Hardware-in-the-Loop Simulation of an Active Heave Compensated Drawworks

Sanin Muraspahic, LawkFarji, Michael Rygaard Hansen, Geir Hovland, Yousef Iskandarani and Hamid Reza Karimi

Abstract**—**thefollowing contents represent the systematic approach of setting up and running the hardware-in-the-loop (HIL) simulationfor an active heave compensated (AHC) draw-works as a conceptual horizon of implementing HIL for any plant whereby the model is determined. A Simulation model of the draw-works is executed on a PC to simulate the AHC draw-workswith a physical PLC. The PLC (ET200S) is configured with a controller architecture that regulates the motor angular displacement and velocity through actuation of the servo valves.Furthermore, a graphical user interface is developed for operation of the AHC system. The HIL test allowed tuning of the physical controller in terms of heave stabilization and positioning. The conclusion after the testing is a PLC which is ready for operation without necessitating the use a physical prototype of the process.Furhtermore, a graphical user interface (GUI) is developed for operation of the AHC system.

Keywords**—** Active heave compensation (AHC),draw-works, hardware-in-the-loop (HIL), hoisting rig, programmable logic controller (PLC).

I. Introduction

HIL simulation was proposed in the early 1990's as a cost and time saving tool for developing electronic and mechanical components [1]. Since then, the application of this strategy for developing embedded systems has become common in several fields. Recent examples include the development of a control system for automatic steering control for an automobile by H. Jamaluddin [2]. Allegre et al. proposed a novel subway design using super capacitors as the main energy source [3]. An HIL test of this design was conducted for experimental validations. Another work by Rankin and Jiangused HIL testing to verify the functionality of safety control systems within nuclear power plants [4].

The setup of an HIL test usually consists of a PC on which a simulation model of the plant is run on. A physical controller such as a PLC is then interfaced with the PC regulating certain parameters of the model. The principle of HIL is illustrated in Fig.1. Sometimes it may be essential to include physical sensors and actuators in the loop along with the controller. This is so actuator lag and sensor noise can be taken into account. This was done by N.R Gans et al. in the testing of their unmanned air vehicle [5].

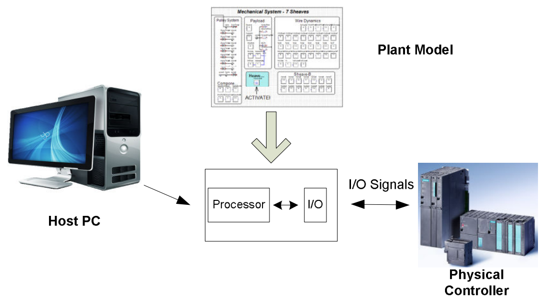

Fig.1 Principle of HIL simulation.

The advantage for using HIL simulation in developing an embedded systemis to be able to tune the controller before its implementation with a physical plant. Furthermore, there may be safety and performance improvements by being able to test various operational scenarios with great flexibility. These could be extreme or failure scenarios which would be potentially dangerous if performed with a physical plant. All in all, HIL testing is a time and cost saving industrial IT tool.

In this case, a simulation model of an active heave compensated draw-works operating on a hoisting rig is to be tested and tuned using HIL simulation. The model was the result of modeling and simulation work done by Walid et al. [6]. This project is the continuation of their work, and aims to set up the physical controller with the simulation model for an HIL simulation.The goal is to tune and verify the controller for operation during two load cases: 1. Vertical position stabilization and 2. The lowering of 5m to the seabed.In addition, the wire force and drum torque must not exceed design limits. The landing of the payload onto the seabed must occur smoothly with no significant impact forces, yet the lowering should happen within a reasonable time frame.

A control system utilizing feedback signals from the platform and draw-works motor needs to be configured. The sensors in this case are thought to be ideal. The actual control components to be used are two servo valvesand a variable displacement motor oftwo hydraulic power units.This control system should do the actual heave compensation and motion control.

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To facilitate an HIL simulation a host must be set up that allows communication with a physical controller. In this way the controller can interact with the draw-works model.

A PLC is to be used as the physical controller regulating the draw-works model. It needs to be setup for sending and receiving signals from the host PC. It must also have the chosen controller algorithmimplemented.

