dredging power during hoist after the bucket is fully closed. In addition, crane operationality is improved significantly so that works from light to heavy loads are performed in a speedy manner.

1.2 Multifunctional capabilities by hydraulic control

1.2.1 Synchronous hoisting/lowering of main and auxiliary hooks

Works, requiring synchronous main / auxiliary hook operations, can now be operated safely and in a speedy manner, thanks to a synchronous control, which automatically equalizes the hoisting / lowering speeds of the main and auxiliary hooks, despite the difference in the number of reeving ropes on hook and rope layers in drums.

1.2.2 Vertical lifting and level luffing controls

A vertical lifting control, along with the boom hoisting operation, is performed automatically by manipulating a single hoist lever which prevents radial sway of loads during hoisting. A level luffing control, along with the hoisting and lowering of loads, is performed automatically by manipulating a boom lever, so that loads are maintained at constant heights either from the pier, or from the pontoon deck, and the pitching and rolling of the pontoon is prevented. Incidentally, the level luffing control is carried out not only for the use of single main, or auxiliary, hook, but also for the simultaneous use of main and auxiliary hooks. The details are discussed in the second and subsequent sections.

1.2.3 Level dredging work by buckets

Dredging finish accuracies are improved by maintaining the locus of the bucket tooth points, leveled through an automatic hoisting and lowering control of the bucket, while the bucket is closed.

1.2.4 Mode selection for slewing operations

Three mode selections are provided for the slewing motions; i.e. the "speed control + torque control" mode, in addition to the "speed control" and "torque control" modes which, so far, have been provided for hydraulic driven machinery with 16t line pull. In addition, improvements have been made so that the mode selection, between a free slewing mode and braking mode, is available in the case that the slewing lever is in a neutral position.

1.3 Overload prevention for main/auxiliary simultaneous operation

So far, overload prevention has been provided either for the main hook operation only, or for the auxiliary hook operation only, however, an overload prevention mechanism was newly developed for the simultaneous main and auxiliary hooks operations. This allows inclination and turn-over of the loads and improves work efficiency and safety.

2. Vertical lifting control

Dangerous situations occur, as shown in **Figure 1**, when lifting a load off the ground just by the hoisting operation. The situations are caused by the load distorting the boom, elongating the rope and inclining the pontoon, leading to a positional misalignment of the boom tip from the vertical line of the load, resulting in sway of the load.

Generally, operators are required to manipulate both the load hoisting and boom hoisting at the same time, so that the tip of the boom is aligned to the vertical line of the load, however, the operation requires well trained skills.

In the present system, a mere hoisting operation controls both the load hoisting and the boom hoisting speeds automatically by a controller, minimizing the sway of the load at the time of the lift off and preventing pitching and rolling of the pontoon (**Figure 2**).

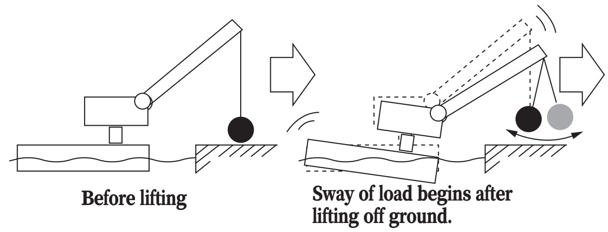

Fig. 1 Liftig without vertical lifting control

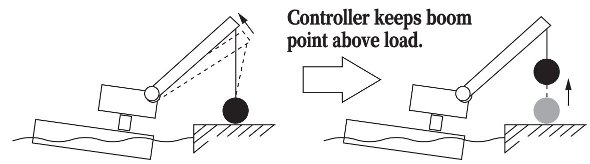

Fig. 2 Lifting with vertical lifting control

2.1 Control target

The target for the radial sway was set to ±30cm, based on advice from operators of four types of floating crane from small (100t hoist) to large (400t hoist).

