MOTION CONTROL SYSTEM FOR SHIP MODEL TOWING TEST TANK CONTROL SYSTEM USING SYNCHRONOUS SERVO DRIVES

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Abstract: *In modern industrial motion control applications, usage synchronous servo drives and coordinated control using PLCs are prevalent. Multiple servo drive synchronization to achieve towing carriage motion and wave generator motion for ship model towing test tank is still novel approach compared to traditional control systems of such applications. Key features of the any modern industrial automation system such as reliability, flexibility to further enhancements, simplicity are thoroughly investigated and incorporated in the design of control system. And this paper presents controlling plurality of servo drives and coordinate them using industrial controller which is Beckhoff soft PLC for ship model towing test tank motion control. It was used EtherCAT field bus network to achieve real-time communication between servo drives. Controller based servo drives are commanded via CiA402 drive profile. Motion control algorithms has been developed using PlcOpen motion function blocks. And software user interface algorithm for the control system and internet based control of the application also discuss here. The system has been fully developed and tested as per current user requirements and all those experimental data are presented here. And also future enhancements for the wave profile motion points generation by embedding MATLAB / Simulink object into the Beckhoff PLC is discussed.*
Key words: Servo drive synchronization, Ship towing test tank, motion control, PlcOpen motion control function blocks.

1. INTRODUCTION

This paper presents ship model towing test tank motion control system developed for Small Craft Competency Centre of Tallinn University of Technology. The system has been implemented and in operation at the moment of writing this paper.

The ship model towing test tank or ship model basin is used as an experimental facility to evaluate hydrodynamic characteristics of ship designs by using scaled down ship models with or without artificially created ocean waves [7]. As shown in Fig.1 the ship model test tank comprise with a ship model towing carriage and a flap paddle type wave maker. The scale down model of ship attached to towing carriage which is pulled by using belt drives. And wave maker creates ocean waves.
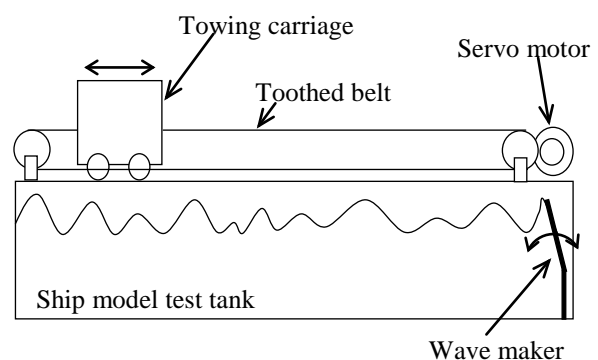

Fig.1. Ship model test tank

There are industrial applications including ocean wave makers with multi servo drive synchronization based on distributed clock concept which uses EtherCAT fieldbus network [1]. However ship model towing

carriage motion control and ocean wave maker applications are still new application areas for EtherCAT networked motion control systems. And in this application it has been used linear toothed belts to drive the towing carriage by pulling it from both sides. This demands servo drive synchronization to overcome carriage skew. Since belt drives are nearly 120 m long, it is susceptible for stretching. The accurate position control is challenging task.

2. CONTROL SYSTEM DESIGN

2.1 Position Control Requirements
Position accuracy of the carriage should be ±20 mm while velocity accuracy ±0.005 m/s [2]. However in order to avoid carriage derailing due to relative position errors of belt drive system, it should be less than **±50 mm** throughout the entire length of travel [4]. This required accurate drive synchronization. The wave generator has no such critical position control criteria due to fact that wave paddles can be controlled individually and such fine accuracy doesn't influence water wave creation. Since wave model developed to create uniform waves from each paddle, it was required to synchronize wave generator servo drives as well.

