Automation of Ship-To-Shore Container Cranes: A Review of State-of-the-Art

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The paper gives the state-of-the-art of automation of ship-to-shore (STS) container cranes, as the biggest investments in the port terminal system. The automation techniques increase the productivity of the ship-to-shore container crane, and consequently increase the port terminal efficiency, as an integral part of logistic network. The paper also shows a short survey of some most important and recent researches in control of ship-to-shore cranes, and main principles of operation of antisway currently existing devices.

Keywords: *ship- to-shore container cranes, automation, control, antisway, efficiency, productivity*

1. INTRODUCTION

The competitive world economy, and the increasing performance expectations of customer lead to a demand for low cost, rapid and dependable shipping of cargo. The development of efficient, automated, high-technology loading/unloading equipment has the potential of considerably improving the performance of terminal operations. Advances in ship-to-shore (STS) container cranes technologies, as the major part and the biggest investment (capital costs for container cranes are 70 % of total costs in ports [1], of the cargo storage and retrieval system, have a significant effect on the efficiency of port terminal operations once properly implemented [2]. Today, any port wishing to be at the forefront of terminal operations and container handling should be able to reduce to a minimum the time that the ship is docked in the berth. The fact of assuring the shipping companies of having a port terminal with a high quality and a fast service of movement of cargo, by means of more and faster cranes, facilitates competitiveness by showing higher productivity [3]. The expansion of multimodal transport has led many ports (even smaller ports because generally 80 % of costs are independent of volume of cargo handled in container operations [1] to make capital investments in facilities, considering automated container handling systems. The purpose is to increase the speed and efficiency of handling containers. The transfer of cargo between ships and ground transportation remains an expensive and time-consuming activity. The need for faster loading is reflected in the current trend toward faster, higher-powered motors and better drives [4]. For the years many authors have been researching and developing ways to make STS cranes transfer containers faster and more safely through computerized anti-sway and automatic controls.

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The STS container crane presents for itself a complex system, but at the same time is a part (Elementary Sub System, ESS) of the port terminal system, Figure 1 [2].

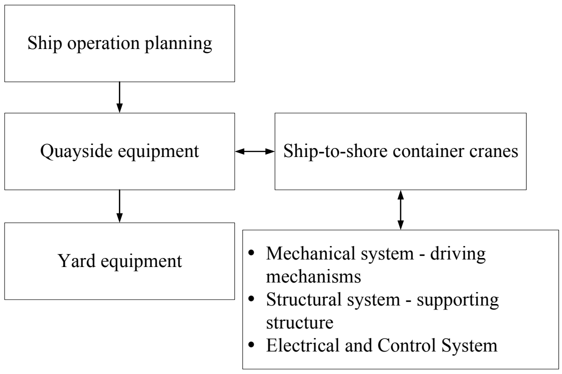

Figure 1. An outline of port terminal system

STS container crane productivity has always been one of the critical components of terminal productivity. But the crane is only one of the terminal elements that controls production. Within the next decade crane productivity may become the limiting component of the terminal production [6]. Increasing productivity is always desirable, but for large ships is necessary. Vessel turnaround time depends on [7]:

- Vessel and crane parameters;
- Operating parameters;
- Container yard performances.

It will take nearly four days to service a 12000 TEU ship exchanging 75% of its containers, using 6 assigned cranes producing 30 lifts an hour [5]. Increasing productivity to 55 lifts an hour cuts the turnaround time to a little less than two days. In Table 1 are presented some typical turnaround times for various vessels and crane lifts per hour [5]. Some improvements increase production incrementally, by 5-20%, and other improvements make a quantum jump, by 25-40%. This paper deals merely with the increasing of port terminal productivity, as a part of logistic network, due to automation of STS crane. Automation continues to evolve and will continue to improve productivity, although marginally to some other solutions that will not be discussed in this paper.

Table 1. Vessel Turnaround Time vs. Lifts per Hour

Vessel Size TEU	6,000	8,000	10,000	12,000
No. of Cranes	4.0	5.0	6.0	6.0
Lifts per Hour	Vessel Turnaround Time, Hours			
20	96	103	107	129
30	64	69	71	86
40	48	51	54	64
50	39	41	43	51
60	32	34	36	43
Parameters: 1.75 TEU per lift. Turnover 75%. Two eight hour shifts/day				

For simplicity, Ship-To-Shore cranes are usually discussed as an isolated entity (ESS), without regard to the yard capabilities. The STS crane production numbers are based on the assumption, unrealistic today, that the yard can keep up with the crane, i.e. assuming the quay operation is always able to deliver and remove a container when the crane needs to be serviced [5]. In most terminals, the actual productivity is between 65 and 80 percent of the computed number, and the crane numbers are calculated using simulation programs. Simulation programs often use random times for dwell times, and calculated times for travel times. Figure 2 presents an example of half-cycle timeline, but this is only a small portion of the simulated operation [5]. The timeline in Figure 2 presents the cycle time from the wharf to the inside the ship's hold. The hoist and trolley times are parallel and the dwell times are in series. The longer parallel times governs. The travel times vary, and depending on the location of the container the hoist or trolley time will govern [5].

