MOKSLAS – LIETUVOS ATEITIS
SCIENCE – FUTURE OF LITHUANIA
ISSN 2029-2341 / eISSN 2029-2252
http://www.mla.vgtu.lt

MECHANIKA, MEDŽIAGŲ INŽINERIJA IR PRAMONĖS INŽINERIJA
MECHANICS, MATERIAL SCIENCE AND INDUSTRIAL ENGINEERING

2015 7(6): 642–648

http://dx.doi.org/10.3846/mla.2015.884

OVERVIEW OF CRANE CONTROL SYSTEMS AND THE RELATED PROBLEMS: ANALYSIS OF CONTAINER OSCILLATION USING DIFFERENT TYPES OF CARGOES

Tomas EGLYNAS[1], Marijonas BOGDEVIČIUS[2], Arūnas ANDZIULIS[3], Tomas LENKAUSKAS[4]

[1, 2]Vilnius Gediminas Technical University, Vilnius, Lithuania
[1, 3, 4]Klaipėda University, Klaipėda, Lithuania
E-mails: [1]tmse@inbox.lt; [2]marijonas.bogdevicius@vgtu.lt;
[3]arunas.iik.ku@gmail.com; [4]tomas.lenkauskas@gmail.com

Abstract. Growing international trading increased cargo transportation in containers, therefore the port cranes have higher loads. Increased cargo flows can influence transportation safety. It is therefore necessary to review the crane systems and determine what factors might influence the volatility of the container and its cargo during transportation. The paper includes consideration and analysis of crane control systems and related problems. The authors consider the reasons of problems, probable damage and solution methods. The paper also provides the analysis of the relationship between different container cargoes and container oscillations occurring during handling operations using a container crane prototype. The analysis of the effect of different cargoes in containers on loading process and the results of occurring oscillations are presented.

Keywords: container crane, loading process, container oscillations, experimental analysis, control systems, manual control, prototype.

Introduction

As international trading increases, cargo transportation by sea containers is increasing markedly as well (Aulanko, Tervo 2010; Yoshida, Tsuzuki 2006; Kaneshige *et al.* 2014; Nenad *et al.* 2006; Vukosavljev, Broucke 2014; Port of Klaipėda 2014). Statistics show that container cargo traffic grows by 6 percent per year. Container traffic increases every year, and in Klaipėda port container traffic in 2014 has increased by 11 percent (Port of Klaipėda 2014). Seeing that the flows of freight transportation increase constantly, it is important to perform freightage efficiently and fast at all stages. One of them – the cargo is transfered from the ship to the ground using container cranes.

In a manual management of a crane, because of lack of experience, inappropriate speed is selected often, there for the volatility occurs which may damage cargo and pose a threat to the safety of staff and equipment. Mismanagement caused oscillations also slow down the turnaround process (Yoshida, Tsuzuki 2006; Vukosavljev, Broucke 2014; Bruins 2010). The vessels have to stay longer in port, cranes move the smaller quantities of containers, all of which increase the cost of container transportation. In order to transport the container, make the process safer, faster and reduce costs, the process of the transportation must be upgraded. This can be achieved with container cranes by integrating adaptive speed control system. In order to create an effective system for unloading of ships, attention should be payed to the containers and the goods. Different cargo (liquid, solid, free-flowing) can cause different type of oscillations, in order to reduce these oscillations it is required to attribute the different speed control parameters for each type of cargo. For this purpose an adaptive speed control system is created, which would adapt the different cargo to its most efficient transfer speed. Using of this system may help to modernize container crane operations and thus it would be a major step toward the full automation of port container cranes.

Related works

Cranes are widely used in various situations, which include moving heavy loads from one point to another, they are used where most technologies do not work. Cranes have been used widely in the industry for a long time, because of their ability to handle large and heavy cargo loads in a short period of time, which makes it possible to increase transportation flows. Some of the most relevant sites of crane using are the port terminals. The freight flow capacity in the seaport depends on the container crane productivity.

