



TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Kuressaare College

**DEVELOPMENT OF WAVE PARAMETERS
MEASUREMENT METHOD FOR AN ACTIVE WAVE
ABSORPTION SYSTEM USING WAVE GAUGES**

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THESIS IN MARINE ENGINEERING

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LIST OF ABBREVIATIONS AND SYMBOLS

FFT	Fast Fourier Transform
IO	Input/Output
LIDAR	Light detection and ranging
MARTE	Marine Technology Competence Centre
NSWCCD	Naval Surface Warfare Centre, Carderock Division
PLC	Programmable Logic Controller
USP	University of Sao Paolo
DFT	Discrete Fourier Transform

PREFACE

This bachelor thesis is a part of a development project of an active wave damper in the towing tank of the Taltech Marine Technology Competence Centre (MARTE). The towing tank, measuring 60m in length, 5m in width and 3m in depth is an important part of the testing facilities in MARTE that enables running various behavioural and resistance tests on scaled down models of vessels in different wave patterns created by the wave generator.

Currently the towing tank uses a perforated artificial beach as a passive wave damper. However, a passive damper is not efficient in removing the longer, lower frequency residual waves. In order to dampen those, an active damper system will be developed. This thesis is written as a part of that project, aiming to develop a method to provide necessary wave identification in order to eventually generate a wave dampening program.

The thesis is written under the supervision of Dhanushka Chamara Liyanage, PhD, mechatronics engineer in Taltech Kuressaare College, who was also responsible for the initial design and development of the towing tank motion control system and necessary software applications. I would like to express my gratitude to the extended support network within MARTE, including but not limited to Ruttar Teär, Chief Officer of Laboratory, Villu Vatsfeld, Head of the Centre and Veiko Viil, ex Head of the Centre for the support and advice during the project and for the warm welcome to the team of MARTE.

1 INTRODUCTION

1.1 Problem statement

Before any vessel reaches full scale production, a validation of its properties and behaviour in conditions similar to its end-use environment is necessary. This could either be done by numerical modelling or by testing a scaled down model of said vessel in a towing tank equipped with a wave generator. In the latter scenario different sensors placed on appropriate locations on the model will measure forces applied during the model's movement through the water and if necessary, with a suitable wave pattern added into the towing tank. Testing a vessel on a model scale before full scale production helps reduce the cost of changes necessary in order to achieve required hydrodynamic properties.

The towing tank used in the Marine Technology Competence Centre in Kuressaare College of Tallinn University of Technology measures 59,4m in length, 5m in width and 3m in depth (Figure 1). Out of this, the usable length is 45,85m. The rest of the space is taken up by a 6-paddle wave generator, a passive wave absorber and a 3,4m braking distance for the carriage. Stainless steel rails are mounted on either side of the towing tank on which a carriage is being pulled by drive belts. The model undergoing testing is attached to said carriage at required draft and pulled through the water with velocities up to 5,5m/s.



Figure 1: MARTE towing tank.

The 6 paddles (Figure 2) on the wave generator are each operated by a 4,7kW Lenze synchronous servo motor. They are moved by belt drives attached to the motors and pressurized air dampers are used to provide reaction force in order to avoid overloading the drive system[1].



Figure 2: Wave generator paddles.

After running a test in the towing tank, the surface of water remains disturbed for a period of time, depending on the wave profile used. Long, low frequency waves can take hours to decay, which makes running repeated tests time consuming. In order to dampen the waves in the tank, either a passive or an active damper can be used. Passive dampers are effective over a range of short high frequency waves, however they do little to dampen the long, low frequency waves that carry within themselves a large amount of energy. In order to dampen said waves and shorten the time period between two consecutive towing tests, an active damper is necessary.

In order to develop an active wave damper in the towing tank of MARTE, a reliable method for measuring and analysing an existing wave profile in the tank is needed. The wave should be measured by using an array of wave gauges fixed on the side of the

tank and the resulting wave profile should be analysed to find and recreate a cancelling wave profile.

1.2 Scope

The scope of the thesis starts with developing the general concept of an active damper program suitable for the MARTE towing tank, however the focus of the thesis rests on developing the method to be used in order to measure the existing residual wave parameters in the tank.

It includes choosing the necessary componentry – wave gauge system as well as the components for the control cabinet, which consists of PLC modules and required power supply. The scope also includes writing a code for a program measuring a wave in the towing tank and generating a cancelling wave profile.

It is not in the scope of this thesis to develop a fully functional wave dampening solution, including the program for dampening the wave or implementation of given solutions on the already existing PLC controlling the wave generator.

1.3 Objectives

The objective of this thesis is to develop a wave measuring and regeneration solution that can in the later stages of updating the towing tank software be used to run an active wave dampening system.

This includes:

- Research on existing active wave dampening systems.
- Research on mathematical models.
- Writing the code necessary for wave measurement and analysis.
- Choosing the componentry and building the measuring system.
- Recommendations for future development

1.4 State of the art

Towing tanks of various sizes and capabilities are used for testing different types of vessel and other marine structures around the world. However, many of them are of older generation and thus do not include active wave dampening technologies. The tanks that do have the capabilities to actively monitor and dampen the waves use a few different approaches to identify the waves present in the basin. Resistive or capacitive wave gauges mounted either along or across the towing tank, in some cases on the wave generator paddles, are the most common, however some more inventive solutions are in use and have been discussed as potential approaches.

The Naples' University Federico II has a larger towing tank (Figure 3) than the one used in Taltech Kuressaare college. It measures 137,2m in length, 9m in width and 4,2m in depth and has a maximum towing speed of 10m/s. The wave generator in the towing tank uses two methods for measuring the waves. The paddles of the wave generator are equipped with force sensors that are used to implement feedback control to remove undesired wave components, thus acting like an active wave damper. In addition to the load cells for sensing force on the paddles, capacitive wave gauges are placed in the constant speed range of the carriage, however these are not used for wave dampening applications. The capacitive gauges provide the ability to constantly monitor the wave profile in the tank and through comparison with the theoretical wave spectra applied in the tank provides a calibration solution for the wave generator[2].

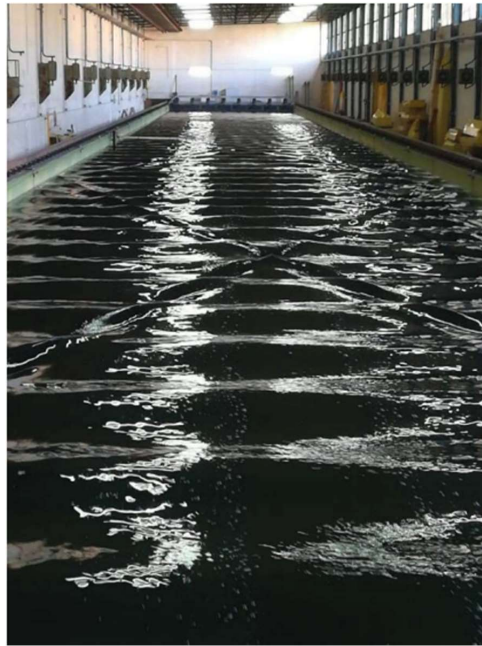


Figure 3: Naples' University Federico II towing tank, wave gauges visible on the sides[2].

Another experimental solution has been trialled in the Naval Surface Warfare Centre, Carderock Division in West Bethesda, MD, USA[3]. NSWCCD has been using a light detection and ranging (LiDAR) measurement technique to measure the wake behind a vessel. LiDAR uses a laser to measure the distance to a reflective target and thus enables the capture of complicated 3D wave patterns, however due to the complexity and extra cost involved, this is not a technique considered in the MARTE towing tank at this time.