Figure 2. An Example Half-Cycle Timeline

The productivity is usually discussed in terms of lifts per hour, i.e. frequency "*f*" [7, 8]. To better evaluate productivity, it should be given the inverse relationship, i.e. hours per lifts, or seconds per lift. This value is reciprocal to the frequency, and presents the period, $T = 1/f$. Although, this calculation is very simple, Table 2 presents the illustration of the difficulty in attempting to decrease period as the period decreases. Considering that dwell times, starting and stopping motions, finding spots on the vessel and quay, and checking clearances, whether automatically or manually, takes about 30 s, it can be seen that to achieve e.g. 40-second, only 10 seconds is available to actually move the load. Even a 48 seconds period leaves only 18 seconds to move the load. However, it should be noticed, this is nearly twice long as for the 40 seconds case [5].

Table 2. Frequency versus Period

Frequency: Lifts per Hour	30	45	60	75	90
Period: Seconds per Lift	120	80	60	48	40

More current STS cranes control systems depend on the skill of the operators to put the load in the right place, quickly and safely. Full crane automation, from ship to shore, may be the answer to greater crane speeds and productivity demands [9]. The higher operating speeds make, the control task more difficult [4]. This is difficult to achieve for several reasons: accuracy will be required to automatically pick a container from a ship, Figure 3 [10], and set it on a truck on the quay, Figure 4 [11]; the new container cranes have increasing degrees of automation that increase crane productivity [9]. The realization of automation for the cranes at container terminal has been delayed compared with indoor service cranes caused by various problems at the outdoors environment.

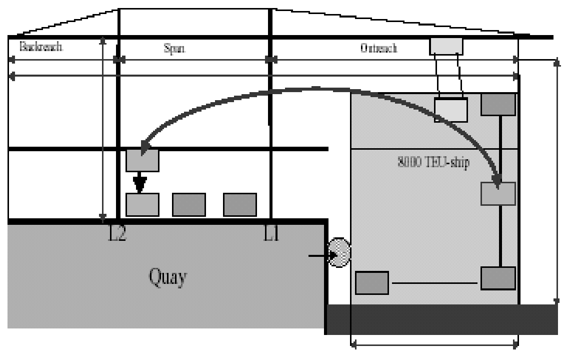

Figure 3. Schematical drawing of crane operation

For the Ship-To-Shore container handling crane, the main objection to achieving the full automation is that relative position of the ship to the crane could not be surely recognized due to the ship's rolling motion.

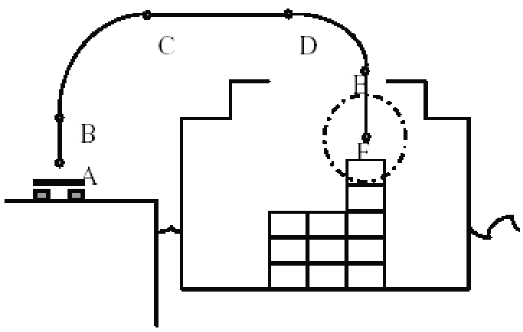

Figure 4. A "desired" trajectory of container

2. BASIC FACTS ON THE AUTOMATION OF STS CONTAINER CRANES

The fact that the STS cranes should be quicker, larger and more efficient force both the manufacturer and terminal operator to incorporate to the equipment some automation for the repetitive process of handling containers. Automation is also another important aspect of the container crane becoming a conglomerate of sophisticated elements of high added value consisting of specialized software and hardware [3]. Productivity is highly improved by automation because the crane operator sits in the cabin during long periods of time just looking down and moving containers from one side to the other, and the repetitive task becomes so routine that it produces discomfort and fatigue [3]. The result is also boredom that easily turns into the cause of accidents, thus including delays in the handling of loads. The basic common types of semi-automated and automated cranes are [12]:

- Cranes with Anti-Sway Systems;
- Cranes with Automatic Positioning Systems;
- Cranes with Automatic and Smart Spreaders.

2.1. Cranes with Anti-Sway Systems

The pressure on the port terminal by the shipping companies to release vessels as fast as possible is used by port operators to specify that the cranes shall be supplied with an antisway system. Antisway systems are now common in newer STS cranes and most specifications for container cranes around the world contain requirements for computer antisway [4]. These cranes are equipped with special control systems for killing sway. Most antisway systems can be installed without requiring major modifications of the crane. The behavior of the crane with antisway device is completely different from that the cranes without it or with the antisway system off [3]. An industrial computer reads the operator's speed and position commands from the control stick and sends appropriate modified commands to the motor drive to control sway while allowing the operator to maintain manual control. The computer measures the acceleration and deceleration of the trolley to match the pendulum period, so that the crane catches the load with no sway at the end of the move. Automatic moves to position the spreader are handled in a similar way. Antisway systems can be either feedforward or feedback, where feedforward means that no independent measurements of load sway are required. Such feedforward systems, by definition, cannot remove sway caused by external forces because the computer has no way of determining the magnitude or phase of the sway. However, such systems reliably limit sway to less than 15 centimeters [4]. For finer control, some methods of measuring the position and velocity of the spreader are required. But the pure feedback systems have not proven effective in practice [4]. Anti-sway devices are not without controversy. Most crane operators at commercial ports around the world are highly skilled and take great pride in their ability to work productively. Some types of anti-sway devices are disruptive to the crane operator in that the devices take control away from the crane operator, sometimes unexpectedly. In these cases the crane operator would be trying to make a move and the anti-sway device would kick in causing the load to move differently than the operator expected. The perception to the crane operator is that something is wrong with the crane controls. Trained operators usually switched the antisaway system off because they are more efficient when operating the crane without using it, but beginner operators prefer to use it. It is not uncommon for the anti-sway devices to be permanently disabled in order to satisfy the crane operator. It is possible that, given enough time and patience, the crane operator would become used to the feel of the anti-sway control system, because, even very skilled operators, when the task becomes routine for extended period of time, prefers to use antisway device, in order to relax from repetitive operations and therefore concentrate on other activities of the container handling tasks. The outline of the classification of existing quay cranes (three different types, according to [12], due to their degree of automation, is shown in Figure 5 [13].