The rapid development of container handling terminals and in particular of the shore cranes, the time required to load and unload container ships has been reduced to a few hours. However, although the rate of cargo handling has increased, there are still many problems which prevent the achievement of the desired results. Though container cranes (Fig. 1) nowadays are able to cope with the huge cargo flows, it is not always enough to have them. Each year the amount of cargo increases and it is required to tackle the problems in the transportation areas in order to eliminate deffects, optimize productivity and increase security.

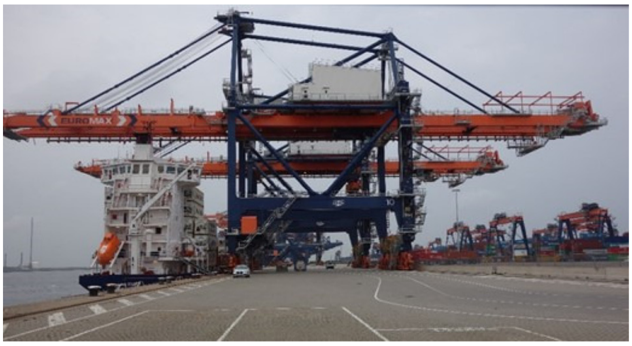

Fig. 1. Container crane in port of Rotherdam

Scientists Nenad *et al.* in their work noted that the biggest problems are container spreader oscillations, shifting and precise spreader positioning under those swings. Oscillations can harm the dynamic interaction between the trolley and the crane structure. Crane can be deformed, which can result in a hazardous situation and lead to additional losses. This reduction can be achieved through difficult testing mathematical models of the container, and proper management system (Nenad *et al.* 2006). The main reasons resulting in variations: if there is a strong wind (poor weather conditions), when a container is transfered, the wind can swing it; when there are sudden movements at the beginning and end stop of transfer – container starts to swing because of inertia. The paper also mentioned the importance of the relationship between train bogie frame and the crane, because it affects the vibrations of the crane, and the best type of construction is when the trolley remains the center of gravity.

Scientists Kaneshige, Kawasaki, Ueki, Miyoshi, and Terashima dealt with the transportation of container filled with liquid. Work was going in poor conditions (Kaneshige *et al.* 2014). The first problem may be caused by the movement of the liquid in the container. When transporting cargo container, moving liquid causes additional forces acting on what influences the emergence of additional volatility. The second problem occurs only in certain cases, when weather conditions reduce visibility, or if the crane is in a harsh work environment, such as metal casting factory, and the crane operator has to work at high heat.

Scientists Kuo and Kang (2014) proposed a simple method of managing container swinging problem. Crane speed settings were regulated in the transportation process by making changes in the three stages: acceleration, traveling at constant speed and braking. The aim was to choose the fastest container transportation, with minimal variations. The researchers proposed three speed control methods. In the first method the transport container had to be transported in fastest possible time, while maintaining a minimum fluctuation during driving. This is achieved by a gradual acceleration of the trolley at certain intervals, depending on the oscillations. The container ranging to the opposite direction of the direction of motion of the trolley is maintained at a constant speed for a while, and after moving at the same direction it accelerates. Thus when the container reaches the maximum speed the minimal oscillations are obtained. When the trolley comes to a halt, the reverse process starts off, the acceleration is reduced when the container swingss to the opposite direction than the moving trolley, and the constant speed is maintained when it moves in the same direction. The second method sought ways to transport a container with minimal oscillations throughout the process and the abscence of oscillations at the end point. In this case, the container speed increased at lower acceleration values and achieved a lower maximum speed. Container moves at a constant speed for a longer period of time. The third container was transported in shortest time. Acceleration is gradual until the container reaches halfway of the road, and after that gradual reduction of trolley speed begins. The result is minimal container transportation time, with minimal variations in the end, but the transportation process involves large container oscillations. This system works well because one may change the settings easily and it is possible to adapt them to the cranes of different sizes. Also, using this system, container transportation is much quicker and has more advantage compared to other systems, where transportation distances are long.