2.2 Operating procedures

Because the present system employs an open loop control method, which does not detect the swing angle and displacement the load, the boom tip has to be adjusted manually to the vertical line of the load at the time of slinging. After the manual adjustment of the boom tip, a "vertical lifting switch" is turned on. This allows the control of the boom tip to stay on the vertical line of the load by controlling the boom hoisting to correct for the radial sway of the load, when starting the load hoisting by manipulating the hoist lever

3. Level luffing control

Level luffing is an operation to change the working radius of the load, while maintaining its lifting height. The operation, as in the case of the vertical lifting control, requires manual, simultaneous manipulations of the hoist and boom levers by an operator. In addition, the pontoon becomes subject to pitching and rolling, as shown in **Figure 3**, because the change in the boom angle, with a lifting load, changes the inclination moment of the pontoon. The present system accurately controls the lifting height, while preventing the pitching and rolling of the

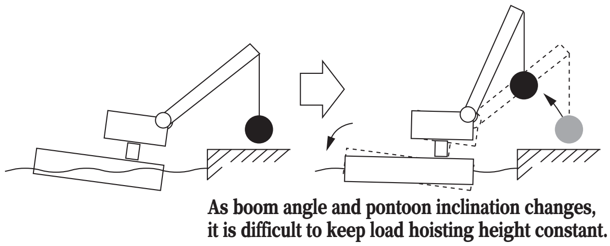

Fig. 3 Boom hoisting without level luffing control

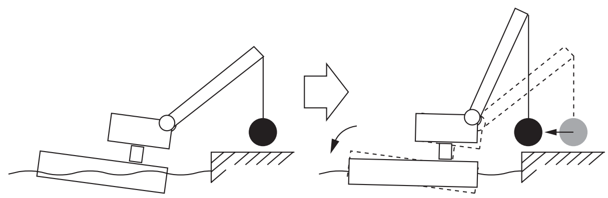

Fig. 4 Boom hoisting with level luffing control

pontoon (**Figure 4**).

3.1 Control target

The target for the vertical height variation was set to ±30cm, based on advice from operators, as in the case of the vertical lifting control.

3.2 Operating procedures

After the load is lifted to a certain height, the "level luffing" switch is turned on. This allows automatic hoisting and lowering of the load to correct for the lifting height, along with the control of boom hoisting, just by manipulating the boom hoisting lever.

4. Control parameters characteristic to floating cranes

Floating cranes are marine objects. Unlike land cranes their control system, therefore, has to take into account the pitching and rolling of the pontoon during vertical lifting and level luffing controls. The pitching and rolling characteristics of the pontoon have dynamics similar to those of dual pendulums, as shown in **Figure 5**. Pitching and rolling occur around virtual rotational centers in the space above the pontoon, a longitudinal metacenter and a transverse metacenter. The dynamics, illustrated in Figure 5, assume that the pontoon is in a free condition and the characteristics may be different when the pontoon is moored to piers.

4.1 The relation between the laden weight on the deck and the metacenter[1)]

A metacenter is defined as "the crossing point between

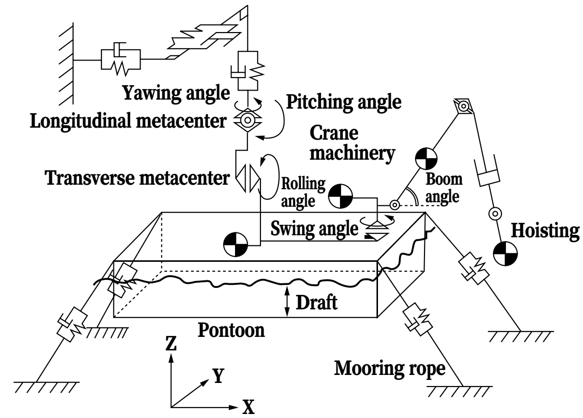

Fig. 5 Simulation model of floating crane

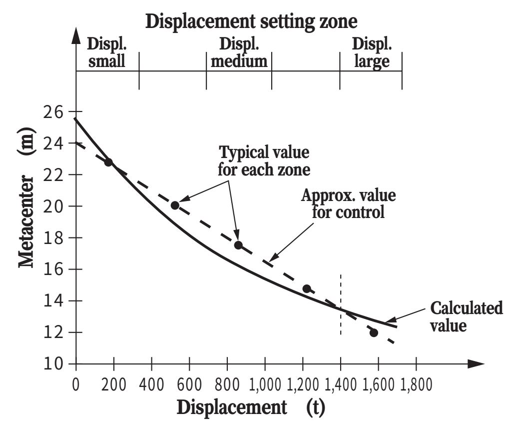

Fig. 6 Metacenter vs. displacement

the vertical line, passing the buoyancy center when the pontoon is tilted by a load, and the centerline of the pontoon when the pontoon is floating vertically at a draft in a static and stable condition". Here, the draft is the depth below the water surface of the pontoon. In the case of a floating crane performing block placement works, the number of blocks, or the laden weight, on the deck changes as the work progresses. As a result, the draft changes, along with the positions of the metacenters.

