TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

TEST DEVICE FOR LIQUID-COOLED TRANSFORMERS

VEDELIKJAHUTUSEGA TRAFODE TESTSEADE

MASTER THESIS

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Tallinn 2022

AUTHOR’S DECLARATION

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No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

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Test Device for Liquid-cooled Transformers

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Thesis main objectives:

1. Determine the theoretical hydraulic resistance of MS Balti Trafo products
2. Develop perspective test device according to the company MS Balti Trafo needs
3. Choose optimal components for the test device considering availability

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CONTENTS

PREFACE

The thesis topic "Test Device for Liquid-cooled Transformers" was initiated by the company MS Balti Trafo OÜ, as a cooperation between the company and the student who received MS Balti Trafo OÜ scholarship though Tallinn University of Technology Development Fond.

In the product development of MS Balti Trafo OÜ there are constantly new innovative green liquid-cooled products (power transformers, chokes) that need to be tested before sending to the client. It is necessary to measure different liquid-cooling parameters in simulated working conditions and at the same time measure temperatures at different points of the product. This kind of test device that is suitable for the company is not available on the market, this necessitated the development of test device that meets the company requirements.

I would like to thank supervisor researcher Maarjus Kirs and co-supervisor lecturer Margus Müür for providing active feedback during writing of the thesis. In addition, I would like to thank tenured associate professor Tõnu Pihu and senior researcher Dmitri Nešumajev from Department of Energy Technology for consultations about heating and cooling applications. Also, I would like to thank MS Balti Trafo OÜ team for data collection and consultation.

Keywords: test device, liquid-cooling, transformers, master thesis

List of abbreviations and symbols

A	Ampere
AC	Alternating Current
AI	Analogue Input
AO	Analogue Output
bar	Bar (unit)
°C	Degree Celsius
CAD	Computer Aided Design
d	Diameter
DC	Direct Current
EUR	Euro (currency)
g	Gravitational acceleration
H_t	Total pressure loss
H_l	Frictional pressure loss
H_k	Local pressure loss
HMI	Human Machine Interface
Hz	Hertz
I	Integrated Controller
I/O	Input/Output
l	Length
kW	Kilowatt
LCD	Liquid Cristal Display
LED	Light Emitting Diode
m	Meter
l/min	Litres per minute
pcs	Pieces
PLC	Programmable Logic Controller
PS	Power Supply
RTD	Resistive temperature sensor
S	Siemens (unit)
STEP	Standard of exchange of product data
V	Volt
v	Speed
VA	Volt-ampere

1. INTRODUCTION

The master thesis is about developing a suitable test device for testing liquid-cooled transformers and chokes according to the company MS Balti Trafo OÜ needs. MS Balti Trafo OÜ is part of the Tech Power Electronics Group which produces state of the art transformers, coil products, and industrial products for the German electrical sector.
The area of application of liquid-cooled transformers and coils are for example in renewable energy sector. Inside a wind turbine nacelle, where cooling circuit is usually available as standard, but a lot of room is not available, it is optimal to use liquid-cooled products. According to the MS Balti Trafo OÜ, the use of liquid cooling, makes possible to make products three times lighter as similar products without liquid cooling.

When a new product enters the production, the various aspects of the product must be tested to give the customer information about the properties of the product, including hydraulic parameters of the liquid-cooled products.
The objective of this thesis is to develop a test device suitable for the company for testing their liquid-cooled products, by analysing the hydraulic properties of their products and taking into account the company wishes what features and properties the test device should have.

Generally - testing hydraulic parameters of liquid are not something difficult or special. In all water pipeline building projects, the building completes with pipeline pressure test where pipe system is filled with water, pressurized and the pipeline must hold its pressure for the required amount of time [1]. For that the pipeline pressure testing equipment is required, what makes a required static pressure, and it contains a pressure gauge, which makes possible to observe pressure drop during a period of time. For that purpose, there are available a lot of different hydrostatic test pumps for pipeline pressure testing as standard products. But when there is need for variable flow rate, as well as other extra features, then that kind of device is not available on the market as standard product. It must be produced as unique product, according to the company needs.

The initial company requirements for the test device are as follows: variable liquid flow rate, variable liquid input temperature, variable liquid-coolant cooling capacity, extra inputs for thermo-couples, compact size of the device and the system must provide possibility to record all the parameters during testing. The finalized test device properties are found during product development process, when analysing example products from the company product range.

Thesis main objectives:

1. Determine the theoretical hydraulic resistance of MS Balti Trafo products
2. Develop perspective test device according to the company MS Balti Trafo needs
3. Choose optimal components for the test device considering availability

The thesis contains of chapters:

1. Overview of the company and products
2. Theoretical hydraulic resistance calculation of the MS Balti Trafo OÜ products
3. Test device product development
4. Optimal components selection

2. OVERVIEW OF THE MS BALTI TRAFO OÜ

MS Balti Trafo OÜ is a private limited company which was founded in 1997 [2]. The company is located in Vändra, about 120 km from Tallinn. The company has about 120 employees. MS Balti Trafo OÜ is part of the Tech Power Group which one of the leading companies of the transformer technology. The company supports customer projects though entire production cycle: from the start of the product development to the serial production of the product. The company has full expertise in the production of inductive components and systems. The main clients of the company are located in the Western Europe, Scandinavia and Baltic States. The company has ISO 9001:2015 quality management system.