After analysis of related works we have noticed that in these days it is important to explore the cranes used in the container handling process. Fully automated terminals already exist, the main problem remains the transfer of containers between ship and shore. Due to difficult conditions in which there are the container oscillations, operator must control the process of loading in the areas. One of the easier realized managing methods for handling of oscillations is to change an acceleration in transportation process, it is effective at the longer distances of the transfer, such as using port cranes. Scientists Kaneshige *et al.* (2014) in their work argued that different load and their oscillations influence transported ontainers, and proposed a system to manage liquid cargo transportation, taking into account the additional costs because of oscillations. Therefore we may suggest that different types of cargo may influence the transportation process.

The next section describes the existing problematic areas and presents the technical equipment used for the experiment.

Developed prototype and vision of solution

Cranes and the related problems. After analyzing the literature, it was observed that the main problem for moving the containers from ship to shore is the variations in the container. The problems emerge due to different causes. One of the main reasons still remains the human factor. In the process of the crane's manual operation when there is an improper selection of start-up and braking speed, the container begins to oscillate, each time during the the container decreases crane productivity, operator has to wait until the load stabilizes and he shall be able to lower the load to a designated location. It was also noted that the oscillations are caused by bad weather conditions. In high winds the container can swing. These oscillations are dangerous and can arise unexpectedly. Different cargo (liquid bulk, solid) affects from inside the container, thus changing the fluctuation dynamics. Currently this problem is investigated not good enough. We study swings in our work and we will create a system that could reduce them. Container crane problems are shown in Figure 2.

To stabilize the container handling process, it is necessary to create adaptive speed control system to adapt to different types of container loads, each of them applying the optimal algorithm. The proposed container management system for controlling container handling speed is shown in Figure 3. Here is shown how an operator selects type of container cargo and sends data into the controller. The controller processes received data and selects the most suitable speed control settings. The following control signal is sent to the motor, which moves the rotating trolleys and is dependent on precise positioning and transporting the cargo to its proper place. After container transportation, accelerometer measure oscillations. When oscillations finish, signal is sent to the controller, which compares it with the selected limit time and changes the settings for more accurate results. This system minimizes the variations in different types of cargo in order to speed up the transportation of containers. Also parameters are constantly refreshed to obtain the best result for each type of load.