In addition, the sizes of pontoons vary even for the same model of crane, because the sizes are determined not only by the model of the crane, but also by the space required for their work. **Figure 6** shows an example calculation of metacenters from the minimum laden weight to the maximum laden weight.

The present control system applies collinear approximations for the displacements of metacenter values against laden weights, as illustrated by the broken line in the figure, based on the longitudinal and a transverse metacenter values for the minimum and maximum laden weights, calculated in advance as basic data for each floating crane. This not only reduces computations in the controller, but also allows selection of the longitudinal and transverse metacenter values at the time of the laden weight parameters input by operators. Although detailed explanations are abbreviated in this article, the collinear approximation has been confirmed to give close enough values for the controls.

4.2 Effect of mooring

Modal tests were carried out on actual floating cranes, including one free from a pier and another moored strongly to the pier with mooring ropes. It was found that, in case of the floating crane free from the pier, the metacenter is the rotational center of pitching and rolling, while in case of the floating crane moored to the pier, the metacenter is not the rotational center of pitching and rolling.

Taking those facts into consideration, an algorithm was designed so that the aforementioned metacenter values are applied to floating cranes not moored and free from piers, while zero value is applied for the floating crane moored to the pier with stretched mooring ropes. This allows selection of the longitudinal and transverse metacenter values when operators judge the conditions of the mooring ropes.

5. Control system[2)]

The present control system configuration is shown in **Figure 7**. In the vertical lifting control, the boom hoisting control is performed so that the boom tip always stays on the vertical line of the load and, at the same time, the load hoisting speed is controlled, in response to the lever operations by an operator, to prevent pitching and rolling of the pontoon at the moment of lift off.

In the level luffing control, target speeds for hoisting and lowering of the load are set in advance, based on the boom hoisting speed of the boom hoisting operation by an operator. The control is performed to make corrections of the speed of hoisting, or lowering, against the target values to prevent the swing of the load.

The working radius in Figure 7 is the horizontal distance between the metacenter position and the tip of the boom, and the lifting height is a value taking the metacenter position as the datum point. The controls have a capability of adjusting the metacenter positions depending on the laden weight of the pontoon and the conditions of the mooring ropes, as described previously.

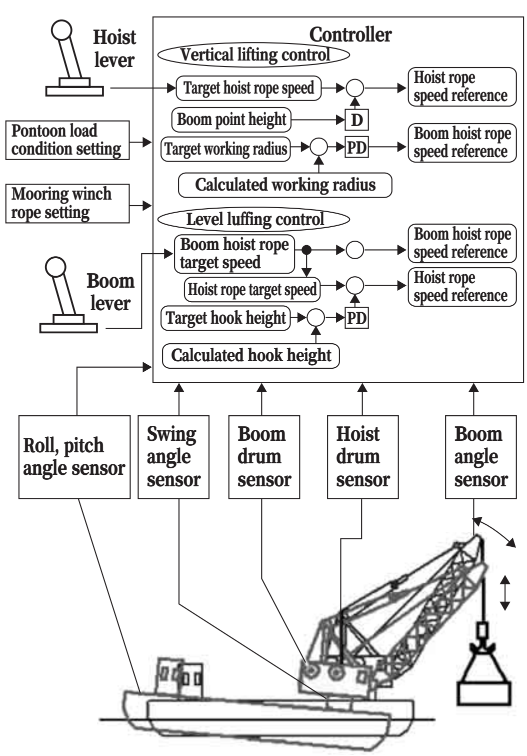

Fig. 7 Control system configuration

6. Verification by simulation

Prior to the confirmation of the actual operation, verification was carried out for the vertical lifting control, using the simulation model shown in Figure 5. The results are shown in **Figure 8**.