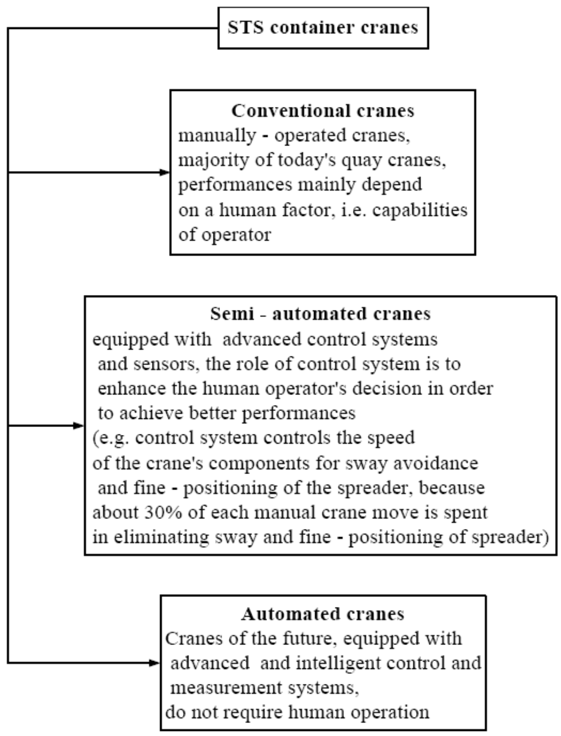

Figure 5. Classification of cranes by their degree of automation

2.2. Cranes with Automatic Positioning Systems (APS)

One of the main causes of delays during container loading/unloading is the positioning of the chassis so that container and chassis properly mate or the positioning of the container so that the flippers on the spreader bar can mate precisely. The current positioning technique involves the cooperation of the hostler or crane operator with human spotters who communicate with each other with hand and voice signals. A technology called automatic positioning systems (APS) has been introduced which minimizes this positioning difficulty [12]. Manufacturers Wagner and August Design have demonstrated systems that measure the relative position of chassis and container beneath cranes. Manufacturer Matson and others have used vision systems to position straddle carriers beneath cranes. The automatic positioning systems are equipped with sensors such as cameras and machine vision systems with specially designed software. In the August Design system, the machine vision processes the images provided by the cameras and locates the twist locks on the chassis. Using this information, a control signal is transmitted to the crane or hostler operator using either LED displays or other means of communication. The control signals transmitted provide the crane operator with information on how to move and do the alignment.

2.3. Cranes with automatic and smart spreaders

Another technique for reducing the positioning difficulty of the spreader bar is the so-called automatic spreader. Automatic spreaders are equipped with electro-hydraulic controls for automatic rotation of the twist locks by 90 degrees for locking the spreader into the container. The most advanced technology in this area is the Bromma Smart Spreader used for loading/unloading two twenty-foot containers simultaneously [12]. Seven sensors located at the center of the specially designed spreader are used to detect the existence of any gap between the containers. Using the information provided by the sensors, the spreader expands or retracts accordingly. Special attention is given for impact avoidance. The automatic positioning system automatically adjusts the length positioning of the spreader in the event of an impact. If a particularly hard impact causes the telescopic ends of the spreader to be pushed in or out, the spreader will automatically expand or retract to return the spreader to its original position.

3. BASIC PRINCIPLES OF ANTI-SWAY SYSTEMS OPERATION

Before analyzing the problem, further is presented a simplified description of the sway problem. A large STS container crane with Rope Towed Trolley system is presented in Figure 6 [14]. The first simplication of the trolley system is presented in Figure 7 [15]. For analyzing sway problem, a simplified crane model is often used, consisting of a weight suspended on a long string. This final simplification is presented in Figure 8 [16]. Such a system acts very much like a pure pendulum. This approximation is frequently used, although the period of container sway is not exactly accure. The exact expression for period of sway is presented in [17]. In a frictionless environment, once the weight is offset from the vertical, it will swing back to a point just as far on the other side and keep doing that forever. The length of time it takes for the weight to get back to the same position on every cycle is called the pendulum period. The period is dependent only on the length of the pendulum and has nothing to do with how much weight is attached. In the real world, there is always some air friction on the string and the weight, so the heavier the weight, the more it acts like a frictionless pendulum. If the weight is stationary and the top of the cable (called the fulcrum) starts to move, then sway also occurs. If the fulcrum now stops suddenly, then there will be residual sway. Unless there is significant friction or something else to stop it, it will keep swaying for a long time. With well-timed fulcrum movements, it is possible to reduce this residual sway but it takes time. When an actual crane is operated, the unavoidable movements of the trolley and the container lead to sway and the operator has to trade off speed and fine positioning with sway [12].