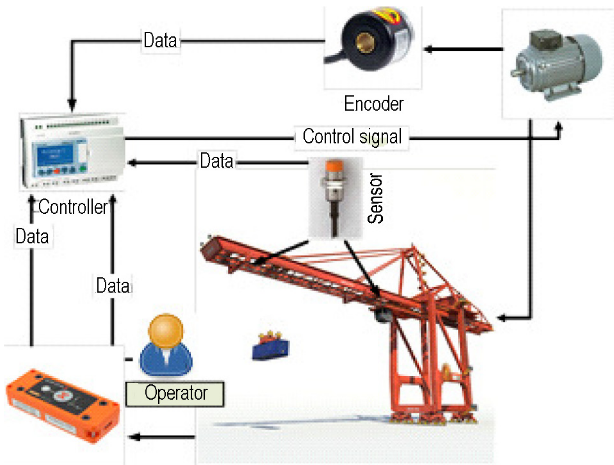

Fig. 3. Container management system for controlling container handling speed

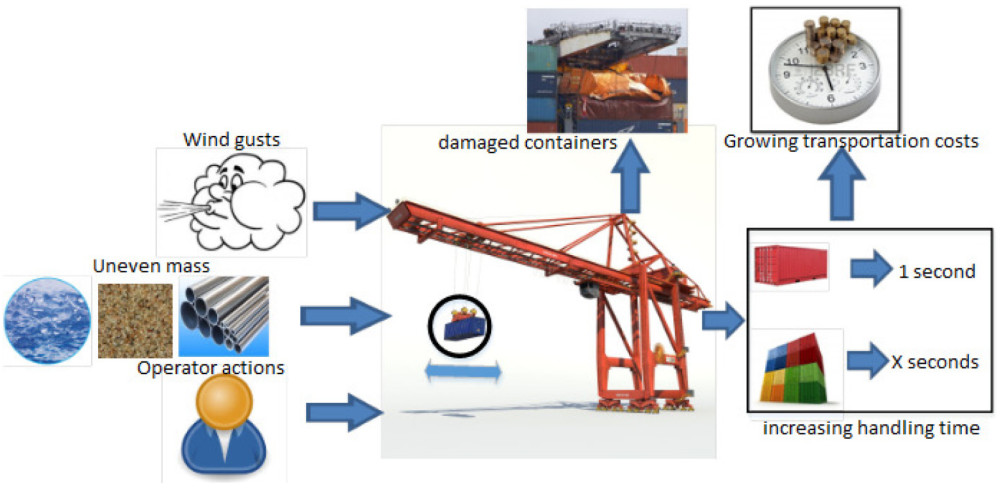

Fig. 2. Problematic areas of crane container handling process

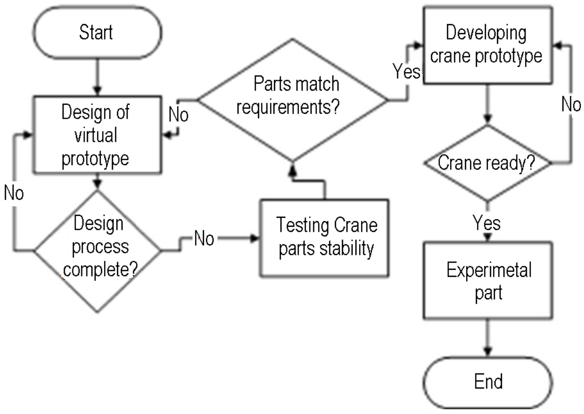

Fig. 4. Design stages for crane prototype

Prototype design. Crane prototype designing consisted of a number of key stages: virtual prototype, virtual prototype parts' durability simulation and manufacture of crane model (Fig. 4). Each stage is especially important in producing high-quality, well-functioning crane. Using of graphic programs allows to to create an accurate vision of the crane. Also, all of the currently developing complex industrial designs are tested with the use of virtual simulation programs in order to save time and money, which help to find the possible defects (Aulanko, Tervo 2010). This makes production process much simpler. To test the container crane management system and verify its effectiveness crane prototype was developed. In order to save time and finances it was implemented in a virtual environment (Fig. 5), using the selected SolidWorks software.

Design crane prototype in *SolidWorks* environment is visible in the Figure 5. The measurements were chosen which would match to the future prototype in the process of design, and the details have been drawn according to the available resources in order to recreate them in a real prototype. When creating a virtual sketch we discovered all the potential errors that would prevent the crane to operate in the real prototype and corrected them, also we learned how much material will be required for its manufacture. Finally, to make sure that everything works properly we made simulations of components durability in order to avoid accidents during testing. In order to design a functioning system, it is required to design its virtual system at first and only after the testing and analysis it is possible to produce the real system components. As this is the creative work we need to have sequence of steps for faster and smoother work. In this case, the sequence of steps necessary for working is in *SolidWorks* software environment. Container handling process simulation action sequence can be divided into two parts: the virtual design and simulation of action sequences. First of all, we have made the reduced model of quay crane using the virtual design activity sequence presented (Fig. 6).

The real prototype has been created 10 times smaller than the real port crane. To get accurate results, the crane structure is as similar as possible. For real prototype manufacturing wide variety of metal products, bearings, screws, cables, etc. was used. The main components that make up the crane: rails, trolley, chuck, engine, transmission, and tensioning part. In Figure 7 number "1" marks container spreader. It is connected with carts on four cables, thus maintaining greater stability in the loading process. To lift or to lower the gripper, the drum is operated by an engine in the motor box. To it the accelerometer shall be attached which shall measure the oscillations which happen in the transfer of containers. The number "2" in Figure marks the tension part which is attached to the container track. It is designed to maintain the tension of the cables to ensure that all parts move properly and are not loose. The 4 cables are attached in the tension part for the lifting of gripper, and 2 cables are intended for trolley movement. Number "3" in the next part of the picture shows a trolley for container spreader movement from one point to another. This part is fixed to the rails to move freely, it is manipulated with the motor which turns the drum in the motor box. Crane rails