2.2 System Configuration
There are eight synchronous servo motors and drives in the motion control system. It has been selected controller based servo drives for the application by considering centralized motion control. They are Lenze i700 servo drives [6]. And also there is a Beckhoff soft PLC working as master controller in the system which runs motion control algorithm. The drives have been connected with master controller with line topology as shown below Fig. 2. using EtherCAT fieldbus [2]. First two servo axes comprised with 10 kW servo motors which are responsible to move carriage. And the remaining six servo axes comprised with

each 4.7 kW are responsible for wave generator motion.

Software user interface is running on a PC where it connect to the PLC system using TCP/IP through Beckhoff ADS interface [9].
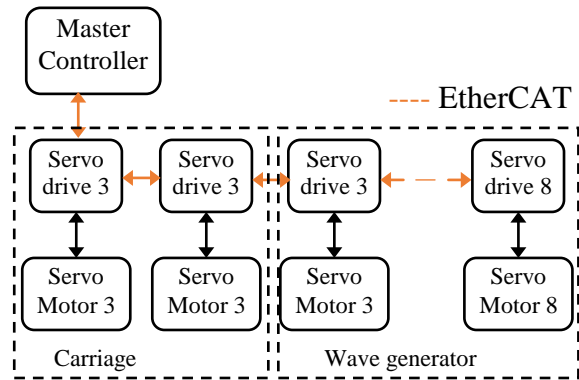

Fig. 2. Electrical drive circuit.

2.3 Carriage Motion Control Algorithm
The algorithm can be sub-divided into three sub routines. Such as homing routine, experiment motion profile routine and manual control routine.
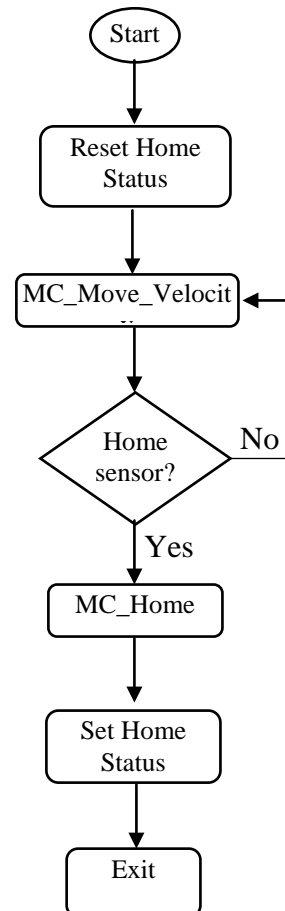
Fig. 3. Homing routine flowchart for carriage

As shown in Fig 3. The homing routine uses MC_MoveVelocity function block to move the carriage until it finds a position limit sensor. Once it detect the limit sensor MC_Home PlcOpen function block used to perform homing [8].

Start

Homed? — No → Exit (Not Done)

Yes

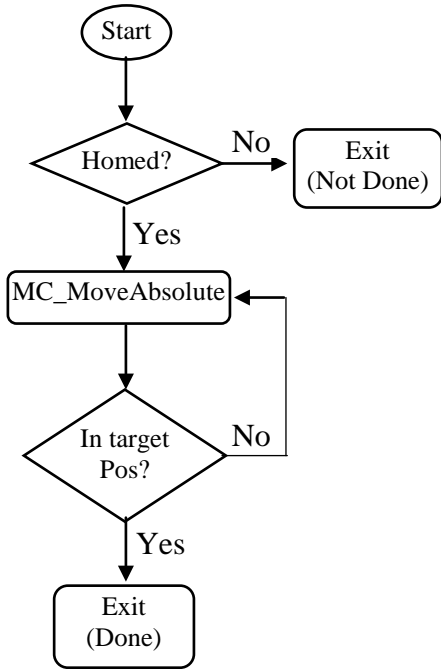MC_MoveAbsolute

In target Pos? — No

Yes

Exit (Done)

Fig. 4. Experiment motion profile routine flowchart for carriage

Experiment motion profile routine is mainly uses MoveAbsolute PlcOpen function block to perform point-to-point motion. Its position, velocity, acceleration and deceleration parameters are fed by using user interface application. The algorithm flowchart is shown in Fig 4.