The University of Sao Paulo (USP) has a square wave basin measuring 14m by 14m. The basin has wave generating flaps on each of the four sides in order to generate and absorb multidirectional waves. In order to measure the waves in the basin, each paddle has a gauge attached(Figure 4). USP uses ultrasonic wave probes in order to try and eliminate variations in the measuring process resulting from physical or chemical properties of the water that might affect the more commonly used capacitive and resistive gauges and thus shortening the calibration time of the sensors. As ultrasonic sensors use the pulse-echo technique to evaluate distances between the sensor and the target, it comes with a unique problem. The surface of the water can reflect the ultrasonic pulse away from the sensor, thus signal losses might occur. In order to solve the problem, guided ultrasonic waves need to be used[4]. While beneficial due to

above mentioned lesser need for calibration, due to simplicity and cost effectiveness as well as reliability, ultrasonic sensors will not be used in the towing tank in MARTE.

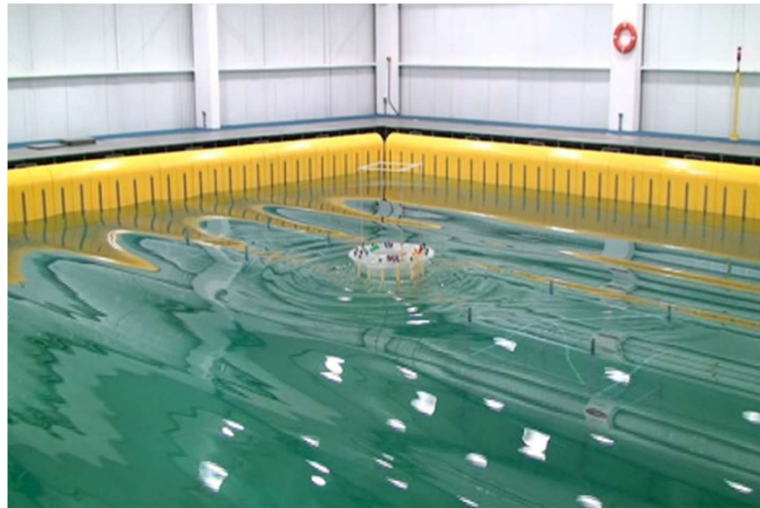


Figure 4: USP towing tank, ultrasonic sensors mounted on paddles[4].

The closest towing tanks for the Baltic Sea region besides the one in the Kuressaare College of Tallinn University of Technology are found in Aalto University, Finland[5], Statens Skeppsprovningens Anstalt in Göteborg, Sweden [6] and in Aalborg University, Denmark[7]. The latter can be considered technologically advanced compared to many others in the region, due to the extensive list of capabilities that include the ability to generate accurate 3D waves and to generate strong currents simultaneously with waves among other functionalities. The piston type wavemakers in the test basin also work as an active wave damper.

However, while both the software developed for wave generation and wave analysis in Aalborg has since been used in more than 20 different laboratories, the towing tank in Kuressaare College has been developed as a custom setup both hardware and software wise, thus the extra functionality needed, in this case the ability to use the wave generators as an active wave damper, also needs to be developed as a one-off solution.

2 THEORETICAL WORK

2.1 Theory of wave dampening

Hydrodynamic waves in the towing tank follow the general principles of linear wave theory.

For the linear wave theory, also known as the Airy wave theory after George Biddell Airy, to apply, some conditions need to be set. The most important requirement is for the amplitude of the waves to be small compared to the length of the wave and depth of the water. Secondly, the fluid, in our case water, needs to be idealised in some properties – namely, the fluid needs to be considered incompressible, inviscid and have constant density. It is also important for the bottom to be horizontal and non-porous.

A propagating, harmonic wave moving in the positive x -direction (Figure 5) can be written as follows:

$$\eta(x, t) = a \sin(\omega t - kx) \quad (1)$$

Where η is the surface elevation, a is the amplitude of the wave, k is the wavenumber and ω is the angular frequency, x stands for horizontal co-ordinate and t for time respectively [8].

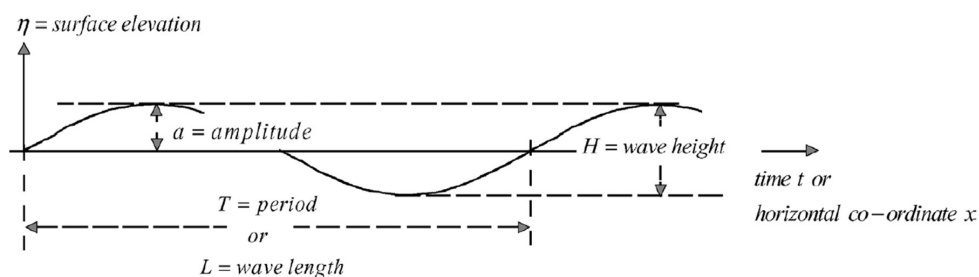


Figure 5: sine wave[8].

Through superposition, waves of different frequencies are added into a complex wave that consists of different sinusoids (Figure 6). Adding two different harmonic waves with different frequencies, travelling in the same direction will result in a reinforced wave in one moment, when they are in phase but a cancelled wave when they are 180° off phase.[8]

This can be written as follows:

$$\eta = \eta_1 + \eta_2 = a \sin(\omega_1 t - k_1 x) + a \sin(\omega_2 t - k_2 x) \quad (2)$$

Those waves can be created on purpose should a towing test require such a wave pattern, or they can happen as a result of said towing test and waves being mirrored from the objects in the towing tank.

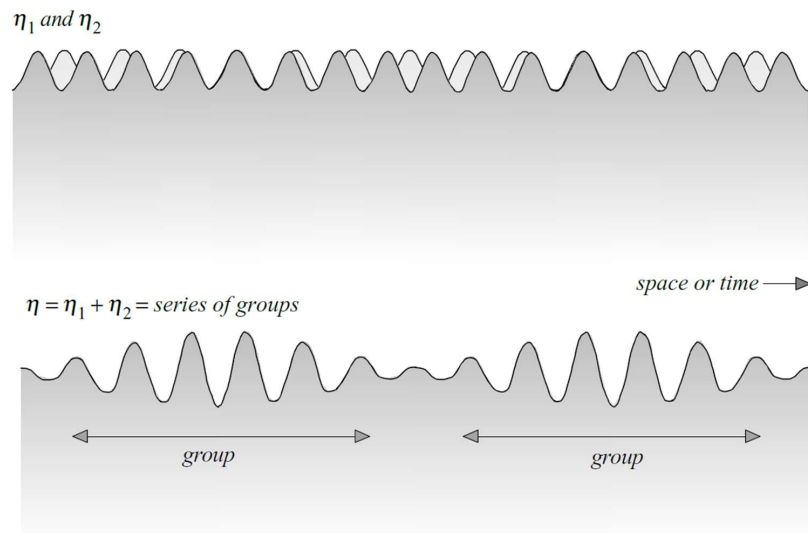


Figure 6: Superposition of sine waves[8].

The towing tank in MARTE currently uses a passive wave damper – a static, perforated metal construction designed to absorb waves created by the wave generator. However, a passive damper is most effective eliminating short, high frequency waves and long, low frequency waves remain in the towing tank regardless of the passive damper. In order to remove the residual long waves an active damper needs to be used.

In order to dampen the waves present in the towing tank, a wave with the frequency of the highest magnitude measured in the existing wave needs to be added in the opposite phase, thus dampening the dominating frequency.

2.2 Fourier transform

In order to eventually generate a dampening wave, identifying the dominant frequency in the existing wave is necessary. That can be achieved by using a mathematical

conversion from the time domain to the frequency domain. In the context of this thesis, a Fast Fourier transform (FFT) is used.