Simulation conditions:

- Pontoon dimensions
  Length×Width×Depth＝57m×22m×3m
  Displacement＝1,300t Mooring: free
- Crane
  F&G3111 with a 37m boom
  Load＝165t×working radius 13m, 90 degree angle slewing lift

The results show that the load swings approximately ±6cm in the radial working direction (Y axis) and approximately ±15cm in the direction perpendicular to the radial working direction (X axis). The control is verified to be effective, with both the swing values within the target range, and especially the swing in the radial working direction, which is under control, is suppressed to about 40% compared to the

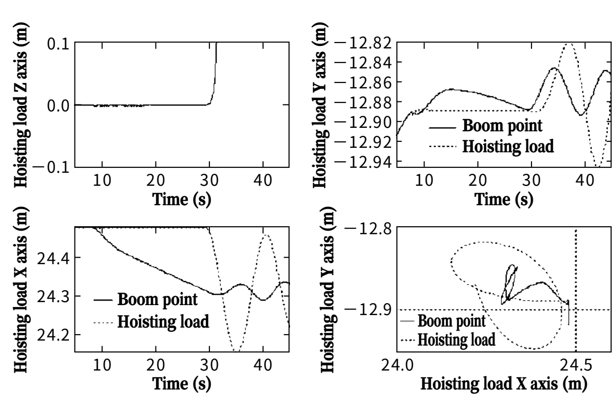

Fig. 8 Simulation results of vertical lifting

perpendicular direction, which is not under control.

7. Verification on the actual equipment

An F&G3111 was installed on a pontoon, and the F&G3111 was slewed by 90 degrees for vertical lift off and was slewed for 0, 45, 90, 135, 180 degrees for the level luffing. The control targets were visually confirmed to have been achieved. The operations of the vertical lifting control and level luffing control are shown in **Photo 2** and **Photo 3**, respectively. Although the pontoon is not shown in Photo 2, the fact, that the landing bridge between the pontoon and pier did not show any significant displacement, indicates that not only the swing of the load, but also the pitching and rolling of the pontoon were suppressed.

Conclusions

The control system described in the present article is aimed at preventing the sway of load and pitching and rolling of loads and pontoons when floating cranes lift off heavy loads from piers. It has been explained that the effectiveness of the two dimensional algorithm, based on the load hoisting and boom hoisting, was verified both by a simulation and actual tests. We are determined to develop control technologies, to further reduce the operator 's burden and improve the safety of work, by developing a three dimensional control with slewing operation, as an additional control target, and a closed loop control, in which swing angles and movements of the load are detected.

References

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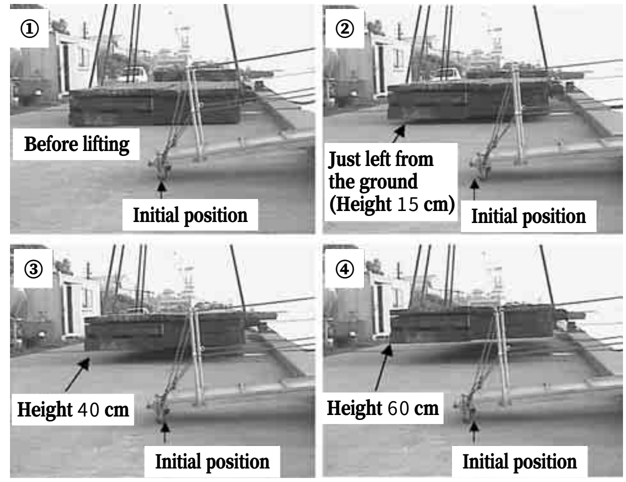

Photo 2 Experiment of vertical lifting

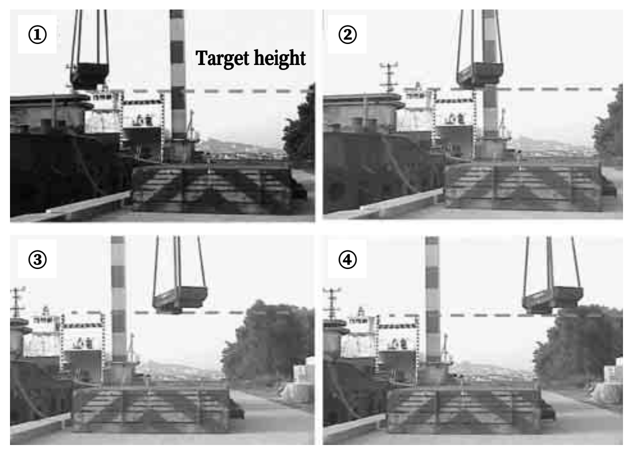

Photo 3 Experiment of level luffing