The mission of the company is to be flexible partner to the clients of the electrical sector and to provide clients with the products of small transformers, inductive components and power supply units.

Figure 2.1.1 MS Balti Trafo OÜ production premises in Vändra

2.1 The products of the MS Balti Trafo OÜ

MS Balti Trafo OÜ has a wide array of standard and custom-made products – transformers and coils. The company offers transformers from 0.5 VA to 100 kVA in 50-60 Hz, inductive components, and power supplies. The products are used in telecommunication equipment, radio electronics, audio and video equipment, power supply and transmission units etc. The premises and prodution of the MS Balti Trafo OÜ can be seen in Figures 2.1.1 and 2.1.2.

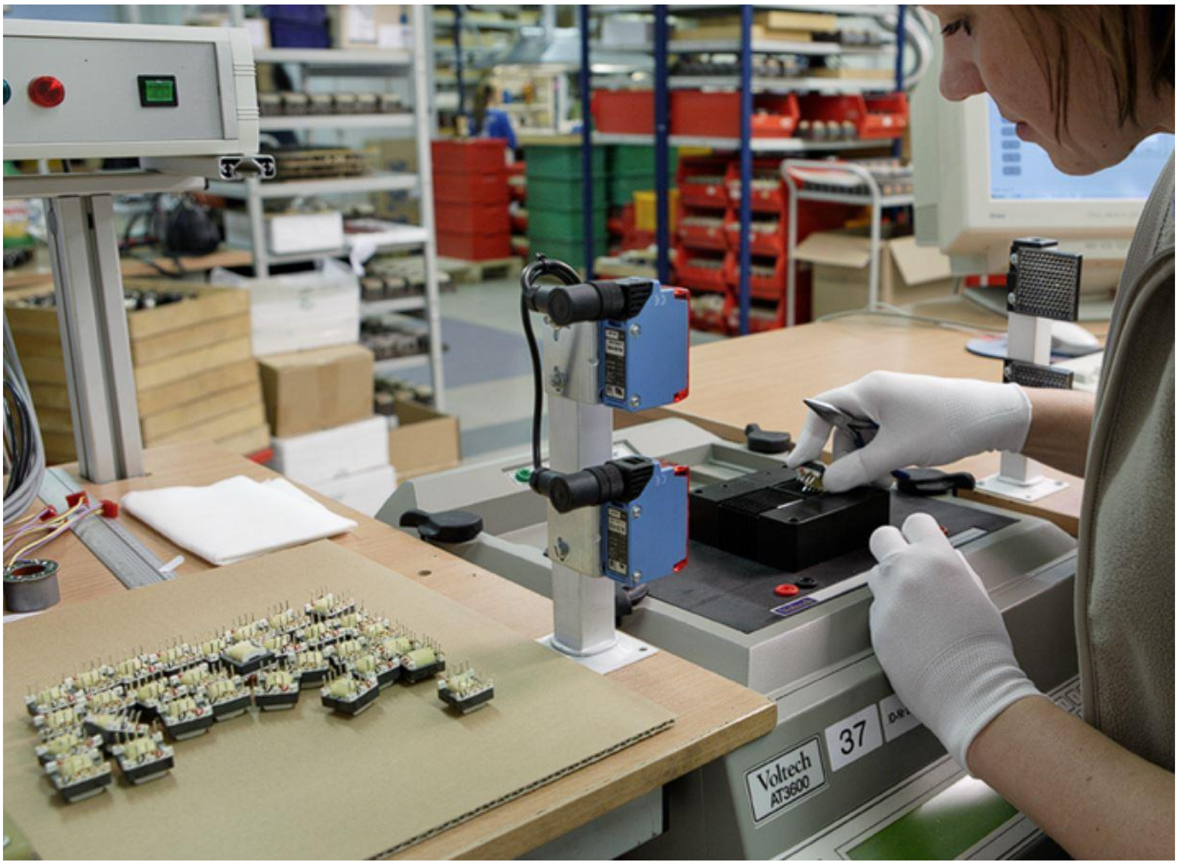


Figure 2.1.2 Production of small transformers in MS Balti Trafo OÜ production

Overview of the liquid-cooled products.