The active heave compensation system must have a graphical user interface (GUI) for practical operation and observationof the AHC process. In short terms the objectives are to establish communication between physical controller and the draw-worksmodel on the host PC,establish communication between PLC and the GUI, implement cascade controller on PLC, and use the GUI to operate the AHC system.

II. Setup for Co-Simulation

A. *Industrial IT*

The industrial IT part of this work included setting up the communication between the hardware controller and the PC host where the hydro mechanical model is located. This allows the controller to interact with the model. Configuration of the intended control algorithm on the PLC is also completed. Both of these objectives were done in SIEMENS S7 and downloaded to the PLC.

B. *Communication*

SIEMENS ET 200S which is the used PLC controller will be reviewed in this work. ET200S has interface module with integrated PROFINET which uses TCP/IP standards and runs in real-time.

However, SIEMENS ET 200S CPU was the only essential component whenever doing Hardware in Loop setup. In this project a setup is designed and constructed in order to facilitate the process of understanding the HIL of the AHC model. In this setup the following components are presented and described as shown in Table I.

Table I.

Example setup of 3 addresses defined as inputs and 3 as outputs.

Component serial number	Description	No. of Units
6EP1 333-2AA01	Power supply with 2x24 V channels	1
6ES7 151-8AB00-0AB0	IM151-8 PN/DP CPU , CPU Interface Module for ET 200S	1
6ES7 138-4CA01-0AA0	PM-E DC24V ,Power module	1
6ES7 132-4BF00-0AA0	8 DO DC24V/0.5 A ,Digital output module with 8 channels	2
6ES7 131-4VF00-0AA0	8 DI DC24V ,Digital input module with 8 channels	3
6ES7 131-4BF01-0AA0	2 AI ST U, 2 Analog output with 0-10V range	2
6ES7 135-4FB01-0AB0	2 AO U, 2 Analog output channels with 0-10V range	1

The PLC interacts then with the host through an industrial Ethernet standard. The industrial Ethernet standard offer many value propositions added to the simplicity when establishing the connection between PC to the PLC. Siemens Step7 will be the Ethernet connector to the PLC. There the programmer can store different programs and applications and download them to the PLC. Moreover, it can use different set of languages (STL, FBD, andLadder) but in this case most programs are implemented as Ladder.

The hardware setup as shown in Fig. 2 consist of the assembly of the chosen PLC components as presented in Table I, whereby the assembled components are mounted using a DIN rail on tilted base. 8 digital inputs, 8 digital outputs, 2 Analog inputs and 2 analog outputs are wired to a specially designed electronics box which is integrated with switches, LEDs, Voltmeter and Potentiometer enabling the operator of the plant to access the simulation with an actual signal. It is very important to wire the Power module to avoid the failure of the PLC, the hardware setup provides the operator with the feeling of operating an actual process, and however, it is a simulation.

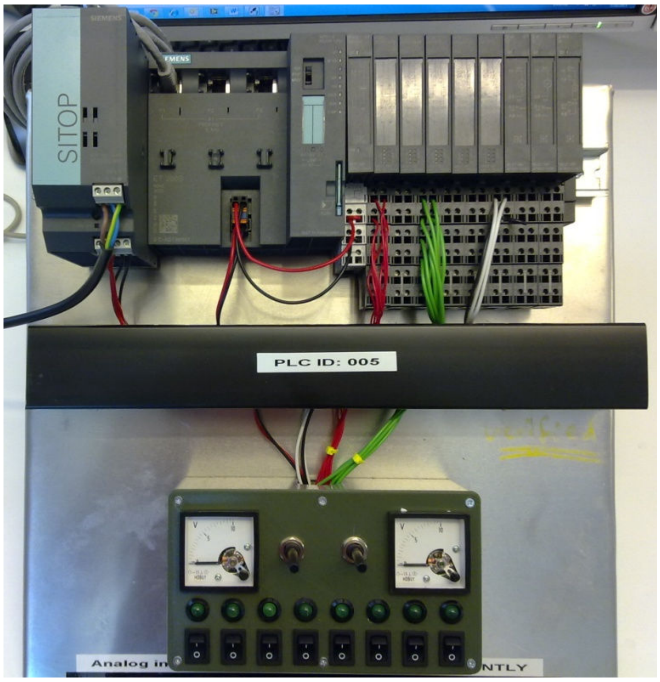

Fig. 4 the Hardware setup showing the used SIEMENS ET 200S and peripheral components/accessories

First, communication between the PLC and the host PC must be established. This was done through ahardware configuration on the host PC. The modules and MAC address for the PLC must be correctly set. Completing this procedure allows communication between the PLC and SIEMENS S7 on the host PC.