The Fourier analysis is based on the fact that any continuous function can be described as a sum of sines and cosines over an interval of time (t to $t+T$), where t is arbitrary and T is the time period over which the function $f(t)$ is periodic[9]. The Fourier series is written as follows:

$$f(t) = \sum_{n=0}^{\infty} (a_n \cos n\sigma t + b_n \sin n\sigma t) \quad (3)$$

Where $\sigma = 2\pi/T$ and $b_0 = 0$ as $\sin(0)=0$, a_0 the mean of the record. a_n and b_n are obtained as presented in [9].

The Fourier transform of a covariance function for finding the power spectrum, or in case of water waves, more accurately energy spectrum of the waves has been a laborious process. However, in modern days a method called the Fast Fourier transform is being used instead, which makes the time needed for computation drastically quicker.

Today FFT is available as a built-in function in most computer library systems, including MATLAB and Beckhoff TwinCAT 3, one or both of which will eventually be used in the towing tank development project[9].

The Fast Fourier Transform is an algorithm of which there are many versions, that are used to reduce the number of calculations needed for a discrete Fourier transform (DFT), which is a subclass of Fourier transform. DFT is used when the signal analysed is discrete and periodic, that also applies when measuring waves in the towing tank. FFT combines progressively larger weighted sums of data samples and ultimately produces the DFT of the complete series by combining the DFTs of individual samples taking into account the occurrence and sequence of the samples[10].

3 SOLUTION ARCHITECTURE

The wave measurement solution can be divided into 4 stages. Resistive wave gauges mounted on the side of the tank and on one of the wave generator paddles measure the wave height throughout the measurement process and send that data as a 0-5V value to the amplifier based in the measurement system control cabinet, which is connected to the IO modules. The signal is then processed in the wave generator's main PLC and after the dominating wave frequency is found using FFT, a wave profile in the opposite phase is generated. The wave gauge mounted on a wave generator paddle will be used to identify the trigger point for the wave dampening program to start based on the wave period and the time needed to generate the necessary wave profile in the wave damper software and transmitting the datapoints to the wave generator.

3.1 Choice of hardware components

3.1.1 Control Cabinet

The control cabinet for the wave measurement system will eventually only include modules required to transform the signal from the wave gauges to the existing PLC controlling the wave generator and the power supply for the IO modules and wave gauge amplifier (Figure 7). For initial testing and measuring purposes, a temporary PLC will be installed in the cabinet. As the existing wave generation and carriage control system in the towing tank is based on Beckhoff products, due to compatibility issues the wave measuring system will also use IO modules from the Beckhoff line up, thus avoiding buying an extra PLC from another manufacturer and building an industrial field bus connection to the main PLC currently used.

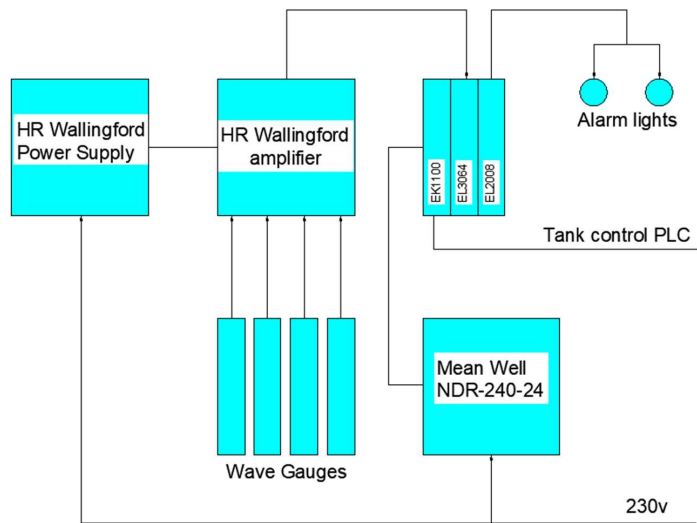


Figure 7: Control cabinet block diagram.

The modules used for the wave measuring process are as follows:

Beckhoff EK1100 EtherCAT Coupler[11] is used to connect the IO modules in the wave measurement control cabinet to the wave generator PLC. Since the wave measuring system is eventually going to be a part of the wave generation system, it will not have a standalone PLC, rather it will act as a remote module for the system mounted in the main control cabinet.



Figure 8: Beckhoff EK1100 EtherCAT Coupler[11].

In order to capture the wave data from the gauges mounted on the sides of the tank, a Beckhoff EL3064 EtherCAT 4 Channel analog input terminal[12] is used. It has a signal

voltage of 0-10V, a resolution of 12bit and a conversion time of 0,625ms, thus providing adequate accuracy for the 0-5V measuring range of the wave gauges used.

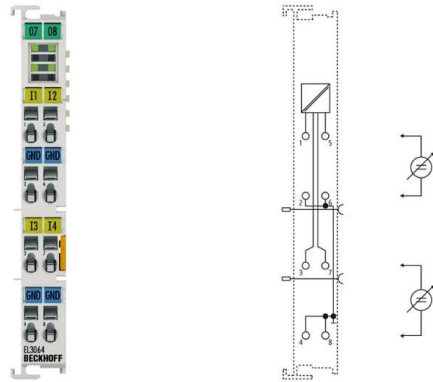


Figure 9: Beckhoff EL3064 EtherCAT terminal[12]

Two lights are mounted on the door of the control cabinet- to indicate the cabinet being in operation and having power. Beckhoff EL2008 8 Channel digital output EtherCAT Terminal[13] is used to power the "in operation" light, the "power on" light will be turned on when the cabinet power supply is switched on.

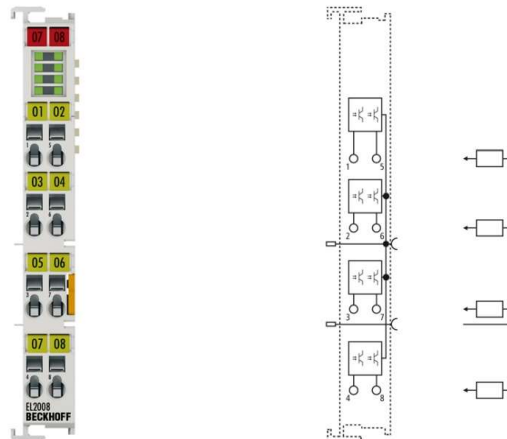


Figure 10: Beckhoff EL2008 EtherCAT terminal[13].

The power supply is a Mean Well NDR-240-24[14] which is mounted on a DIN-rail. The Mean Well NDR-240-24 is used to convert conventional 230V to 24V used within the component range inside the cabinet. The power supply has an output current rating of 10A.

3.1.2 Wave gauges

The chosen system of wave gauges is a HR Wallingford HRWG 0106[15]. The HR Wallingford HRWG 0106 Wave gauge system (Figure 11) consists of 8 x 900mm two wire resistive wave probes, an 8-channel amplifier for the probes and necessary cables. A 24V power supply is required. Initially only four of the gauges will be in use due to supply chain issues with corresponding PLC modules. Eventually the other four gauges will be added to the same amplifier. This makes it both simple and cost effective compared to alternatives like the Akamina AWP 24 Wave Height Gauges[16] which each require a separate amplifier.

The probes work by measuring the change of resistance in the rods that is directly dependant on the amount of rod exposed from the water, as the length of the probe is a direct input for resistance measurement when the cross-section area remains unchanged.



Figure 11: HR Wallingford wave gauge system, wave gauge on the left, amplifier in the centre[17].

3.1.3 Hardware setup

The wave measuring system is built inside a Rittal metal enclosure measuring 600mm in width, 380mm in height and 210mm in depth[18]. It is an IP66 rated enclosure mounted on a wall by the towing tank.

The hardware within the cabinet is mounted on two horizontal DIN rails(Figure 12). The bottom rail carries the electrical equipment – power supply, a switch, a conventional 230V power socket and terminal blocks for connecting the power supply to the devices used for the wave measuring process.