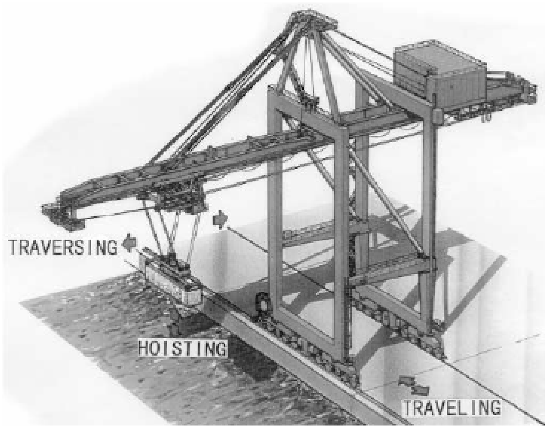

Figure 6. An outline of STS crane in operation

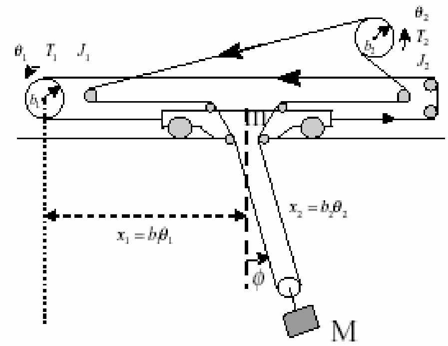

Figure 7. First simplification of trolley model

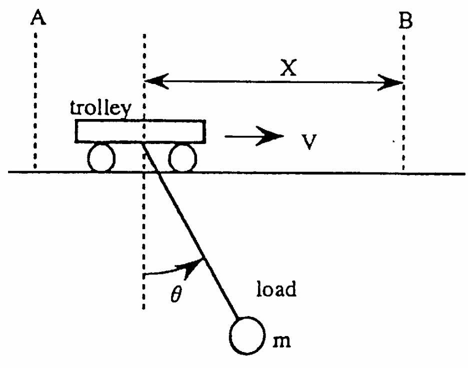

Figure 8. Final simplification of trolley model

The most existing STS container cranes use the simplest “bang – bang” control technique that will be discussed in further text. If the motion of the fulcrum is controlled properly, then the sway can be eliminated from the accelerations at both ends. In this case the fulcrum is first accelerated to half the speed and, one-half period later, it is accelerated to full speed, Figure 9 (the three lines, respectively from the top are: trolley speed reference, trolley speed reference via speed pattern system, and sway angle). If this is done precisely, then the weight will be hanging straight down below the fulcrum, Figure 10 [12]. Stopping sway is just the reverse procedure: slow to half speed and then wait one-half pendulum period before stopping. So, the acceleration is in two pulses, allowing the load to catch up with the trolley. The deceleration is also in two pulses, letting the load get first ahead of the trolley and then the trolley catches up with the load. The load is being lowered rapidly at the end of the move [12].

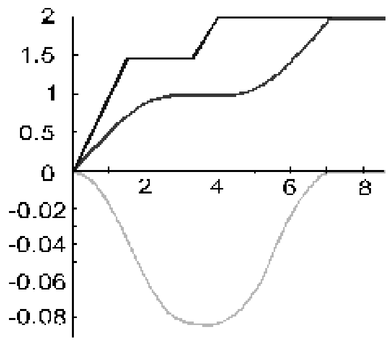

Figure 9. Speed reference pattern

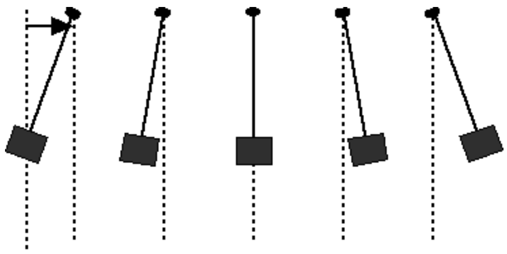

Figure 10. The bang-bang sway problem

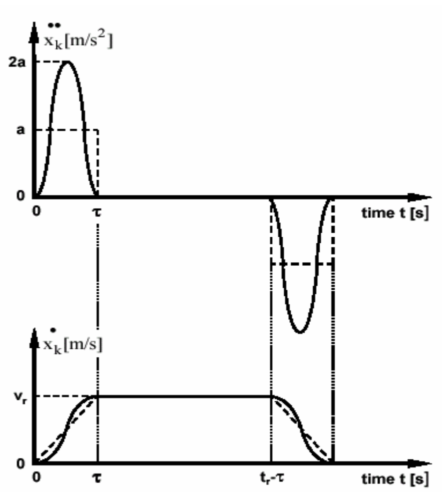

Figure 11. The modification of standard trapezoidal velocity pattern

However, an actual crane is not as simple as pendulum. The actual crane dynamics is highly nonlinear, and due to the effect of human operator quite unpredictable. This has three implications:

1. Due to the system nonlinearities and operator interference, the antisway system may not improve, and even in some cases worsen the crane performances;
2. In many cases the use of antisway systems has a negative effect on productivity, which lead the operators to switch the antisway off;
3. From a mathematical point of view, simple control strategies, as "bang – bang", may lead to instabilities or poor performance when applied to complicated nonlinear systems.

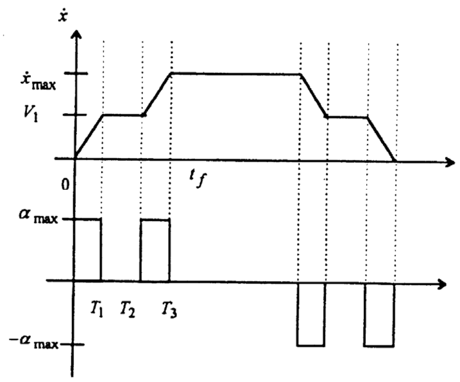

Figure 12. The stepped velocity pattern

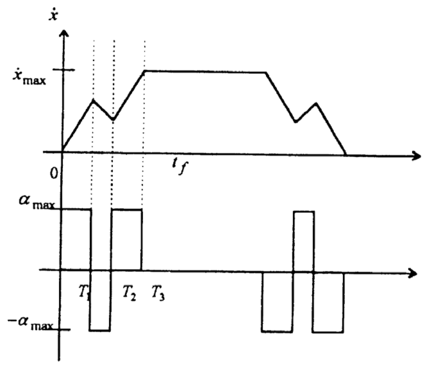

Figure 13. The notched velocity pattern

For mentioned reasons it is necessary to reshape the standard trapezoidal velocity pattern [13]. The traversing time of the trolley must be reduced as much as possible and the swing of the spreader must be stopped at the end point. For these requirements, usually the traversing interval is divided into three parts such as accelerating interval, the constant speed interval, and the decelerating interval [18]. The modification of trapezoidal velocity pattern is presented in Figure 11.