For the PLC to control the *Simulation X* model, communication must be set up internally in the host PC between PLC and *Simulation X*. This is done through *MatlabSimulink* using a toolbox called the Instrument Control

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Toolbox. The setup in *Simulink* using a simplified model can be seen in Fig. 3. This will be set up for the full model in the HIL chapter. The data that is incoming from the PLC is single (32-bit), which needs to be converted to a double (64-bit) for *Simulation X* to receive and the opposite for data coming out of *Simulation X*.

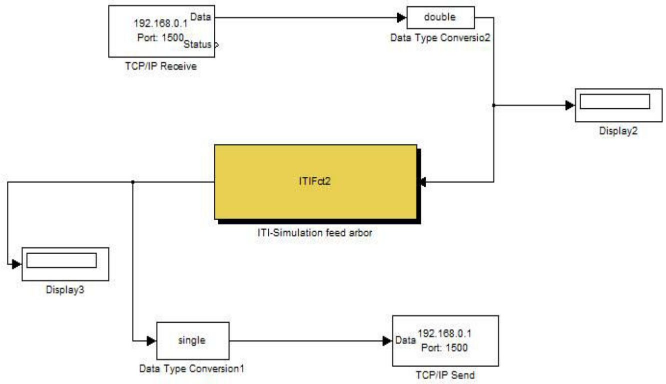

Fig. 3Co-simulation between Step7 and SimulationX through MatlabSimulink.

The data which is being sent from the PLC is received through the *TCP/IP receive* block and sent to the*ITIFct2* block which is the connection to the *TCP/IP* block in *Simulation X*. The output data from *SimulationX* is further sent to the *TCP/IP Send* block which is received by the PLC. For the PLC to send and receive data, a function block called *FB300* is used. This block contains the main parameters for communicating with the host PC. In the FB300 block one can set the desired *TSEND* and *TREC* signals. Since 4 bytes equals 1 REAL, the*TSEND* needs to go from 0.0 to 12.0 bytes and *TREC* from 12.0 bytes to 20.0. An example of 3 inputs and 3 outputs is shown in Table II.

Table II.

Example setup of 3 addresses defined as inputs and 3 as outputs.

Input	Output
“data”.input1 (DBX0.0)	“data”.output1 (DBX.12.0)
“data”.input2 (DBX4.0)	“data”output2 (DBX16.0)
“data”.input3 (DBX8.0)	“data”output3 (DBX.20.0)

For the graphical user interface to be able to send data to the PLC it also needs to communicate with S7.To do this the PG/PC (Ethernet) interface must be correctly set, this is done in S7. Furthermore, tags mustbe set equivalent to the memory addresses. These addresses are the ones that send and receive data from*Simulation X*. Completing this will allow operation and observation of the model process in the GUI. Values sent from the GUI to the PLC are received in DB120. From there they are sent to the blocks that use these values. DB121 is used to mirror the values sent to the PLC such as the set point and controller parameters. This allows the operator to see the values which someone has set.

The initial controller concept as shown in figure 4was the cascade P-PID. To implement this controller, two function blocks (FC1 and FC2) were made, each representing its own regulator using *TCONT*.

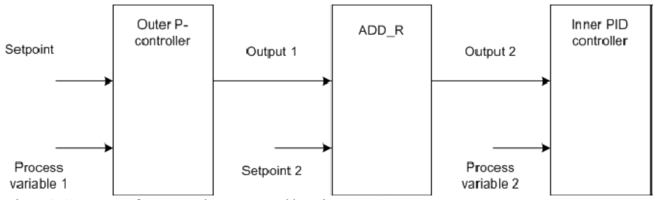

Fig. 4 Setup of cascade controller in PLC.