The top rail carries the IO modules for the PLC and a temporary PLC that will be removed once the cabinet is connected to the main tank control PLC. The HR Wallingford wave gauge amplifier is mounted separately and has an external power supply, but is connected to the IO modules for transferring the wave data. Two lights are mounted on the door of the cabinet, one to indicate “power on” and the other for “in operation” (Figure 13).

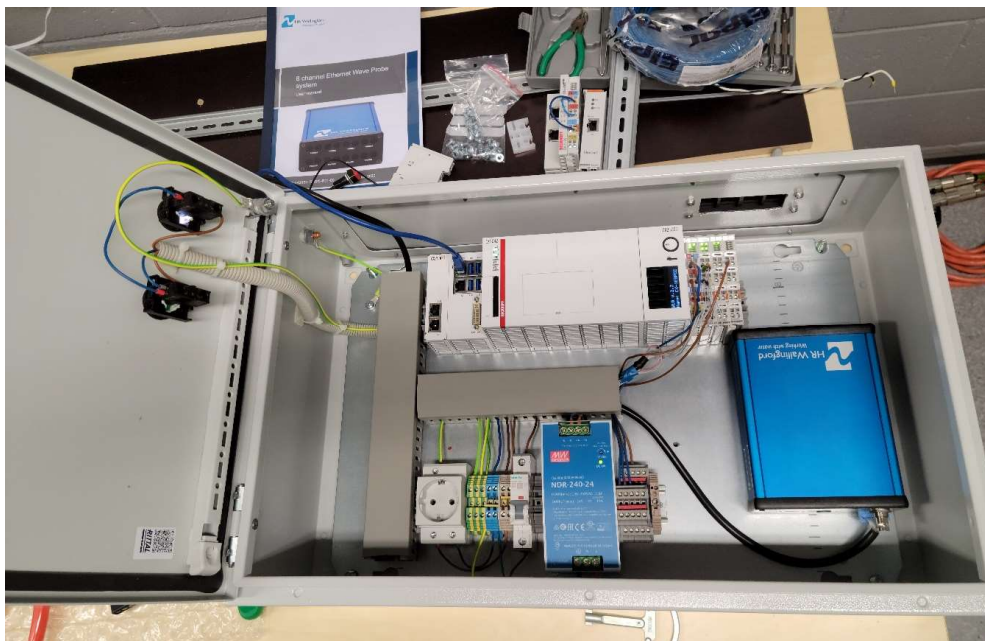


Figure 12: Control cabinet internals



Figure 13: Control cabinet alarm lights

The wave gauges are mounted externally on the edges of the towing tank and will be connected to the control cabinet using 30m cables supplied with the set.



Figure 14: HR Wallingford wave gauge assembled.

3.2 Measurement methodology

3.2.1 Test measurements using Akamina system

In order to start the design process for the wave measuring system and its program, test measurements were required. For this purpose, different wave profiles were generated in the tank and measured with a single, existing Akamina wave gauge and amplifier which was connected to a HBM Quantum X MX440B data acquisition system[19]. Resulting 2 channel dataset was analysed and a test program written.

3.2.2 MATLAB code

The initial trial of the FFT and resulting dampening wave profile was created using MATLAB and ran on the data collected with the Akamina wave measuring system. The program was divided into 4 parts: reading and sorting the wave data, running FFT on the dataset, identifying the dominant frequency and constructing a dampening wave.

The wave data was saved directly into MATLAB format, thus the data was easily available as 2 different variables, the time vector and the amplitude vector(Figure 15).

```
time_measured = (Channel_1_Data);  
amp_measured = (Channel_2_Data);
```

Figure 15: MATLAB code snippet for reading variables

The Fast Fourier transform is available on MATLAB as a function, thus transforming the data from the time domain to the frequency domain is simple(Figure 16). However, this data needs to be sorted in order to remove anomalies in the measurement. From the resulting data the frequency sample with the highest magnitude needs to be identified.

```
L= numel(amp_measured);  
Y = fft(amp_measured);  
M2 = abs(Y/L);  
M1 = M2(1:L/2+1);  
M1(2:end-1) = 2*M1(2:end-1);  
dt=1/Fs;  
Fs = one_sec_row-1;  
f = Fs*(0:(L/2))/L;
```

Figure 16: MATLAB code snippet for FFT

After identifying the most prominent frequency in the wave, a new sine wave is generated(Figure 17). A phase shift is added in order to dampen the previously measured wave as per the linear wave theory and the superposition of waves.

```
[~,Ra_max_int] = max(Ra_w_perc(:,1));
```

```

Ra_max_row = Ra_w_perc(Ra_max_int,:);
f_max_int = Ra_max_row(:,2);

[~,amp_max] = max(amp_measured(:,1));
amp_max_row = amp_measured(amp_max,:);

if amp_max_row < 0

[~,amp_min] = min(amp_measured(:,1));
amp_min_row = amp_measured(amp_min,:);
amp = (abs((amp_min_row(:,1))-(amp_max_row(:,1)))/2)/2;

else

[~,amp_min] = min(amp_measured(:,1));
amp_min_row = amp_measured(amp_min,:);
amp = (abs(amp_max_row(:,1))+abs(amp_min_row(:,1)))/2;

end

StopTime = max(time_measured(:,1));
time_cancelling_wave=(0:dt:StopTime)';cancelli
ng_wave=amp*sin(2*pi*f_max_int*(time_cancelling_wave+2*pi));

```

Figure 17: MATLAB code for wave generation.

The original wave(Figure 18) and the dampening wave(Figure 19) are then added and the resulting wave(**Error! Reference source not found.**) shows a considerable decrease in amplitude compared to the wave initially measured as seen on graphs plotted below(Figure 20).

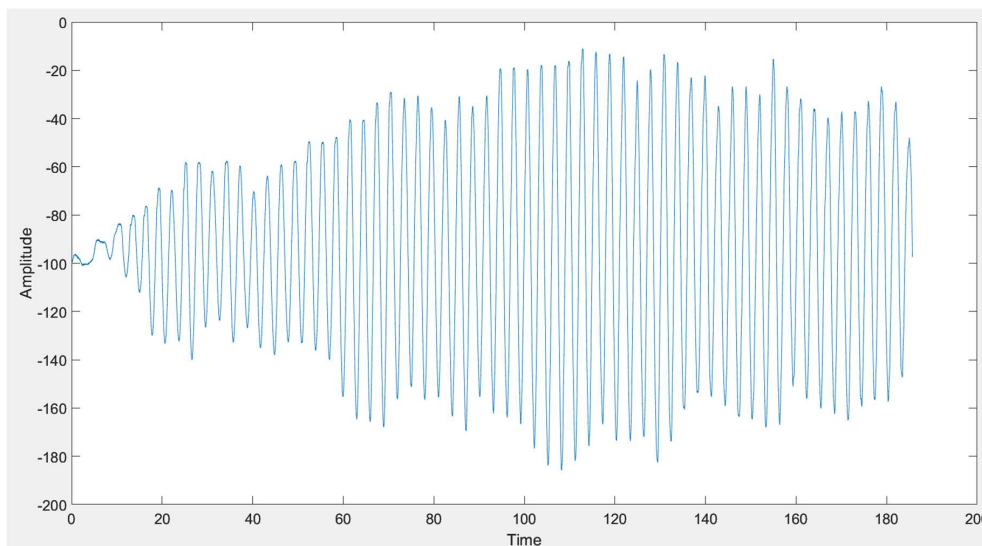


Figure 18: Measured wave.