Table 3. Speed and acceleration performances of large STS container cranes

Mode	Speed	**Acceleration times**	**Deceleration times**
Hoisting with rated load	70 m/min	2,0 s	1,5 s
Hoisting with 40 t container	100 m/min	2,0 s	1,5 s
Hoisting with spreader only	180 m/min	4,0 s	3,0 s
Trolley drive	250 m/min	5,0 s	5,0 s

A comparison of most suitable velocity patterns is given in Figures, 12, and 13 [16, 19].

Finally, in the container terminals the requirement of faster cargo handling leads to higher speeds and higher accelerations in the motion of the crane. For example, some of these values for large container cranes are given in Table 3 [20].

4. A SHORT REVIEW OF STS CONTAINER CRANES CONTROL RESEARCHES

The basic scheme for the feedback control of STS crane systems and damping of vibrations (involving both payload and structure) is shown in Figure 14 [21, 22]

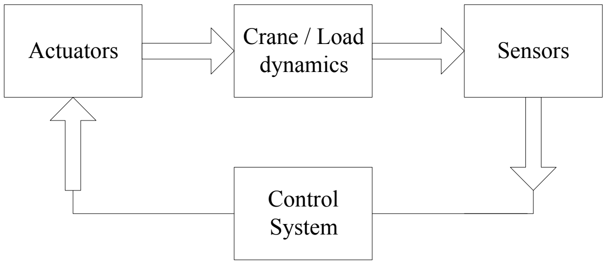

Figure 14. General feedback configuration for vibrations damping

It is worthwhile to mention some of the following basic researches in control of container cranes, not stringently in order of publication date. In [23], a dynamical model of a container crane was derived which is equipped with a hoist motor and a trolley drive motor. The considered problem was to transfer a container to the desired place as quickly as possible, since a large swing of the container load during the transfer is dangerous, while minimizing the swing of the container during transfer, as well as the swing at the end of the transfer. On the basis of dynamical model the optimal control of the motors was calculated. Several fundamental types of motion of the crane were specified; such their combination gives the efficient overall operation of the crane. They consist of vertical motion, horizontal motion, and diagonal motion. In vertical motion, the container, which is originally at rest, is hoisted vertically with the maximum torque up to some point, where it has the maximum upward velocity. In the horizontal motion the trolley runs at the maximum velocity, and the container runs at a constant height from the earth surface keeping the swing angle equal to zero. The diagonal motion connects the vertical motion with the horizontal motion. The time – optimal control of the vertical motion can be calculated easily. The problem was to calculate the optimal control of the diagonal motion, where the optimal trajectory should satisfy specified initial and terminal conditions. The dynamic model is derived by using Lagrange's equations. In [24], the minimum time transfer of a load, suspended from a trolley by ropes, from an initial point at rest to a terminal point where it is required to be at rest again, has been investigated by controlling both the traversing motion of the trolley and the hoisting motion of the load. Special care was given to the modeling of the mechanical and electrical features of the system. Mathematically, a boundary value problem with constraints both in the control and state variables has been given. Necessary and sufficient conditions for time optimal solutions are derived using an extension of the Pontryagin maximum principle. The nonlinear control problem was solved analytically. Minimum – time control was also considered in [25], where an approach was proposed that converts the control problem of crane, having simultaneous traverse and hoisting motion, into a finite dimensional problem via control parameterization with an appropriate basic function. Such approach simplifies the treatment of the constraints and allows for the easy satisfaction of the endpoint constraints. In [18], the crane system with two trolleys (Figure 15) was proposed and demonstrated for the experimental results. This is done for the reason to avoid the problem controlled by the separation of the traversing interval.