MS Balti Trafo OÜ has in the product range new innovative liquid-cooled transformers and coils, that use liquid - deionized water – to transfer heat from the product to the environment. This allows – according to the company - to make the products three times lighter than comparable products without liquid-cooling. The deionized water has almost all its ions taken out and therefore poor electrical conductor, it makes possible to design products where for example cooling liquid flows inside transformers windings. Deionized water has an electrical conductivity of $5.5x10^{-6}$ S/m, it is several thousands of times smaller than drinking water 0.005…0.05 S/m or sea water 5 S/m [3]. The production of liquid-cooled choke can be seen in Figure 2.1.3.

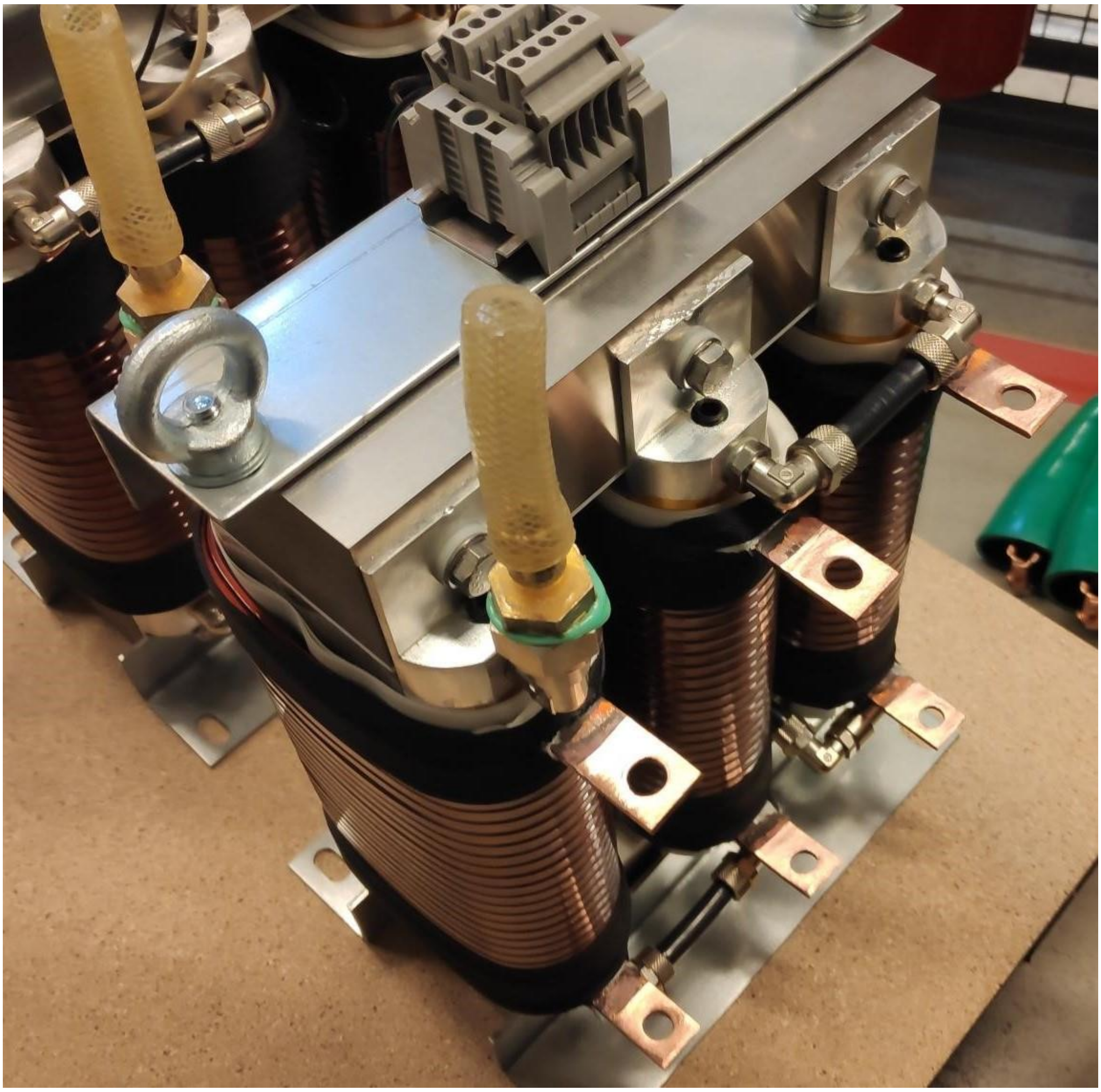


Figure 2.1.3 Production of liquid-cooled choke – filter unit UPS

3. THE PRODUCT DEVELOPMENT OF THE TEST MACHINE

The product development of the test device for the liquid-cooled transformers consists of five steps as seen in figure 3.1. The first step is the input gathering from the company MS Balti Trafo OÜ as their requirements for the test device. The second step is an idea generation of different perspective solutions for the test device. The third step is an idea screening with cooperation of the company. The fourth step is product development which consist of