Both are stored in the OB35 block with an *ADDR* between them. This is to sum the output of the outer controller with the set point of the inner one. The concept of the setup of the cascade controller in the PLC is shown in Fig. 5. The last network in OB35 works as an enabler to activate the *TSEND* function in the communication block FB300.

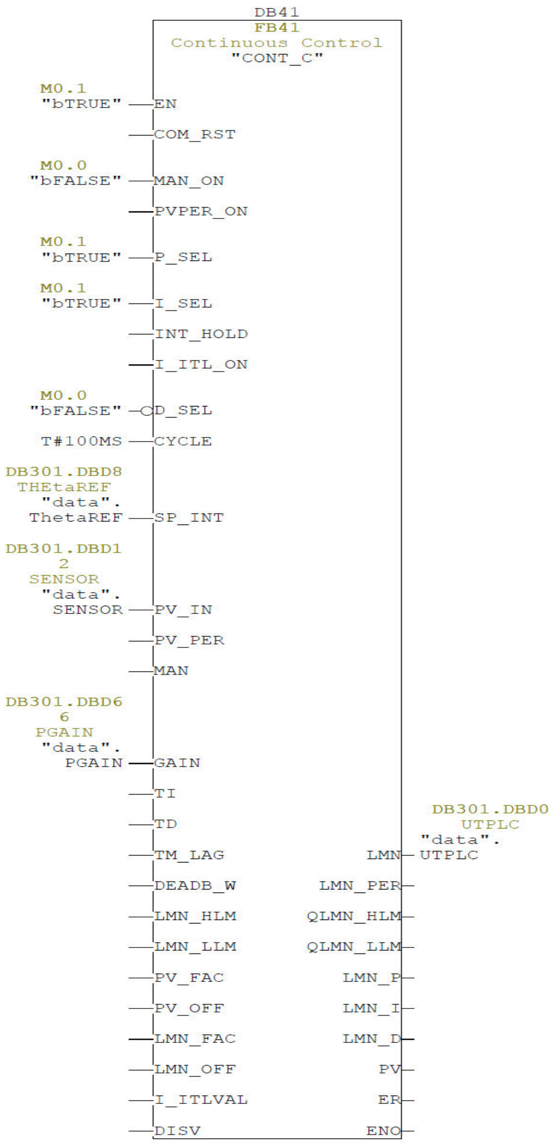

Fig. 5The OB35 continuous block as used in Step 7

C. Graphical User Interface

The graphical user interface was developed with the WinCCSCADA(Supervisory control data acquisition).This software is produced by SIEMENS and was used for control and surveillance of industrial processes.The WinCC works as a Human machine interface (HMI) which connects the operator

The goal is to tune the PLC for optimal control in load case 1 and 2. The end result should satisfy therequirements of the load cases as well as staying within the limits the hydro mechanical system is dimensionedfor.

The model is simulated in *Simulation X*. Simulink will be used as a connection interface between the PLCand the