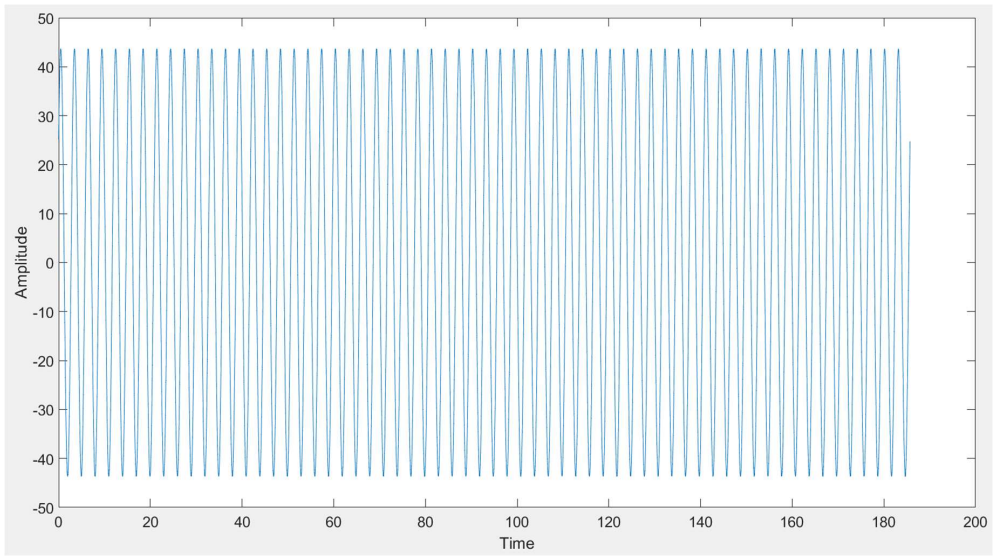


Figure 19: Dampening wave.

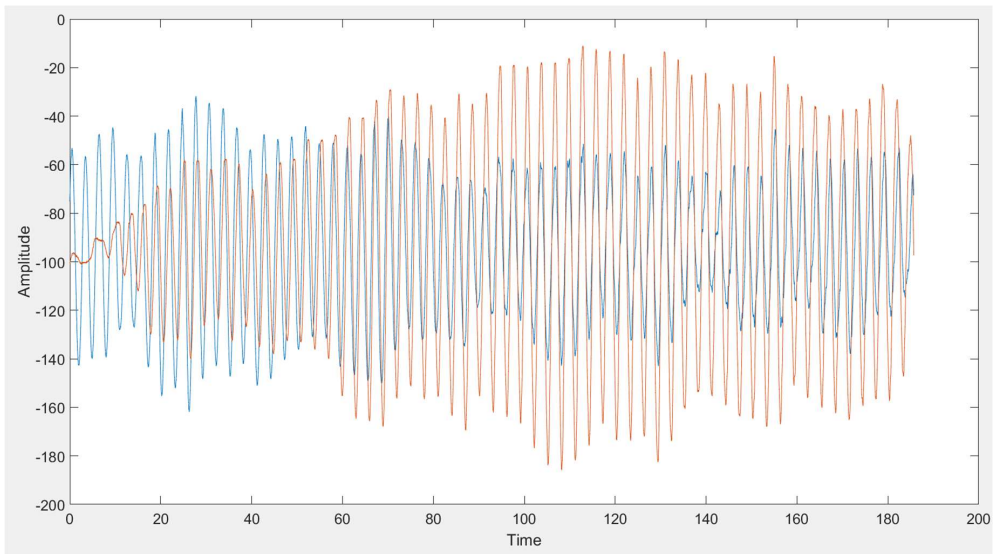


Figure 20: Dampened wave(blue) overlaid on measured(orange) wave.

4 FUTURE DEVELOPMENT

4.1 Further steps for the PLC program

In the current timeframe the program created is a proof of concept based on simulation using MATLAB. However, in the later stages of the development of the wave generator software a dampening function needs to be added. This can be done using two different methods – implementing the code directly into the Beckhoff TwinCAT 3 program running the wave generator or by installing MATLAB in the PLC and running MATLAB functions in the PLC program by using available MATLAB interface software to create the communication between the two.

The recommended option is the first of the two. TwinCAT 3 library includes different function blocks for running FFT directly in the program depending on the purpose of said FFT [20]. Options are available for complex or real valued input, as well as sample-wise analysis. However, in the context of this program a function block FB_CMA_RealFFT [21] for real valued input should be used, since the data from the wave gauges is captured as an integer in a discrete time series and any real time analysis is thus not relevant. The data collected is used to generate a wave profile that will be used for a certain period of time and not updated during the process.

The second option would be to use either the TwinCAT 3 Interface for MATLAB[22] or TwinCAT 3 Target for MATLAB[23]. TwinCAT 3 Interface for MATLAB enables the exchange of data between MATLAB and the TwinCAT runtime. This is done by using and ADS communication protocol between MATLAB and TwinCAT 3 runtime[24]. This will enable initiating data exchange either by MATLAB or calling functions written in the MATLAB environment from the TwinCAT runtime.

TwinCAT 3 Target for MATLAB enables compiling functions developed in MATLAB into objects for TwinCAT 3 and using them for creating the overall TwinCAT project. This enables writing the complete project within the MATLAB environment if necessary and thus makes it possible to integrate different complex functions into the PLC programs.

However, both of the communication channels between TwinCAT and MATLAB require two different software products installed on the PLC as well as a separate licence, thus making it financially less viable as well as potentially less reliable should communication between the two environments fail.

4.2 Further changes to the hardware

Two updates are recommended for the future development of the wave measurement solution. An extra Beckhoff EL3064 EtherCAT Terminal should be installed if the full eight-gauge array is going to be used, since the EL3064 only supports four analog input channels.

A cooling solution needs to be created for the cabinet within which the amplifier for the wave gauges sits. Since the wave gauges are resistive and part of the cables connecting the gauges to the amplifier will be run inside the cabinet, the accumulation of heat in the cabinet becomes a problem since the hardware will eventually be powered at all times. Initial experiments have shown a consistent float in values displayed as the temperature changes, thus the reliability of the measurements will be limited. This could be remedied by manually turning the cabinet on and off between each measurement or by calibrating the system before each measurement, however this is not practical in the long term. Adding ventilators on two sides of the cabinet for forced air exchange is recommended, one pushing the outside air in and the other for removing the hot air inside the cabinet.

SUMMARY

Measuring the wave parameters using resistive wave gauges shows potential to be a reliable method for developing an active wave dampening system in the MARTE towing tank. Measuring the wave and following analysis using FFT in MATLAB provides the dominating frequency along with amplitude data, which can later be used to construct a wave profile suitable for dampening the residual wave in the towing tank. Initial tests using MATLAB show a significant decrease in wave amplitude, however not a completely flat surface as a result. Repeated execution of the program is recommended, as well as more accurate phase identification once the program is implemented on the main PLC of the towing tank and wave generator.

After carefully choosing the componentry considering both the reliability and usability of the system as well as cost, the eventual build of the control cabinet and the hardware system inside it was successful, however due to production and delivery issues within the industry an extra Beckhoff EL3068 analog input terminal has to be added later in order to use the full range of wave gauges available. Due to heat build-up inside the measuring system control cabinet having an influence on the readings of the resistive wave gauges, extra ventilation needs to be added before the wave dampening system becomes operational.

As the development of the towing tank continues, the hardware needs to be mounted on the tank and the PLC software controlling the wave generator updated. This includes the addition of the wave measuring and eventual dampening program, which is recommended to be done within the Beckhoff TwinCAT3 environment using the function blocks available in the TwinCAT 3 library. However, should this option not succeed, further choices are available implementing MATLAB functions used in this thesis either as function blocks within TwinCAT 3 or by using TwinCAT 3 as a method of input for MATLAB itself.