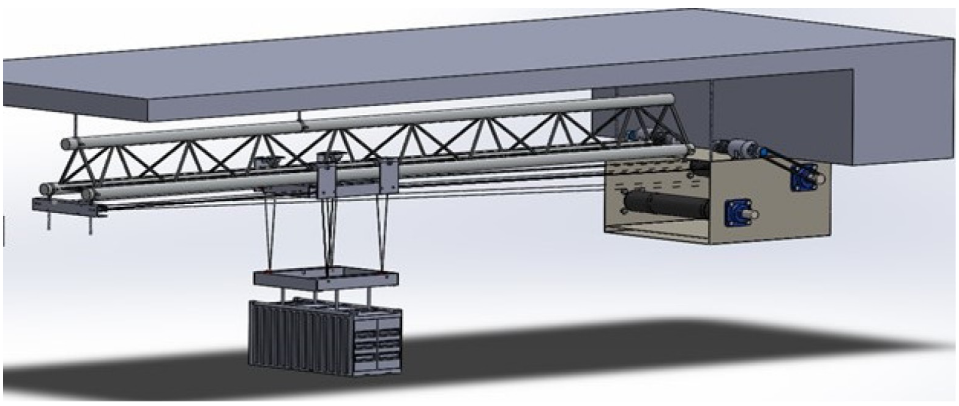

Fig. 5. Virtual prototype of container crane

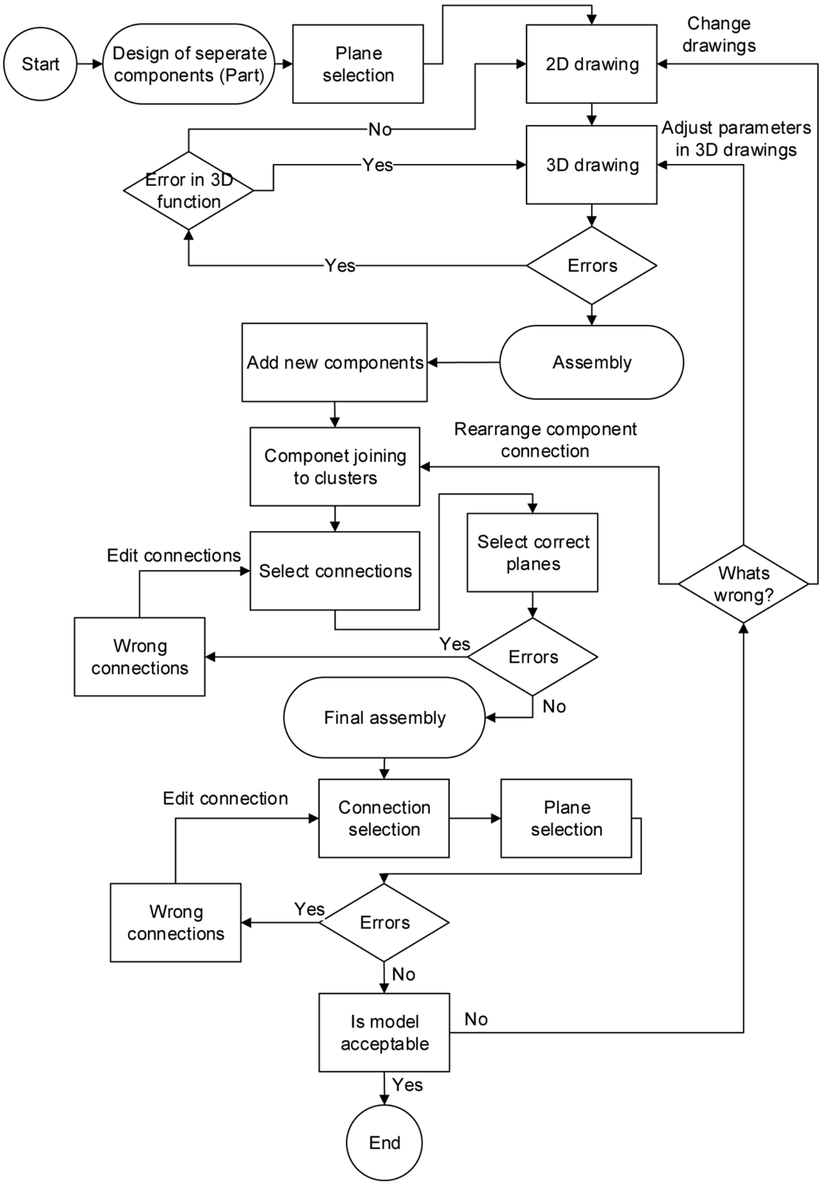

Fig. 6. Container crane virtual prototyping process

are marked in the picture with number "4", it shows the conteiner's trolley movement forward and backward. On the front and rear of track the magnetic sensors are located, which enable to locate trolley when it loses its position and stop automatically it at the start and end positions. Number

Fig. 7. Small-scale container crane

"5" indicates power transmission, which moves all major container crane components. It contains DC motors for moving the trolley and gripper, and the controller intended for engines control.

Experiment equipment. The system development process requires use of an accelerometer, which helps to measure variations in load transport processes and the results obtained will allow to create the new algorithms. For this task Slam Stick X data logger (Fig. 8) was selected, which

Fig. 8. Data logger "Slam Stick X"

is capable of measuring vibrations in all three axes, also, it measures temperature and pressure. Device capacity is 2 gigabytes, battery life – up to 10 hours. The accelerometer was chosen for a good user interface.

Experiment and results

To find out the influence of different cargo on the handling process, some tests were carried out using a prototype created, mimicking manual operation. The four most common situations of cargo in the container were selected: Solid; Liquid – the water was used; Bulk – the sand was used; Empty. During the tests the container was already connected to the spreader and raised. The length of the cables between the trolley and the gripper was of 0.75 m, and the distance the load moves from point A to point B was equal to 2 m. Speed at which the trolley moves is 0.25 m/s. During the experiment no other environmental factors can affect the operation of crane (Fig. 7). The first experiment was carried out with an empty container (25 kg). After the