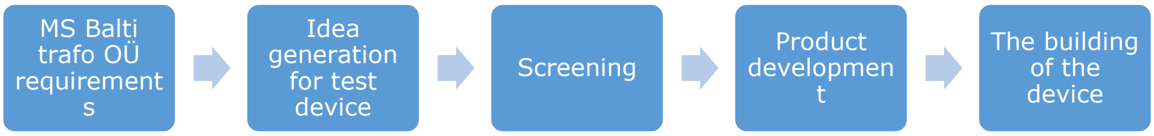


Figure 3.1 Product development process of the test device for liquid-cooled transformers

3.1 The MS Balti Trafo OÜ requirements for the test device

The MS Balti Trafo OÜ initial requirements for the test device were delivered via e-mail from the research and development manager Marius Luik and are listed as follows:

1. Pipe diameters of devices tested 6…12 mm
2. Flow rate of the liquid 0.5…10 l/min, adjustable
3. Cooling capacity – 10 kW
4. Incoming liquid temperature range to device tested 50…60 °C, adjustable
5. Outgoing temperature from tested device: 80 °C maximum
6. Estimated pressure drop from device tested 0,3 bar, may be exceptions
7. Recommendation to use Beckhoff automation controller and HMI
8. The device should have emergency stop feature for the tested device due overtemperature
9. The budget of the device – 10000 EUR
10. The test device must have several thermocouple inputs for conducing and logging temperature measurements from device tested: 6 k-type thermocouples and 6 PT-100

type thermosensors. Also, pressure drop from the tested device, flow rate of the liquid and incoming and outgoing temperatures must be measured and logged
11. The liquid used: distilled (deionized) water
12. The quick cooldown possibility (to environment temperature) of the tested device
12. The recommended size of the test device 1000 x 1000 mm, height 2000 mm

3.2 The idea generation for the test device

The test device consists of different types of parts: hydraulic circuit, electrical circuit, and mechanical design. The hydraulic circuit is the most important one, as it is directly as the main function of the device. The electrical circuit and the mechanical design are in supportive role as it is an industrial device and the mechanical design is only generally limited by the company recommendations of the size of the test device. The recommended size is 1000x1000 mm and the height of the test device is up to 2000 mm.

Initial proposed solutions for the company requirements can be seen in table 3.2 and for the idea generation phase several hydraulic circuits were made considering requirements for the test device, as seen on Figures 3.2…3.5.

Different hydraulic circuits have its strengths and weaknesses, they are evaluated afterwards in the screening process, where the most perspective is chosen to go forward.

Table 3.2 Initial proposed solutions for the MS Balti Trafo OÜ requirements

The company requirement	**Solution**
Variable liquid flow rate 0.5…10 l/min	Pump with speed control
Cooling capacity 10 kW	Calorifier
Incoming temperature range variable 50…60 ℃	Mixing valve or heat exchanger
Beckhoff controller and HMI for control and logging data	Controller and HMI
Flow rate measurement	Flow rate meter
Pressure drop measurement	Differential pressure gauge

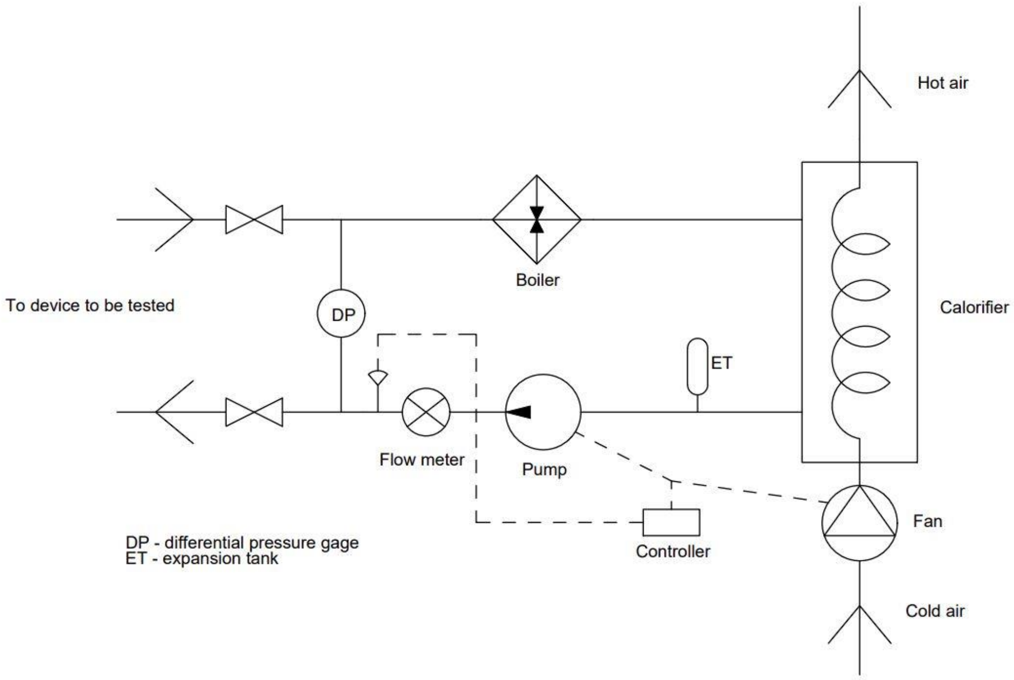


Figure 3.2.1 Test device version 1 with boiler and calorifier

The test device version 1 with boiler and calorifier can be seen in figure 3.2.1. The device to be tested is connected to the hydraulic circuit with hoses. Then the system is filled with liquid from the external source. After that the liquid is preheated to required temperature with a standard boiler with boiler internal temperature control.