KOKKUVÕTE

Enne veesõiduki täisskaalas tootmist on ebavajaliku aja- ja rahakulu vältimiseks vajalik läbida mudelkatsed. Selleks kasutatakse kahte viisi – numbrilist modelleerimist ja katsebasseinis sooritatavaid mudelkatseid vähendatud mõõdus mudeliga. Tallinna Tehnikaülikooli Kuressaare kolledži meretehnoloogia kompetentsikeskuses on selle tarvis katsebassein mõõtmetega 59,4 x 6 x 3m, millest mõõtmiseks kasutatav pikkus on 45,84m.

Veesõiduki kasutuskeskkonnaga ligilähedastes oludes katsete läbiviimiseks on katsebassein varustatud kuue labaga lainegeneraatoriga, mis võimaldab erineva profiiliga lainete basseini lisamist. Bassein on küll varustatud passiivse lainesummutiga – perforeeritud metallist konstruktsiooniga mis on võimeline eemaldama kõrge sagedusega lühikesi laineid, ent pikad, madala sagedusega ja kõrge energiasisaldusega jääklained jäävad basseini püsima pikemaks ajaks. Seetõttu on kahe katse vaheline aeg tihti mõõdetav tundides.

Selle probleemi lahendamiseks on tarvilik aktiivse lainesummuti paigaldamine katsebasseini. Kuivõrd bassein on juba lainegeneraatoriga varustatud, on mõistlik selle juhtimistarkvara täiendamine aktiivse lainesummutuse võimalusega.

Selle töö eesmärk oli niisuguse lahenduse tarvis mõõtmisüsteemi välja töötamine alustades riistvarakomponentide valimisest kuni laineanalüüsini, mille tulemusel on edaspidi võimalik luua lainet summutav programm. Esimese sammuna komplekteeriti riistvarasüsteem, mis koosneb takistusel põhinevatest laineanduritest, võimendist, PLC moodulitest ja kõigele sellele tarvilikest vooluallikatest. Lained mõõdeti kõrgusandureid kasutades, anduritel saadav info loeti MATLAB programmi ja kasutades FFT funktsiooni tõsteti loetud andmestik ajadomeenist sagedusdomeeni. Seejärel leides mõõdetud laine profiilist domineeriva sageduse, genereeriti uus siinuslaine mille liitmisel esialgse laine profiiliga toimus amplituudi märkimisväärne vähenemine.

Katsebasseini arendamise edasiste sammudena tuleb mõõtmisüsteem lõplikult paigaldada. Täieliku funktsionaalsuse saavutamiseks lisada üks tarneahela häirete tõttu puuduolev Beckhoff EL3064 moodul ja täiendada süsteemi kapi ventilatsiooni – kuivõrd temperatuur mõjutab takistust, on süsteemi pideva tööhoidmise tõttu tekkinud temperatuuritõusu tagajärjel saadav info ebatäpne.

Laineanalüüsiks loodud programm tuleb paigaldada olemasolevasse katsebasseini juhtimiseks mõeldud PLC-sse. Seda on võimalik teha kahel viisil – Beckhoff TwinCAT 3 platvormi funktsioonikogus on vajalikud FFT funktsiooniblokid saadaval, samuti on

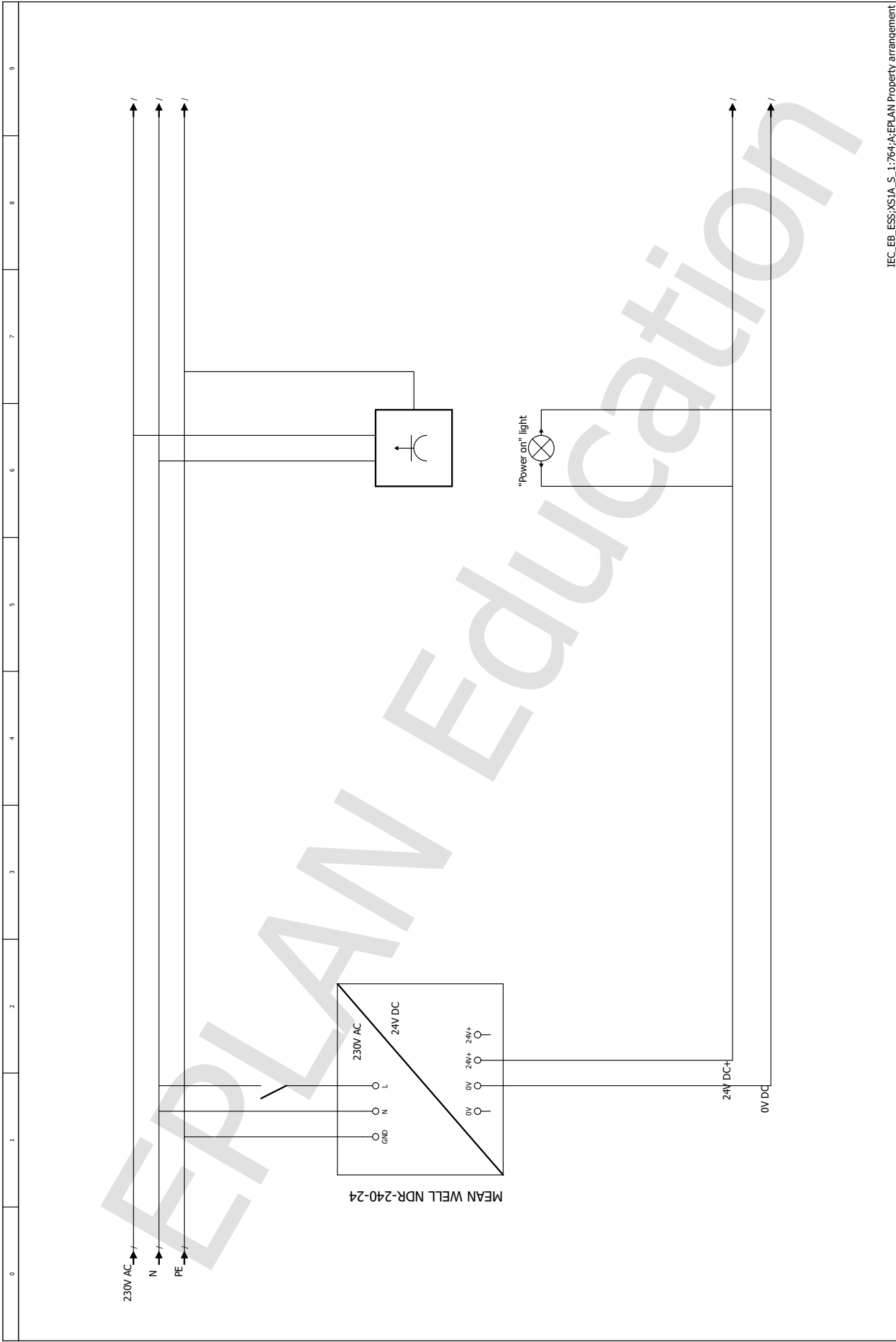
võimalik kasutada MATLAB'is loodud funktsiooniblokke TwinCAT 3 platvormil või TwinCAT 3 platvormi MATLABi andmeallikana. Tulenevalt lahenduse lihtsusest ja madalamast kulust, on soovitatav esimene variant, kuivõrd eeldab ainult ühe keskkonna kasutamist ja sellest tulenevalt ka vaid üht tarkvaralitsentsi.