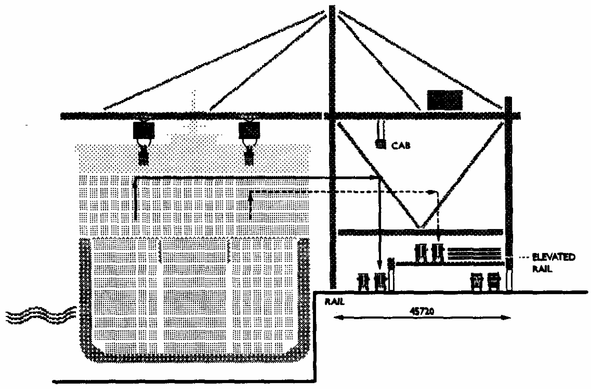

Figure 15. Crane system with double trolleys

In [26], a two-stage control of container cranes has been investigated. The first stage control is a modified time – optimal control with feedback for the purpose of fast trolley traveling. The second stage control is a nonlinear control for the quick suppression of the residual sway while lowering the container at the target trolley position. The secondary control combines the partial feedback linearization to account for the unknown nonlinearities as much as possible and the variable structure control to account for the unmodeled dynamics and disturbances. The nonlinear control is investigated from the perspective of controlling an underactuated mechanical systems. In [27], time – efficient feedforward controls of input shaping has been proposed in order to reduce the residual vibrations for container crane systems. Considering the change of rope length by the hoist, several versions of input shaping control have been evaluated and compared over a wide range of parameters. The proposed time – efficient input shapes for container cranes are more effective than conventional shapers in maneuver time and intensivity range. Also, the time – efficient input shapers relax the tradeoff relationship in maneuver time and insensitivity range. The proposed input shaping control for container cranes modelled as linear time – varying (LTV) systems does not yield exactly zero residual vibrations. When the change of rope length by the hoist is small, this method yields essentially zero residual vibrations. The cycle of the crane is divided into four paths, Figure 16.

The four paths are described separately for the purpose of facilitating understanding of the semi-automatic modes. In actual semi - automatic operation mode, the four paths are continuous and at times overlapping (AB-hoisting up, manual mode, BChoisting up and traveling of the trolley, auto mode, CD-traveling of the trolley, auto mode, DE-hoisting down, manual mode. In [28], a modified input shaping control methodology has been presented to restrict the swing angle of the payload within a specified value during the transfer as well to minimize the residual vibration at the end – point. The conventional method was enhanced by adding one more constraint to limit the transient sway angle within a specified value using the sway angle based on a linear time – invariant system. In [29] the numerical aspects of sensitivity analysis were presented for the problem of optimal control of container crane with a state constraint on the vertical velocity. The multiple shooting method has been used to determine a nominal solution satisfying first order necessary conditions. In [30], a constrained predictive control setup which considers an exponentially decaying rate bound on the control action has been applied to the feedback linearized model of a crane container, resulting in a stable motion with acceptable tracking performance. A fuzzy approach of the control problem has been applied in references [15, 16, 31, 32], also as the use of Genetic Algorithms in [21], but these, not often used, approaches would not be explained in this paper.

Structural control problems arise from the various dynamic problems. The basic outline of dynamics of quayside container cranes is shown in Figure 17 [20].

It is important to know that two basic structural phenomena in quayside crane dynamics, i.e. vertical vibrations of girder, due to the motion of trolley with load, and excessive sway of moment resistant gantry frame in the trolley travel direction are both the consequence of dynamic interaction between trolley, hanging load and crane's supporting structure [36]. These two problems are the most significant low frequency – large displacement dynamic problems with the entire quayside crane structure, and could be solved in practice by applying structural control to suppress vertical vibrations of girder and excessive sway of gantry frame. Further considerations of structural design for automation will be shown in Section 5 of this paper. The basic diagram of structural control problem is presented in Figure 18 [33], implemented to the problem of structural control of crane due to the moving load

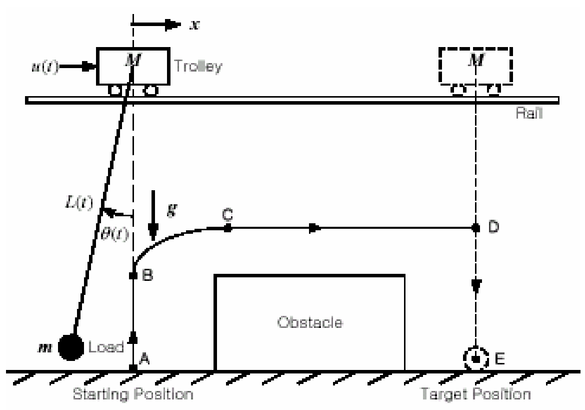

Figure 16. Path planning: Four stages of operation cycle

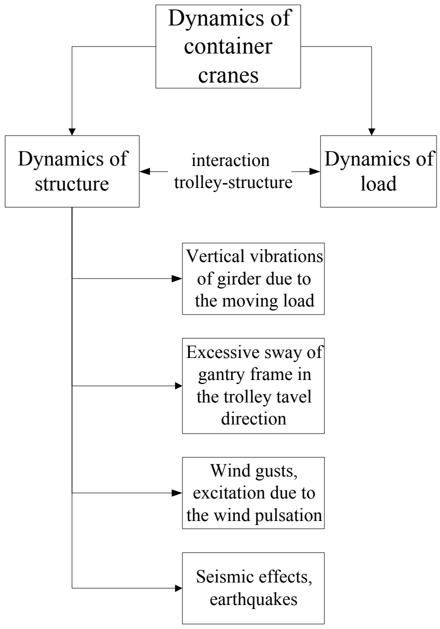

Figure 17. Basic outline of crane dynamics

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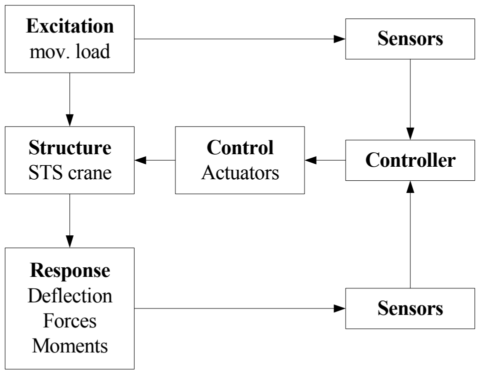