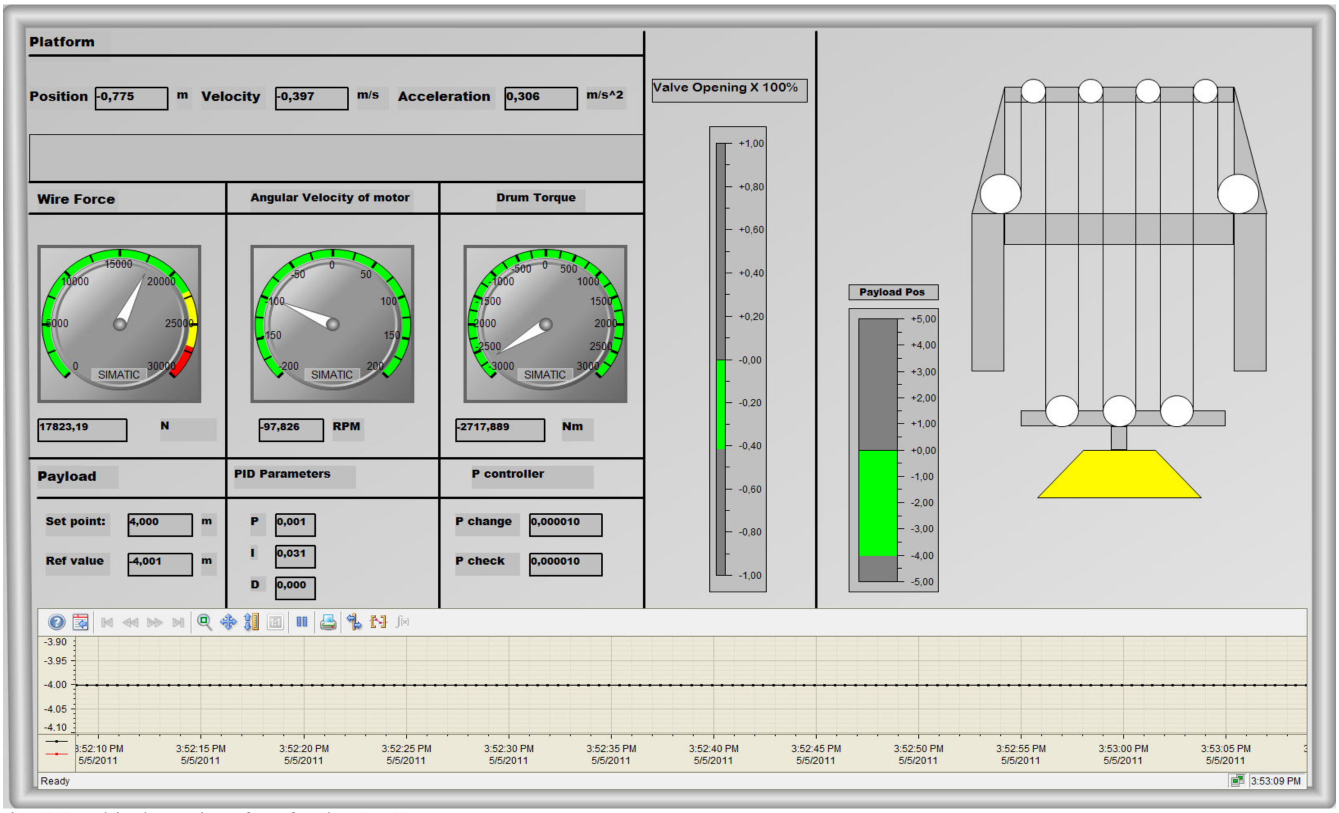

Fig. 6 Graphical user interface for the AHC system.

to the PLC and allows him to change certain values for different types of applications for the AHC of the draw-works.

The final GUI allows adjusting of the payload lowering distance and controller parameters. It also allows observation of important values such as the wire force, drum torque, motor velocity, payload position, platform motion, and valve opening of the servo valves. The GUI can be seen in Fig. 6. The trend graph in the bottom half of the figure shows the payload position.

Communication between the PLC and host PC has been established. This means the PLC is enabled for sending and receiving signals from the Simulation X model. This has also been achieved between the PLC and WinCC GUI. The cascade P-PI regulator has been implemented in the PLC. A WinCC graphical user interface has been developed.

D. Hardware in the loop

For this project, the HIL simulation was ready to be run after the main elements required for such a testwere developed:

- Hydro mechanical simulation model.
- PLC configured with a control algorithm.
- Communication between PLC and a Host PC.

dynamic model. The use of the Simulink block can vanish if the proper data transmission protocol isavailable unlike for the case of *Simulation X*. The operator can then control the desired level of the payloadthrough WinCC. The hardware in the loop setup for active heave compensation for the drawworks is seen inFig. 7.

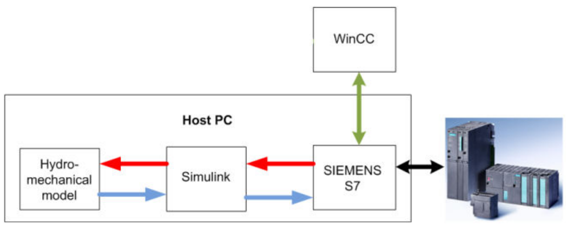

Fig. 7HIL setup for active heave compensation of drawworks.

The whole system for sending and receiving signals through Simulink is shown in Fig. 8. There are a total of 14 outputs and 2 inputs. Some outputs like the Drum Torque which does not have a sensor, can be calculatedout of the wire force times the arm in a different operation block in the PLC. But out of simplicity we choseit to do it this way. The addresses for storing the I/O's is in DB301.