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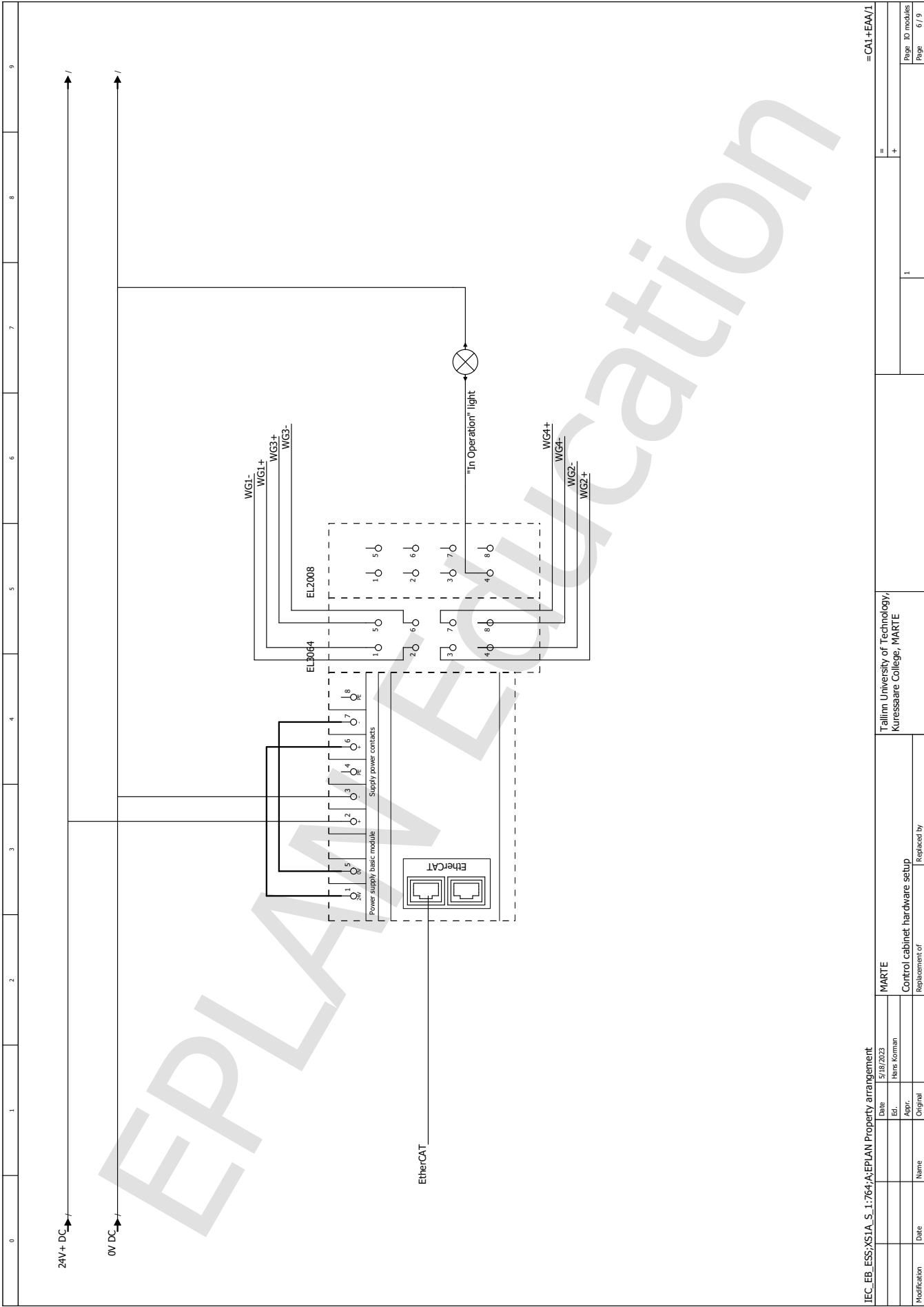
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APPENDICES