test large oscillations were observed, as presented in Figure 9, and the results were grouped into 4 stages. In the first stage, we see oscillations encountered in the container which is set in motion and they caused excessive initial speed. When container moves from the start point to the end point (2) the oscillations happen because of sharp movement and they increase slightly, then they start to decrease. After reaching the final point (3) the container is stopped because of inertia caused by movement, the oscillations reach the maximum amplitude because of sharp stop – 0.098 g. At this point the oscillations appear which last 39 seconds.

In further successive experiments the results were compared with the first attempt on an empty container. To spot the differences, raising various loads, tests were carried out with containers filled with wooden pads (solid cargo), water and sand. Simulated trials were identical to the situation as in the first experiment.

During the test, the container was filled with wooden pads, which portrays a hard type of cargo. The container

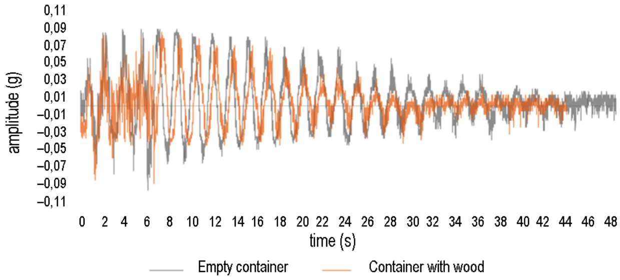

Fig. 10. Container with wood and empty container motion comparison

weight – 35 kg. The results are compared with the results of an empty container. After the test it was noted that in the container with timber oscillations were shortest of all, they lasted only for 27 seconds. Maximum acceleration due to gravity relative to the ground during braking was 0.089 g. Comparing the amplitude ofoscillations in the start-up, it is identical, reaches 0.06 g, but when the container moves from one point to another, swings are quickly reduced to 0.05 g, when the container stops both containers› values are almost equal, and a striking difference is observed in the beginning of suppressive oscillations. Due to the higher weight and stable cargo container with wooden pads completely stops much faster than the empty one. Through the entire period the oscillations decrease gradually (Fig. 10).