Figure 18. Block diagram of structural control problem

5. STRUCTURAL DESIGN FOR AUTOMATION

Full crane automation, from ship to shore, may be the answer to greater crane speeds and productivity demands. This is difficult to achieve for several reasons: accuracy will be required to automatically pick a container from a ship and set it on a truck on the quay; the new container cranes have increasing degrees of automation that increase crane productivity. For automation to operate correctly, the location of all system components must be known. For fixed object, this is an easy task [34]. For moving objects, such as the crane structure flexing with the movement of the trolley, the task becomes more difficult. One approach is to require a very stiff structure with strict deflection limits. A stiff structure helps with load control and provides an easier ride for the operator. A detailed structural design process is required to minimize the weight and optimize the geometry and sections. The alternative is to account for crane movement in the load control system design and not specify deflection limits. This requires more complex software, but will result in a lighter crane structure. The rigid structure of a crane is presented in

Figure 19 [35]. This structure provides deflection limits in all three directions at the outreach. The deflections and major members that contribute to those deflections are tabulated in Table 4, according to data given in [34]

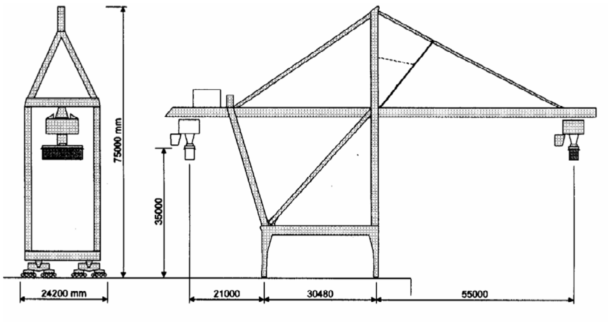

Figure 19. Rigid structure mega crane by Mitsubishi Heavy Industries

Table 4. Deflection requirements for a rigid STS container crane

Direction	Calculated deflection	Contributing effects on members
Perpendicular to gantry rails	4 mm	Stretch of the backstay Bending of the portal frame
Vertical	128 mm	Elongation of the forestay Stretch of the backstay
Parallel to gantry rails	49 mm	Rotational stiffness of the crane Stiffness of the boom

To be super productive, sway (list) and yaw (skew) need to be controlled, where sway is swinging in the direction of trolley travel, and yaw is rotation about the vertical axis [36]. Micro motions of container (possible) are shown in Figure 20 [37].

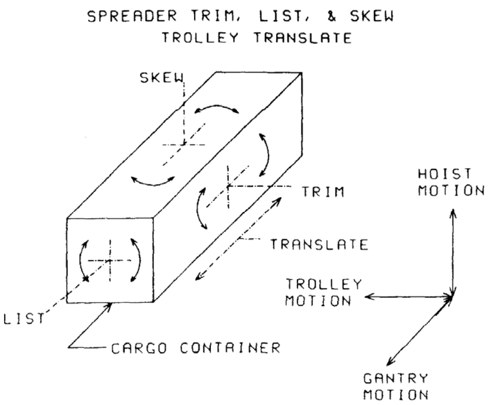

Figure 20. Possible micro-motions of container

Sway and yaw may be controlled by using rigid reeving. Trolley motions may be controlled automatically by an electronic anti-sway system, manually by the crane operator, or by a combination of both. When semi and fully automatic crane operation is achieved, which will happen during the next years, automatic sway control will be required. If sway control is manual, the rigid reeving is desirable. For rigid reeving the main falls should be inclined. But, if sway control is automatic, the falls should be nearly vertical, Figure 21 [11].

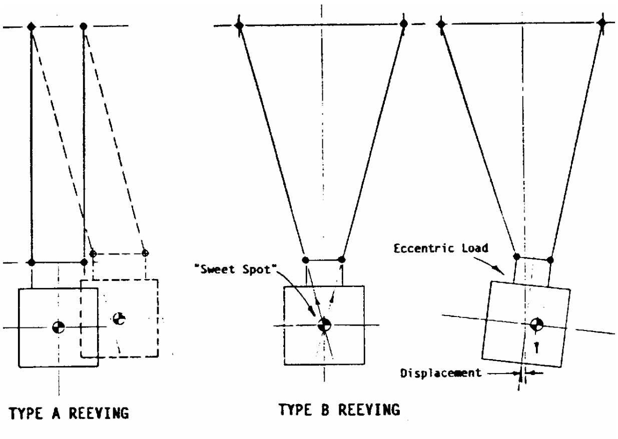

Figure 21. Types of reeving

For rigid reeving the swing period depends on the spring stiffness of the reeving and tributary mass. When load is eccentric, the effective mass is not the same at both ends of the container, but the stiffness of the falls is the same, so the swinging period is different at each end, and the load tends to yaw. For vertical falls, the period depends only on the length of the falls. The difference in mass at each end does not affect the period, the load does not yaw and trolley motion alone can eliminate sway. Containers tend to yaw on rigid reeving and swing on flexible falls. So the reeving that is best for manual control (Figure 22) is not suitable for automatic control, and visa versa [22]. A new problem has developed for load control on Post-Panamax cranes with vertical falls. The dynamic interaction between the frame, the trolley, and the load can be problematic, Figure 23 [22]. If the natural period of the frames is one half the period of the hanging load, the motion of the trolley that is expected to control swat will instead excite the frame. The frame period depends on the mass and stiffness of the frame. For vertical falls, the natural period of the hanging load is about 5 or 6 seconds. For inclined falls the period is less. For typical Panamax cranes, designed for moderate stowed winds, the natural period of the frame in the trolley travel direction is about 1.5 seconds, and dynamic resonance is not the problem.