The waiting time before the start of the test depends on the heater elements power inside the boiler. The testing process can be started with the starting of the pump and light electrical load to the device to be tested. After the starting of the testing process the boiler is no longer needed, as extra heat comes from the device tested. As the boiler has a built-in temperature control, it shuts itself off automatically. Nevertheless, when there is a wish to test at the end of the testing process - with smaller temperatures than the pre-heated temperature - then the boiler must be switched off manually.

The liquid is pumped through calorifier with speed-controlled pump, the required temperature is maintained with controller that gets data from temperature sensor and controls calorifier fan speed.

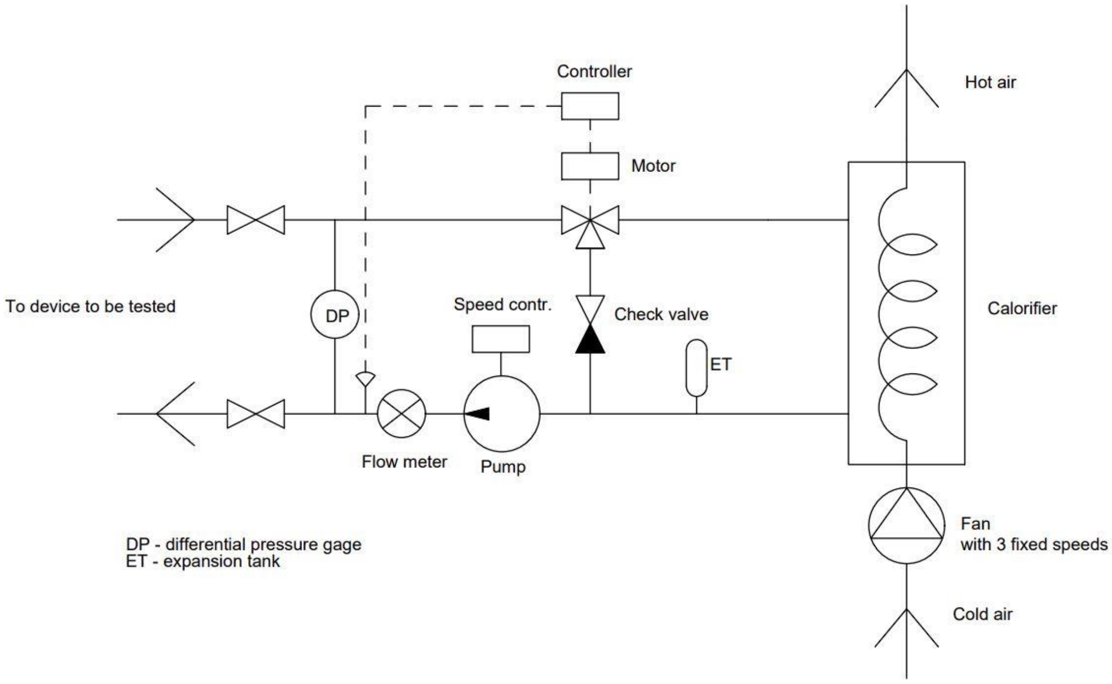


Figure 3.2.2 Test device version 2 with 3-way diverting valve

The test device version 2 is with 3-way diverting valve and can be seen in figure 3.2.2. The testing process starts the same as with version 1, the hoses are connected to the device to be tested and the system is filled with liquid. This time calorifier fan is controlled with 3 fixed speed settings and the required temperature is maintained through 3-way valve with controller.

The liquid is preheated to the required temperature using the device under test as heat source. The test starts with staring of the pump and by applying the electrical load to the device under test. At first the valve diverts all the liquid to the pump and back to the device under test. When the required temperature is reached, then the valve diverts some or all the liquid trough the calorifier.

The fan of the calorifier is operated manually with three fixed settings, before the start of the test it must be evaluated what speed setting to use, depending on the projected heat load.