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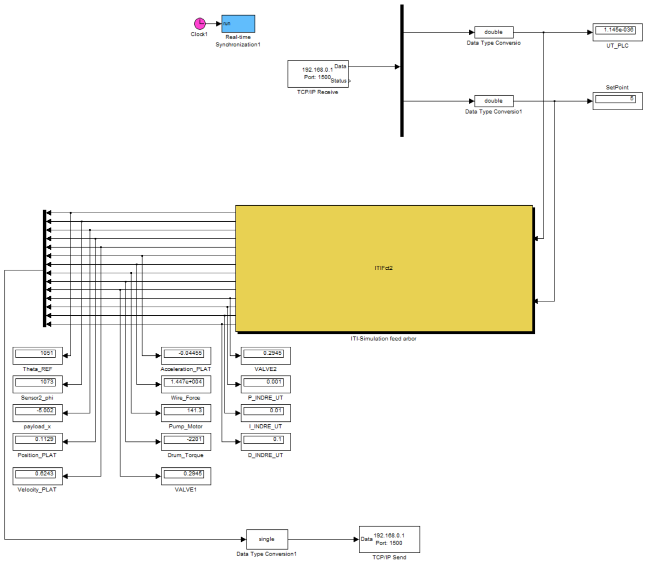


Fig. 8 Communication between PLC and model through Simulink.

E. Tuning

The manual tuning has been done by following these guidelines:

- K_I and K_D values set to zero.
- K_P should be set to half of the value for a ¼ amplitude decay type response.
- Increase K_I until any offset is correct in sufficient time for the process. Too much increment will cause instability.
- Increase K_D if required, until the loop reaches reference after load disturbance acceptably. Too much K_D will cause excessive response and overshoot.

Manual tuning is an iterative process. Starting with only the P parameter at a value of 0.001, each parameter is tuned until a desirable response is found. Results with P=0.001 and the rest turned off is used as a reference.

It is noticed that having the gain over 0.001 will yield an increased overshoot, but better steady state error.The motor's actual velocity follows the reference, but oscillatesa lot. This is because the servo valves are working very hard. This is not desirable because the valves will wear out very quickly. The P-parameter is left at 0.001, while the I- andD-parameters are investigated.

A high I-parameter might be causing instability which makes the payload position drift down to the seabed. Lowering the value showed better stability with the steady state error being quite small. The point at whichthe I-parameter started giving worse results for SSE is around 0.031.The I-parameter seems to have the most effect when it comes to drastically reducing the steady state error. This is however, only if it is within a small range of values. The payload position moves with a range of about 1.1 cm about the equilibrium point, see Fig. 9. The actual motor velocity follows the reference velocity quite nicely and the valve stroke is within an acceptable range. By keeping the I-parameter at 0.031 and increasing or decreasing the gain yield moreovershoot,so the P parameter seems to be optimal at 0.001. Thus, the gain value of 0.001 and integrator value of 0.031 are kept, while the remaining D-parameter is investigated.

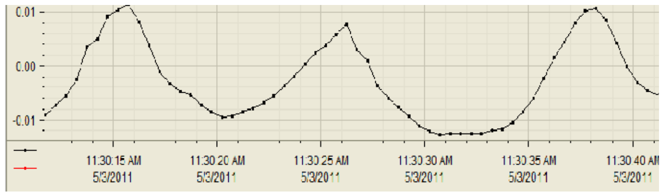


Fig. 9 Payload position for load case 1, with inner loop P = 0.001, I=0.031, D=0.

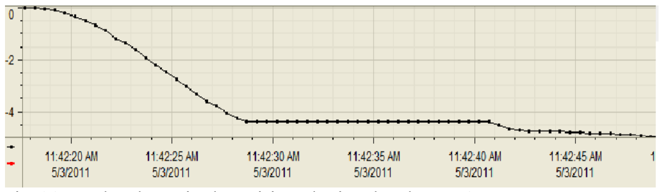


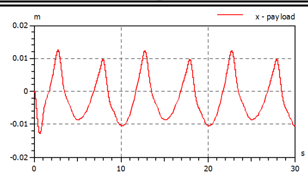
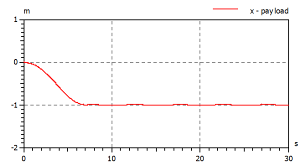
Fig 10 Payload vertical position during load case 2.