During the test the container was filled with water, so we had a liquid-filled container, the weight of cargo was 35 kg. These results are compared with an empty container oscillations in results (Fig. 11).

Comparing the results we have noticed that the suppressive oscillations of the container with water lasted even for 42 seconds. The biggest free fall acceleration earth-wise was obtained at the stop point in the final position of the container, as well as in all other stests, in this case it was equal to 0.093 g. Amplitude of oscillations, compared with an empty container, is released during the transfer of conteiner. Although at the beginning the oscillations were identical, but it is observed that when the container moves to the final point, the oscillations become uneven, the cargo

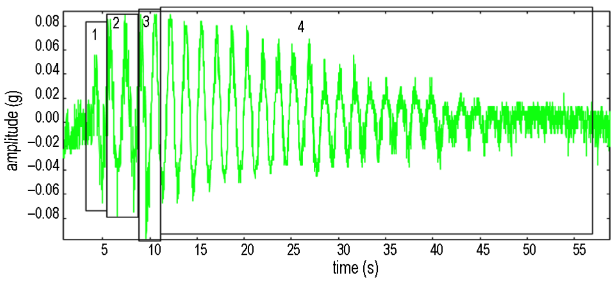

Fig. 9. Manually operated crane with empty container accelerations

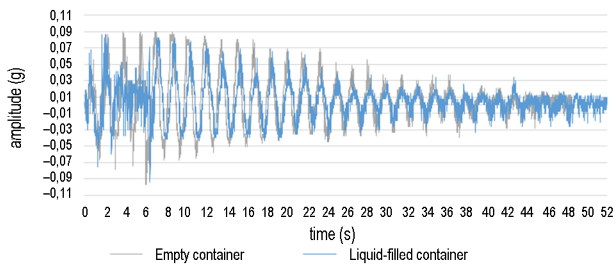

Fig. 11. Container with sand and empty container motion comparison

moves unstable with vibration, until value of 0.05 g, while in an empty container even oscillations are visible equivalent to 0.09 g. This tendency is visible as well when the load stops, although amplitude of oscillations is decreasing gradually. At first the oscillations of container with water decrease faster, but the time of stopping is longer when compared to the empty container. This happens because of internal water oscillations in the container. Container stops harder, therefore in the end the long period of time is seen when the oscillations of the container are small, but container doesn›t stop completely (Fig. 11).

Table 1. Experiment results

	Oscillations, s	Maximum accelerations, g
Empty	39	0.098
Wood	27	0.089
Water	42	0.093

Conclusions

After the experiment the results were analyzed and it was discovered that during the manual management of container the huge oscillations happen, and the oscillation amplitude decreases for a long time. During the experiment it was found that oscillations are caused by a rapid start-up and heavy braking. Therefore, to avoid this issue, it is necessary to move the container from a position gradually increasing speed, as well as to stop by gradually slowing down. This requires the use of prior work proposed in the system and adapting it to the speed control system. The experiment was also seen in different variations, different transport containers filled with cargo were investigated. Therefore, it can be said that in the container handling process the different types of cargo influence the variations. Summary of the experimental results are presented in Table 1. From the results, we note that the maximum amplitudes of the oscillations were similar and significant differences could not be seen. However, if we look at the duration of each of the containers' oscillations, we see that the time varies considerably. The longest oscillations were found in the water container, followed by an empty container, then sand and wood. The reason why this happens is shown in the charts in which each type of load is reflected in different ways. In order to effectively reduce these parameters it is required to adapt different algorithm to each type of load. An experiment shows that the application of automatic control systems or assistance control system for the crane is necessary in order to ensure higher transport process safety and greater productivity.