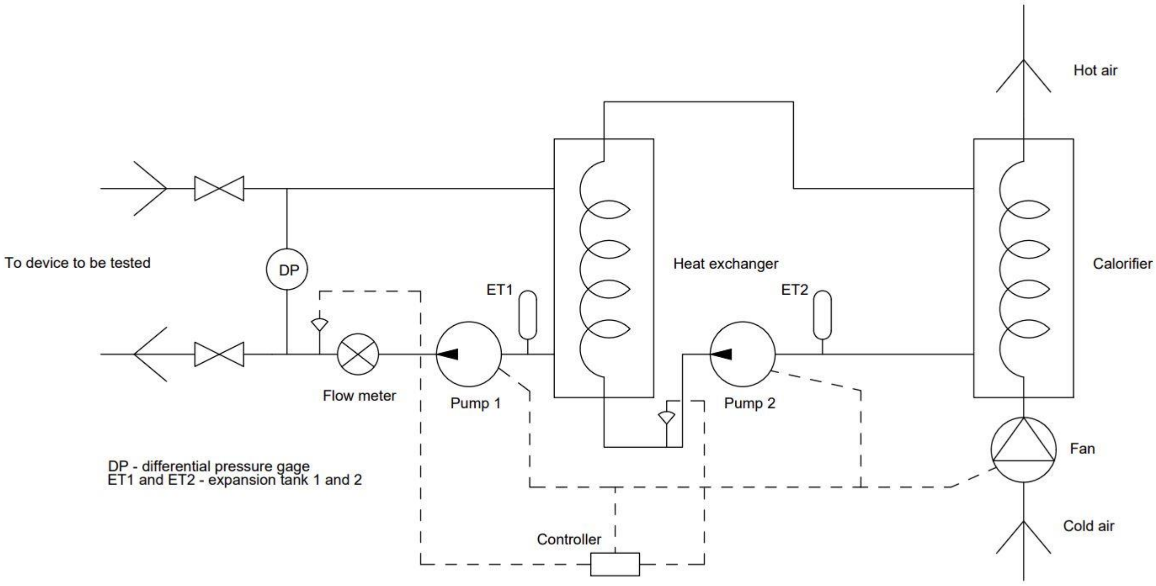


Figure 3.2.3 Test device version 3 with heat exchanger

The test device version 3 is with a heat exchanger and can be seen in figure 3.2.3. In this version there are two different separated hydraulic circuits with two pumps. One hydraulic circuit is open and ready for connection to the external heat source (the device to be tested), the other one is closed and used only for cooling via the heat exchanger.

The start of the testing process starts with connecting the hoses to the device to be tested, then the system is filled with liquid and the pump 1 is started. After that the electrical load can be applied to the device under test and the temperature of the liquid starts rising.

When the required incoming temperature for testing is reached, then the controller switch on the pump 2 and calorifier fan.

This version of test device has the most components compared to the other versions and it makes the estimated cost of the device higher. Also, the automation part of the device is more compilated as the controller has inputs from two different temperature sensors and it has to control two different pumps.

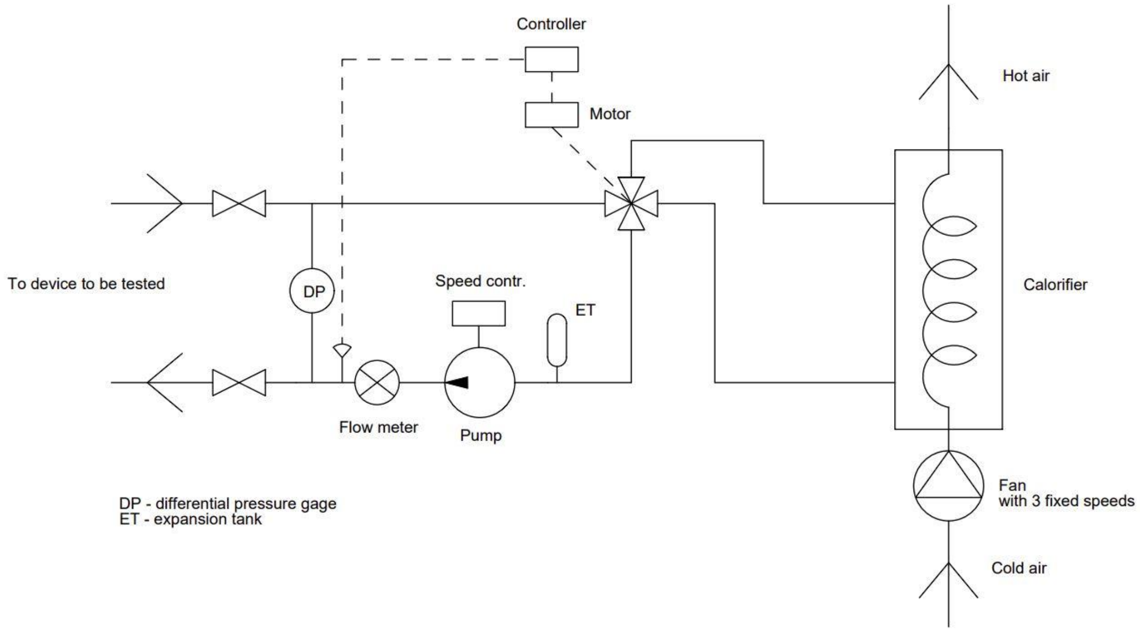


Figure 3.2.4 Test device version 4 with 4-way valve

The test device version 4 is with 4-way valve and can be seen in figure 3.2.4, it is very close to version 2, except for the 4-way valve.