Using different values for the D-parameter gave no visible differences from the results with the P- and I parameters.The conclusion is therefore that the D-parameter is not needed for this application.

III. SYSTEM VERIFICATION

Now that the optimal parameters have been found for the outer P-controller and inner PI-controller for load case 1 and 2, the system needs a final verification for its range of operation. This range is the lowering from 0-5 meters. The control system must be able to position the payload optimally in this range, as well as compensate for heave motion. The verification is done by running the AHC with the set point at 0 and increasing with increments of 1 up to the set point is at 5. The results of this verification are seen in Table III.

Table III.
Verification of AHC system for operating range 0-5m.

Test ID	Set point	Output	Comments
1	0		Zoomed in to show the payload movement of ca. ±1cm.
2	1		Rise time of ca. 3.5s with no overshoot. Oscillation ±1cm.

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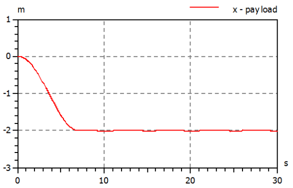
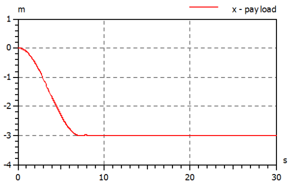
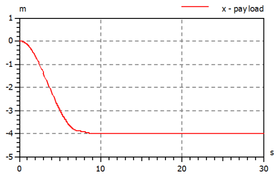
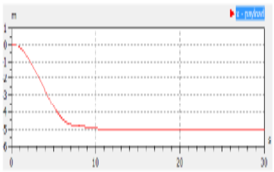
3	2		Rise time of ca. 4s with no overshoot. Oscillation of ±1cm.
4	3		Rise time of ca. 5s with no overshoot. Oscillation of ±1cm.
5	4		Rise time of ca. 5.5s with no overshoot. Oscillation of ±1cm.
6	5		Rise time of ca. 6s with no overshoot. Oscillation of ±1cm.

IV. CONCLUSION

The industrial IT systematic approach for implementing the HIL for the active heave compensated draw-works model was presented. The extracted AHC model was used to tune the controller for optimal parameters in order to provide the best operational performance during load case 1 and 2. The payloadmotion was reduced from ± 1m to ca. ± 1cm with the activation of the heave compensation. Loweringof the payload was tuned to ca. 10s with no overshoot meaning a gentle landing. Furthermore, a verificationof the system for is done for the range of 0-5m with increments of 1m. The results showed the AHC excellent correlation between the controller parameters and the system outputs for this range.

V. ACKNOWLEDGMENT

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VI. REFERENCES

[1] H. Hanselmann, "Hardware-in-the Loop Simulation as a Standard Approach for Development, Customization, and Production Test of ECU's"in 1993 Int. Pacific Conf. On Automotive Engineering.

[2] E.P. Ping, K.Hudha, and H. Jamaluddin. "Hardware-in-the-loop simulation of automatic steeringcontrol for lanekeepingmanoeuvre: outer-loop and inner-loop control design",*Int. J. Vehicle Safety,*Vol. 5, No. 1, pp.35–59, 2010.

[3] D.J Rankin, J. Jiang,"A Hardware-in-the-Loop Simulation Platform for the Verification of Safety Control Systems", *IEEE Trans. on Nuclear Science,* Vol 58, No. 2, pp.468-478, April 2011.

[4] N.R. Gans, W.E. Dixon, R. Lind, A. Kurdila,"A hardware in the loop simulation platform for vision-based control of unmanned air vehicles", *Mechatronics,* Vol 19, No. 7, pp.1043-1056, October 2009.

[5] A.L. Allegre, A. Bouscayrol, J.N. Verhille, P. Delarue, E. Chattot, S. El-Fassi, "Reduced-Scale-Power Hardware-in-the-Loop Simulation of an Innovative Subway", *IEEE Trans. on Industrial Electronics*, Vol.57, No.4, pp.1175-1185, April 2010.

[6] A. Ahmed Walid, P. Gu, Y. Iskandarani, "modelling and simulation of an active heave compensated draw-works" unpublished.