Manual routine has been done using MC_Jog function block. And also it is allowed to move carriage to predefined positions. In this case it is used MC_MoveAbsolute function blocks.

2.4 Wave Generator Motion Control Algorithm

The wave generator supposed to produce regular as well as irregular waves according to different wave spectra [4].

Wave profiles are calculated in MATLAB. And the calculated motion profile is transferred to the software user interface as a text file. The file contains motion points which were generated at 500 Hz sampling rate.

Start

Axes Synchronized? — No → Exit (Not Done)

Yes

Enable ext set points

Read points from array and run

Exc'd target Pos? — Yes → Exit (Error)

No

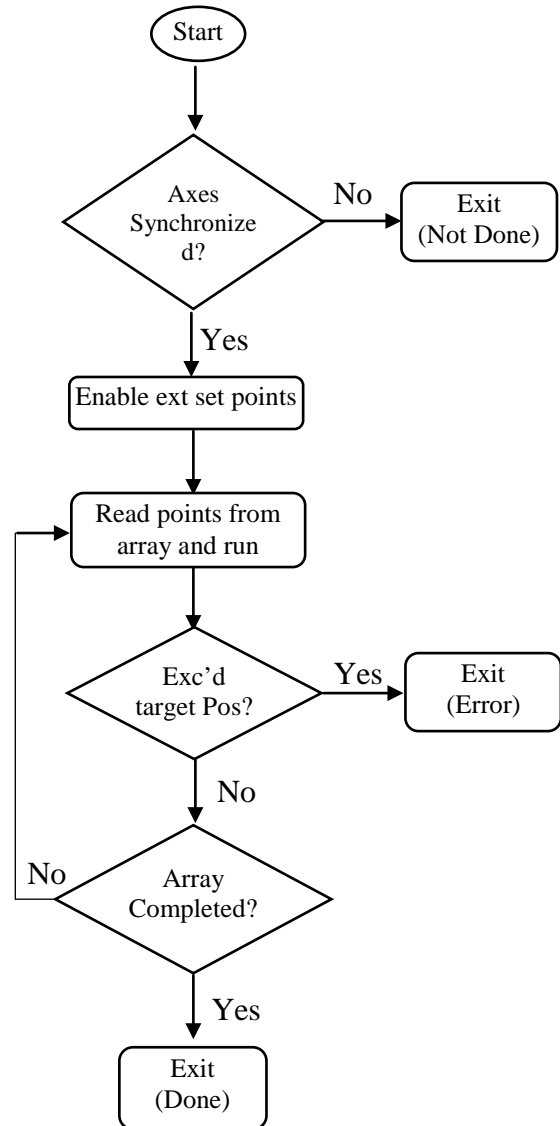Array Completed? — No

Yes

Exit (Done)

Fig 5. Wave profile algorithm flowchart.

In the wave generator control algorithm it is used external set point feed function block which is MC_ExtSetPointGenFeed to run servo drive over an array of position coordinates. Based on position profile, the required parameters for the above function block are calculated in the PLC program. They are velocity and acceleration for each point. Algorithm flowchart is illustrated in above Fig 5.

3. RESULTS

So far actual hydrodynamic experiments have been conducted are resistance tests in calm water and also with regular sine waves.