The testing process starts the same as with version 2, the hoses are connected to the device to be tested and the system is filled with liquid. The calorifier fan is controlled with 3 fixed speed settings and the required temperature is maintained through 4-way valve with controller.

The liquid is preheated to the required temperature using the device under test as heat source. The test starts with staring of the pump and by applying the electrical load to the device under test. At first the valve diverts all the liquid to the pump and back to the device under test. When the required temperature is reached, then the valve diverts some or all the liquid trough the calorifier.

The fan of the calorifier is operated manually with three fixed speed settings, again before the start of the test it must be evaluated what speed setting to use, depending on the projected heat load.

3.3 Screening

After idea generation the screening decision-making task was conducted for the most perspective hydraulic circuit of the test device. The different aspects of the various versions were evaluated in table 3.3, where from scale 1…5 aspects are evaluated if the version is in favorable situation or not. 5 marks the most favorable situation, and 1 the least favorable. At the right part of the table, weights are added to the evaluation of each version. Finally, at the bottom of the table evaluated weighted scores can be seen, the highest score means more reasonable solution to the test device.

Table 3.3 Test device hydraulic circuit evaluation table

No	Description of factor	Version 1	Version 2	Version 3	Version 4	Weight
1	Nr. of different components	5	5	2	5	0,2
2	Ease of automation part	4	5	4	5	0,2
3	Use of widely used standard components	5	5	4	4	0,3
4	Estimated cost of the test device	5	5	2	5	0,3
	Weighted score	4,8	5	3	4,7	

The number of components is almost the same on versions 1,2 and 4, only version 3 has the heat exchanger and one pump as extra, as well as more complicated automation. The possible need for switching off the boiler during testing makes the automation part a little bit more complicated in version 1.

Version 3 is the most complicated and expensive version. Versions 1, 2 and 4 are very close estimating the cost, automation, and standard components, but still version 2 hydraulic circuit with 3-way valve comes out of evaluation with the highest weighted score of 5.0 and therefore is the most favorable version for further development.

The different versions of hydraulic circuits were presented to the MS Balti Trafo OÜ research and development team and the agreement was made to move forward with version 2.

3.4 Product development

3.4.1 Safety risk assessment

Before moving forward with product development, the test device CE marking requirement and safety risk assessment was conducted, also what are the relevant standards and directives what the test device should comply with, were assessed.

For the prototype CE marking is not required during research and development stage as it is not posed to the market yet - in the meaning until the test device is not sold. For the relevant directives Directive 2006/42/EC on Machinery [4], ISO 12100:2010 Safety of machinery – General principles for design – Risk assessment and risk reduction [5] were used for developing the test device.

Inherently safe design measures were considered for geometrical factors, physical aspects, provisions for stability, provisions for maintainability, ergonomic principles, electrical hazards, and hydraulic hazards. Also, hydraulic safety is very important: maximum rated pressure cannot be exceeded in the circuit (pressure limiting devices should be considered), all elements of the equipment protection – pipes and hoses – should be protected against harmful external effects. As well as general safety for safe design measures of control systems: emergency stop function of the test device should be implemented.

The initial risk assessment of the test device can be seen in table 3.4. After the test device finishes prototype stage and all the final solution parts are clear, a new risk assessment should be made.