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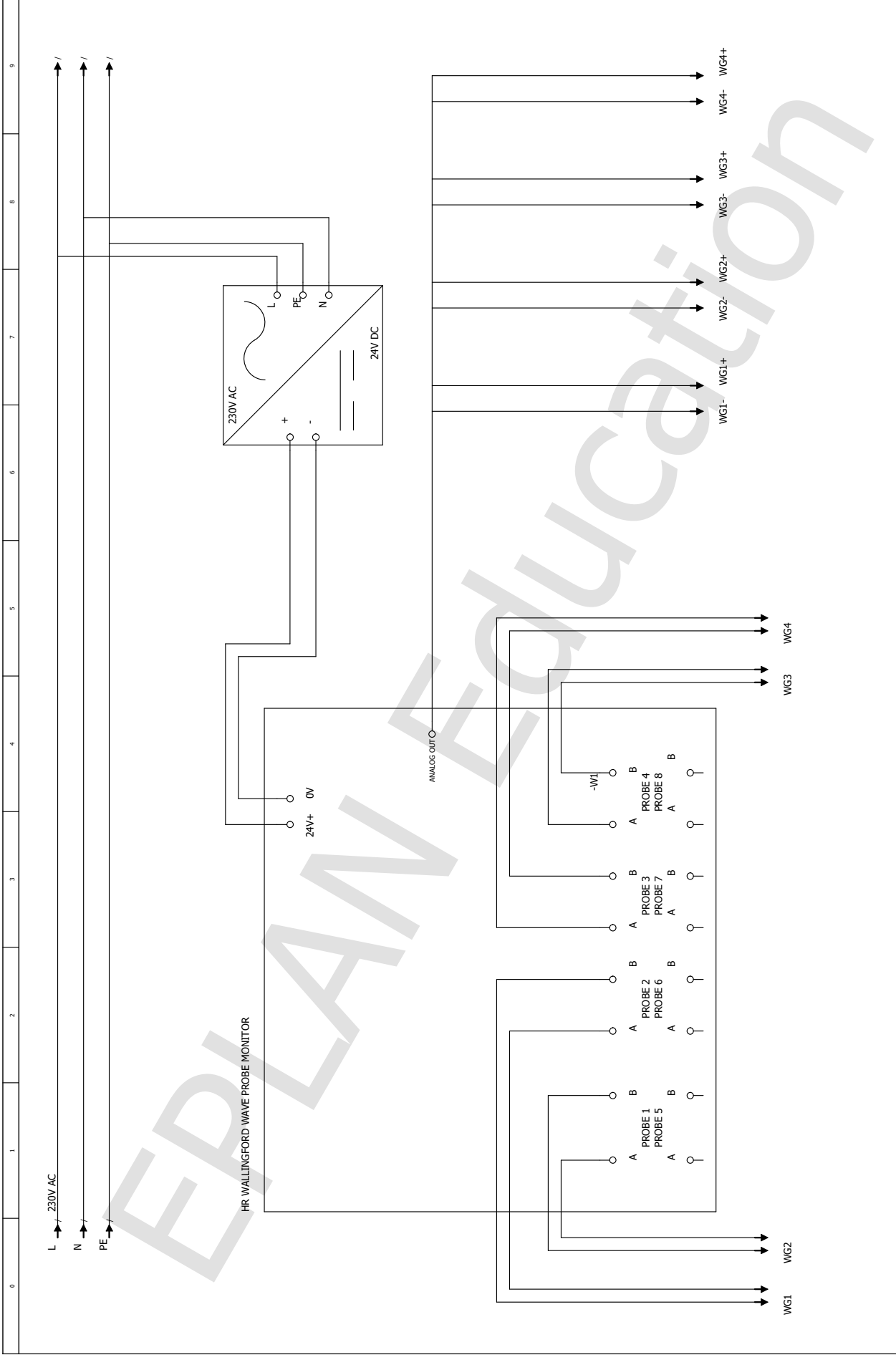
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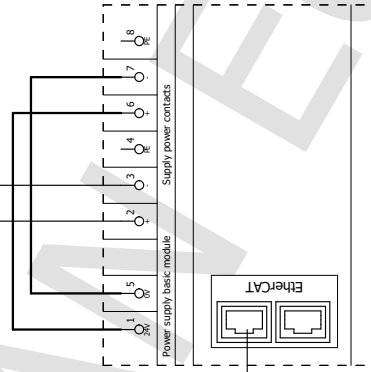
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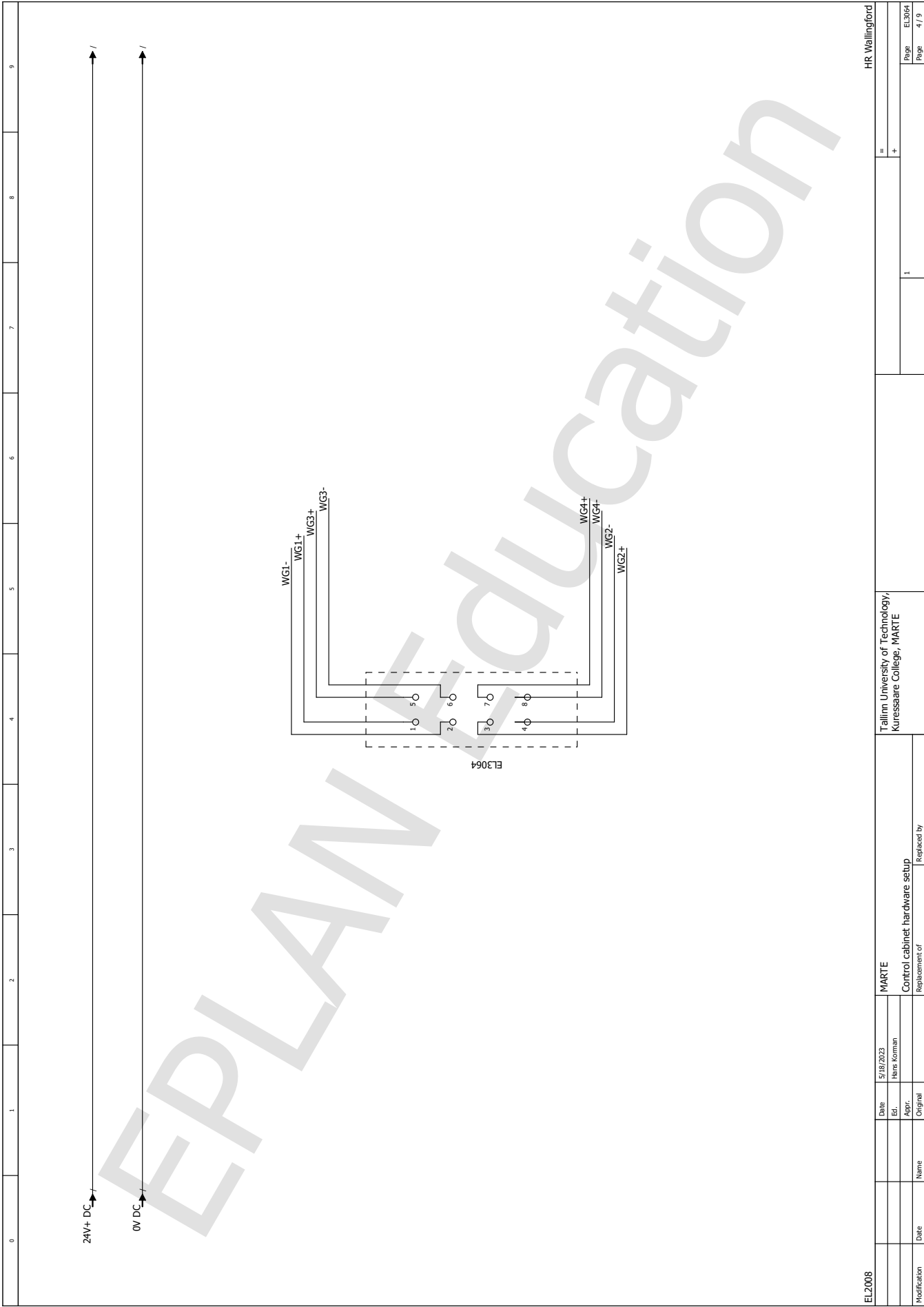
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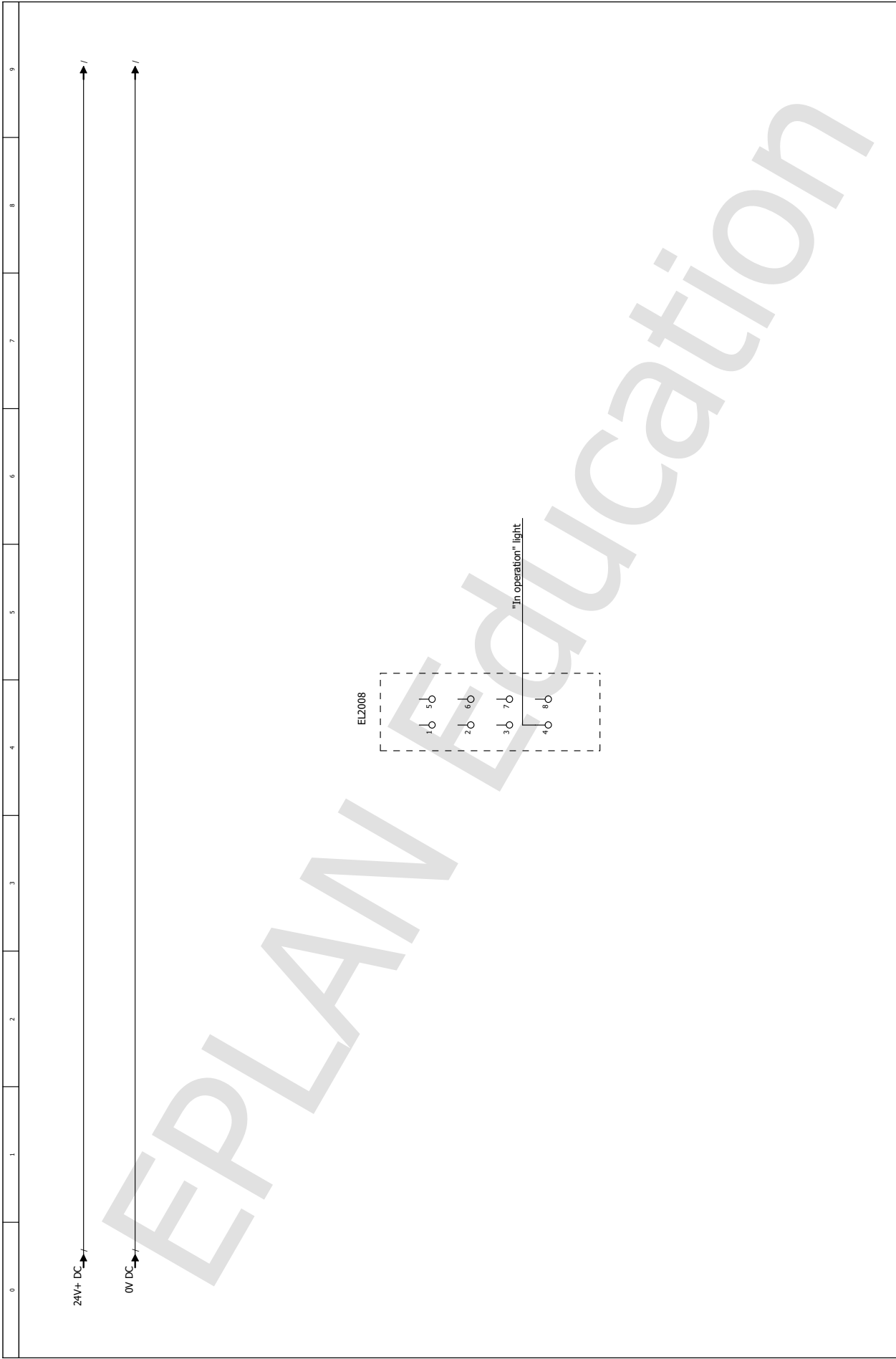
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