In order to verify the positioning accuracy of the carriage, the experiments conducted with several speed settings from 0.5 m/s upto 4.0 m/s. However the maximum required speed of the carriage should be 4.95 m/s. Below waveforms Fig. 5, 6 & 7. showing the positioning accuracy of the proposed motion control algorithm for the towing carriage with speed of 2 m/s 3 m/s and 4 m/s with acceleration and deceleration of 500 mm/s. The first graph is showing the target position curve which is from 0 to 45,850 mm. Second and third graphs are showing the position deviation from target for each axis respectively. The position deviation plots are in scale of +/- 1 mm.
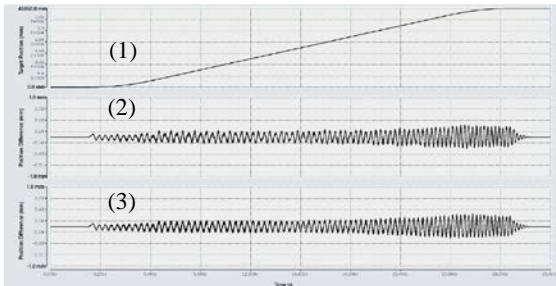

Fig. 5. Carriage position deviation plot for 2 m/s. (1) Target position plot, (2) position deviation of right side servo drive and (3) position deviation of left side servo drive.
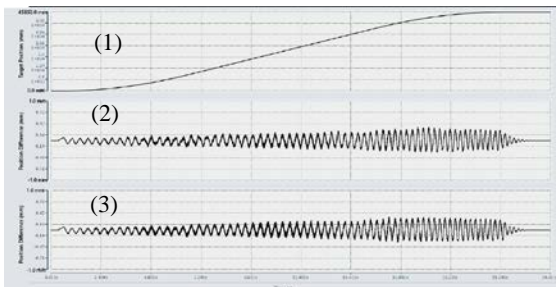

Fig. 6. Carriage position deviation plot for 3 m/s. (1) Target position plot, (2) position deviation of right side carriage servo drive and (3) position deviation of left side carriage servo drive.
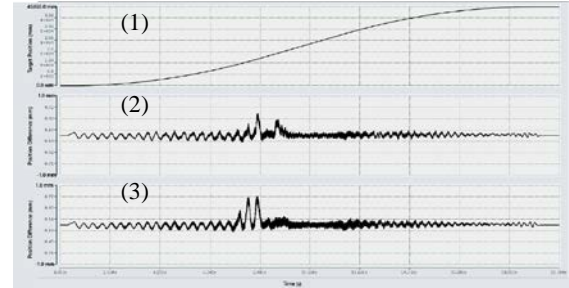

Fig 7. Carriage position deviation plot for 4 m/s. (1) Target position plot, (2) position deviation of right side servo drive and (3) position deviation of left side servo drive.

Set speed	Pos deviation - right	Pos deviation - Left
0.5 m/s	+/- 0.26 mm	+/- 0.25 mm
1.0 m/s	+/- 0.20 mm	+/- 0.19 mm
2.0 m/s	+/- 0.30 mm	+/- 0.31 mm
3.0 m/s	+/- 0.32 mm	+/- 0.31 mm
4.0 m/s	+ 0.73 / -0.18 mm	+0.55 / -0.18 mm

Table 1. Carriage position control.

According to the above data, during experiments the position deviations for each axis remained under 1.0 mm which was desired from the control system. However when the carriage speed increases the position deviation is increasing accordingly as an oscillation. And also with 4 m/s it was noticed that additional vibrations appear in the position deviation plot. There are several reasons for this oscillations and excessive vibrations. Belt vibration during the motion, carriage structure vibration, carriage misalignments and resonance of structural members can be some of the causes.

Wave generator motion control performance also analysed in a similar way by running series of sinusoidal waveforms ranging from 0.1 Hz to 1.5 Hz paddle frequency with 30 mm amplitude over 30 seconds durations and checked its position deviations for each servo axis.
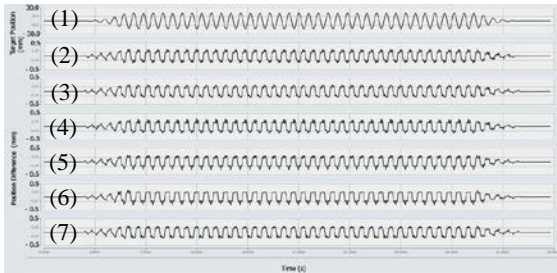
Fig. 8. Wave generator paddle position accuracy waveform at 1.5 Hz, 30 mm. (1) Target position profile plot, (2) Position deviation plot for wave gen. servo drive 1, (3) Position deviation plot for wave gen. servo drive 2, (4) Position deviation plot for wave gen. servo drive 3, (5) Position deviation plot for wave gen. servo drive 4, (6) Position deviation plot for wave gen. servo drive 5 and (7) Position deviation plot for wave gen. servo drive 6,