References

Aulanko, S.; Tervo, K. 2010. Modeling and analysis of harbor crane work efficiency using work cycle recognition, in *2010 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 6–9 July 2010, Montreal, Canada. IEEE, 61–66. http://dx.doi.org/10.1109/AIM.2010.5695907

Bruins, S. 2010. Comparison of different control algorithms for a gantry crane system, *Intelligent Control and Automation* 1(2): 68–81. http://dx.doi.org/10.4236/ica.2010.12008

Yoshida, Y.; Tsuzuki, K. 2006. Visual tracking and control of a moving overhead crane load, in *9th IEEE International Workshop on Advanced Motion Control,* 27–29 March 2006, Istanbul, Turkey. IEEE, 630–635. http://dx.doi.org/10.1109/amc.2006.1631733

Kaneshige, A.; Kawasaki, Y.; Ueki, S.; Miyoshi, T., *et al.* 2014. A design of the tele-operation control system for liquid container transfer by an overhead traveling crane, in *2014 11th International Conference on Remote Engineering and Virtual Instrumentation (REV)*, 26–28 February 2014, Porto, Portugal. IEEE, 29–30. http://dx.doi.org/10.1109/REV.2014.6784179

Kuo, T.-Y. T.; Kang, S.-C. J. 2014. Control of fast crane operation, *Automation in Construction* 42: 25–35 [online], [cited 4 February 2016]. Available from Internet: http://www.sciencedirect.com/science/article/pii/S0926580514000284 http://dx.doi.org/10.1016/j.autcon.2014.02.003

Nenad, Z.; Oguamanam, D.; Bošnjak, S. 2006. Dynamics and modelling of mega quayside container cranes, *FME Transactions* 34: 193–198.

Port of Klaipėda. 2014. *Ten records achieved in Klaipeda Seaport in 2014* [online], [cited 4 February 2016]. Available from Internet: http://www.portofklaipeda.lt/news/651/569/

Vukosavljev, M.; Broucke, M. E. 2014. Control of a gantry crane: a reach control approach, in *53rd IEEE Conference on Decision and Control*, 15–17 December 2014, Los Angeles, CA. IEEE, 3609–3614. http://dx.doi.org/10.1109/CDC.2014.7039950

KONTEINERINIO KRANO VALDYMO SISTEMŲ IR PROBLEMŲ APŽVALGA: KONTEINERIO SU SKIRTINGAIS KROVINIAIS SVYRAVIMŲ ANALIZĖ

T. Eglynas, M. Bogdevičius, A. Andziulis, T. Lenkauskas

Santrauka

Didėjant tarpžemyninei prekybai, išaugo krovinių gabenimas jūriniais konteineriais, todėl uoste esantiems kranams tenka didesnis transportavimo krūvis. Padidėję krovinių srautai daro įtaką transportavimo saugumui, todėl reikia apžvelgti krano sistemas ir nustatyti, kokie veiksniai gali daryti įtaką konteinerio svyravimams transportavimo metu. Šiame darbe yra nagrinėjamos ir analizuojamos konteinerinių kranų valdymo sistemos ir su jomis susijusios problemos. Autoriai nagrinėja problemų priežastis, galimą žalą ir sprendimui taikomus metodus. Straipsnyje pateikiama ryšio tarp skirtingų konteinerio krovinių ir svyravimų, atsirandančių krovos darbų metu, analizė, naudojant konteinerinio krano prototipą. Darbe taip pat pateikiami svyravimų analizės rezultatai, įvertinant skirtingų konteineryje esančių krovinių įtaką krovos procesui.

Reikšminiai žodžiai: konteinerinis kranas, krovos procesas, konteinerio svyravimai, eksperimentinė analizė, valdymo sistemos, rankinis valdymas, prototipas.