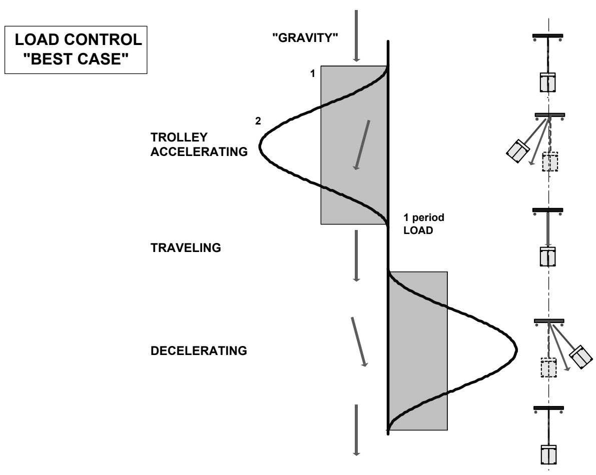

Figure 22. The "best" case of load control

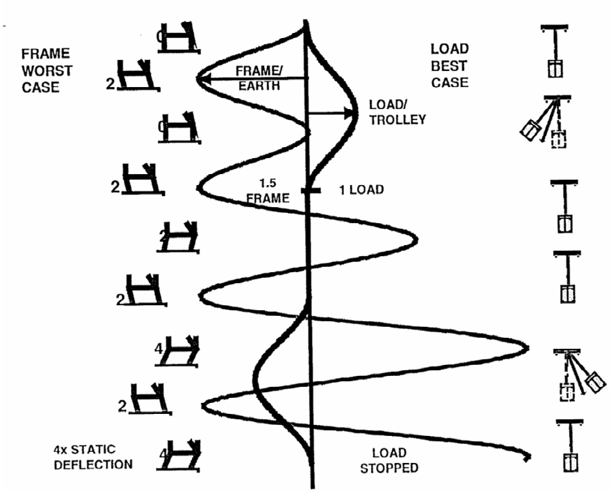

Figure 23. Dynamic interaction load - structure

For Post-Panamax cranes the mass is significantly increased, especially at the trolley level, and stiffness is reduced because the portal height is increased. The frame period is increased to about 2.5 or 3 seconds. So, the ratio of frame period to the load period is about one-half, the worst case. When the operator or computer attempts to control swing, the trolley acceleration forces excite the frame instead of controlling the load. This effect can be reduced by changing the controls. But the best solution is to design a crane to avoid the undesirable ratio. The natural period of the frame in the trolley travel direction should be about 1,5 seconds or less. This can be economically achieved by increasing the depth of the legs and the portal tie [36], or by portal frame stiffening, Figures 24 and 25 [20, 22].

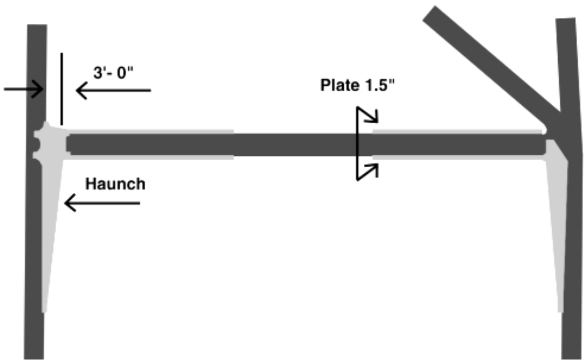

Figure 24. Portal frame stiffening

Figure 25. Temporary stiffening for decreasing period

6. CONCLUSION

The construction industry is relatively still slow in implementing advanced technology to improve safety. Current practice requires that control of the Ship-to-Shore container cranes' dynamic behavior is the responsibility of a skilled operator. The operator applies corrective measures based on experience when any undesirable swaying is detected. The absence of automated sensing and control not only leave room for accidents arising because of human error and/or delayed response of the operator, but also can greatly reduce the productivity of the cranes' operation, also as the productivity of a whole port terminal representing a complex system whose most important and most expensive part is a Ship-to-Shore container crane. There is also a potential danger of an exaggerated response, which will lead to an uncontrollable load swing. The biggest source of dynamic forces is the pendulum motion of the loaded spreader suspended by cables. In future port terminal flexible transportation systems (like in flexible manufacturing systems [39], material handling devices, specially Ship-to-Shore container cranes, should also be automated by computer control (much like machine tools). Container loading automation investments will continue to increase efficiency of ports supplemented by improved infrastructure for storing and transferring containers on the landside. Precise control of the spreader and load is only possible by using mathematically correct algorithms and properly implemented sensor systems. We can expect some other more sophisticated control solutions in future researches. The main utility of this paper is to show a short survey of researches in control strategies of Ship-to-Shore container cranes and to present the state-of-the-art of quay cranes automation.

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АУТОМАТИЗАЦИЈА ОБАЛСКИХ КОНТЕЈНЕРСКИХ ДИЗАЛИЦА: ПРЕГЛЕД ДОСТИГНУТОГ СТЕПЕНА РАЗВОЈА

Ненад Зрнић, Зоран Петковић, Срђан Бошњак

У раду је приказан преглед достигнутог степена развоја и истраживања у области аутоматизације обалских контејнерских дизалица. Применом различитих техника аутоматизације повећава се продуктивност обалских контејнерских дизалица, а следствено томе се повећава и ефикасност лучких терминала као интегралног дела логистичке мреже. У раду је, такође, приказан преглед неких најзначајних публикованих истраживања из области управљања код контејнерских дизалица, а дати су и принципи рада тренутно постојећих уређаја за умиривање осциловања терета – контејнера.