In the Fig 8. First graph is target position profile for all six servo axes. And it is scaled to +/- 30 mm while below six graphs showing position deviation which are scaled to +/- 0.5 mm. Based on this result it is visible that there are position deviations occurring for each sine profile and maximum deviation still below 0.5 mm for all servo axes.

5. CONCLUSION

Carriage positioning deviation was remained less than 1.0 mm throughout all experiment runs. And this is well within specified position deviation limits for the towing carriage motion control. Therefore based on the results it can be concluded that the motion control algorithms developed for carriage motion is sufficient and can fulfil system requirements.

And wave generator motion also achieved less than 0.5 mm deviations while all six axes operate synchronously. Therefore it can be concluded that the motion control system is sufficient to operate the mechanisms safely.

6. FUTURE WORK

TwinCAT software allows to use MATLAB/Simulink models to embed in the controller program [5]. Therefore it is possible to build a MATLAB/Simulink object for each control sub system and embed in the PLC program.

Based on results it seems to be better to analyse the vibrations at various carriage speeds and make a control system model in MATLAB and integrate it to the control program. And also create a MATLAB object for wave generation mathematical model. Then connect it to the software user interface to allow users to modify the wave spectra variables to create desired wave profile. And integrate it into the motion control algorithm instead of reading profile points from a data array. Moreover the wave generator paddles are running in a reversing sequence which need to accelerate, decelerate and stop in every half cycle. In the case of irregular waves, there can be sudden jerks in the motion profile which is not desirable for the drives as it may overrun the limits of accelerations and decelerations whereby putting servo drives to error state. Therefore such irregular wave profiles needed to be adjusted to suit with motion control system while creating required ocean wave pattern.

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9. REFERENCES

1. Lei Wang, Muguo Li, Junyan Qi, Qun Zhang, Design Approach Based on EtherCAT Protocol for a Networked Motion Control System, *Int, Jnl of Dist Snsr Net*,2014

2. Liyanage, D.C, Aasmäe, E., Sutt, K.O., Hiiemaa, M. & Tamre, M, Ship model basin carriage control system, *Proc DAAAM Baltic Conf*, 2015, 1, 151-155.

3. EtherCAT – the Ethernet fieldbus, EtherCAT technology Group, [WWW] http://www.ethercat.org/pdf/english/ETG_Brochure_EN.pdf, (31.03.2016).

4. Ship model basin internal design specifications, *Kuressaare College of Tallinn University of Technology,* 2015.

5. TwinCAT 3 – XA Language Support: Matlab/Simulink, Beckhoff Automation GmbH, [WWW] https://www.beckhoff.com/english.asp?twincat/twincat-3-xa-language-support-matlab-simulink.htm?id=1893323818933262, (31.03.2016)

6. Servo inverter i700, Lenze SE, [WWW] http://www.lenze.com/en/products/inverters/inverters-control-cabinet/i700/ , (07.04.2016)

7. Morgan.W.B, Lin.W.C, Predicting ship hydrodynamic performance in today's world, *Naval Eng Jnl*, 1998, **110**, 91-98.

8. Van der wal E.,PlcOpen function blocks for motion control, [WWW] http://www.plcopen.org/pages/tc2_motion_control/technical_introduction/

9. TwinCAT connectivity, Beckhoff Automation GmbH, [WWW] https://infosys.beckhoff.com/english.php?content=../content/1033/tcadscommon/html/tcadscommon_intro.htm&id=