Table 3.4 Initial risk assessment of the test device

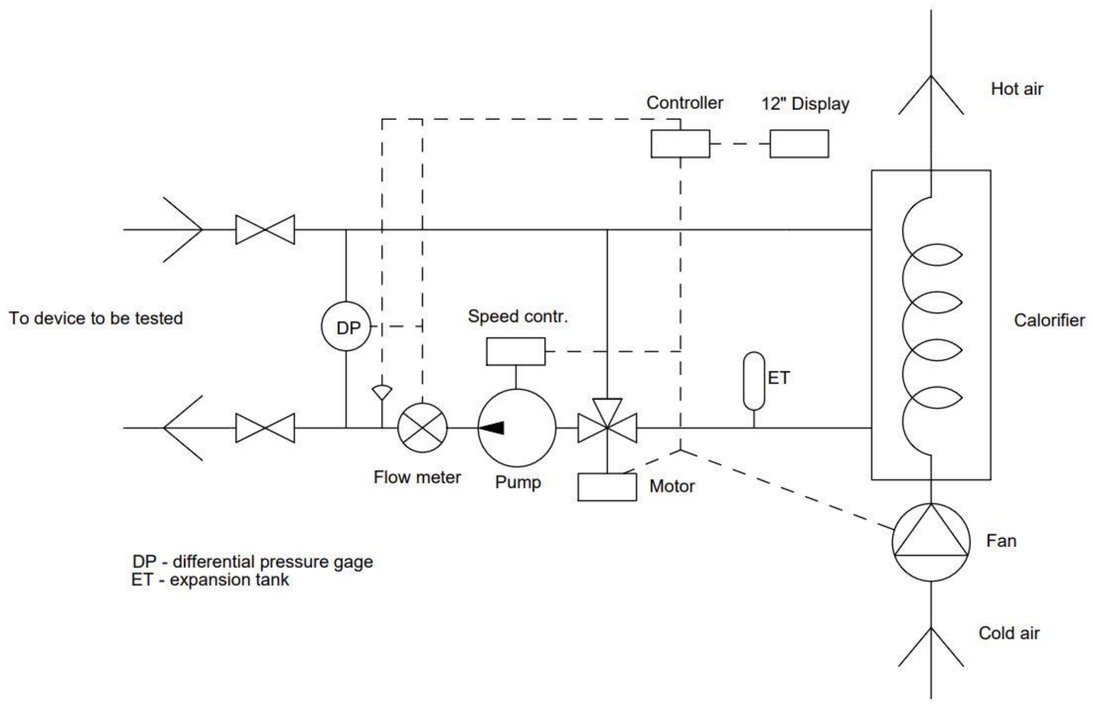
No	Description of risk	Risk mitigation
1	Noise	According to the real noise level, ear protection should be considered
2	Vibration	The frame of the device should be sturdy, vibration dampeners if required
3	Electric malfunction	The electric circuit protection devices should be used
4	Hydraulic malfunction	The hydraulic pressure limiter should be used, emergency stop
5	The use of hazardous liquids	The use of hazardous liquids is prohibited

3.4.2 Test device version 2 hydraulic circuit further development

The test device hydraulic circuit version 2 was further developed to version 2.1 as seen on figure 3.4.2 according to the MS Balti Trafo OÜ requirements, as controller control was added to control the fan of the calorifier. This is easily possible as proposed Beckhoff industrial controllers have a wide range of digital and analogue outputs to control different devices [6], everything is possible to control with one industrial controller. Also, the 3-way valve was switched from diverting operation to mixing operation, as a minor difference, and 12" human-machine interface (HMI) was added to the scheme to control and monitor all the data and functions.

The input data connection from differential pressure gauge and from the flow meter was also added to the scheme, as the 12" display (HMI) can show all the data in real time in one display. Now it can be said that perspective hydraulic circuit for automation development is ready, only minor tweaks will be needed do develop more in the future during mechanical design of the device, such as the location of drain cock, filling tap etc.

Figure 3.4.2 Test device version 2.1 with 3-way mixing valve and 12" HMI



3.4.3 Test device automation selection

For the automation part of the test device, Beckhoff Automation OÜ Tallinn office was contacted, and perspective suitable hardware and controller software were presented by the Beckhoff Automation. The input data for the company was the number of inputs and outputs required for the test device, as well as the need for 12″ HMI.

The required inputs and outputs for automation part can be seen in table 3.4.3.1, altogether at least 17 inputs and 3 outputs are required for automation and as it is a prototype device, a few more of each should be available as a reserve for future development.

Table 3.4.3.1 Input and output requirements of the test device controller

No	Description of input/output	No of inputs	No of outputs
1	Pump control		1
2	Fan control		1
3	3-way valve motor control		1
4	k-type thermocouples	6	
5	PT-100 type thermocouples	6	
6	Pressure sensors	2	
7	Flow meter	1	
8	Temperature sensors	2	
	Sum	17	3

After the inquiry, Beckhoff Automation OÜ made an offer Nr. 805, as seen in appendices 1. The solution is available, it consists of Beckhoff Automation 12″ multitouch panel PC with necessary addons, such as extra input terminals and Ethercat coupler.

Nevertheless, the delivery time from the factory is 20 or more weeks for all the parts and this is a quite long delivery time. As the result, MS Balti Trafo OÜ was contacted for consultations about suitable automation selection considering delivery times of automation components. The decision was to create a cheaper alternative with simple controller and at the same time search for similar controller solution from other manufacturer than Beckhoff Automation OÜ.

The simpler controller solution was created as an alternative with ESBE CRA110 series [7] controller, as seen in Figure 3.4.3.1, it is used for 3-way mixing valve operations, and the hydraulic circuit is presented in Figure 3.4.3.2.

Figure 3.4.3.1 ESBE CRA110 series controller

The controller gets its input from one temperature sensor, and it is capable for controlling 3-way valve with built-in motor to keep the required temperature theoretically in 5...95 °C range.

Nevertheless, the pump motor speed and the speed of the calorifier fan should be controlled manually (with knob) in this case and some solution with a low-cost computer Raspberry Pi 4 [8] or similar should be used for logging data from different sensors and external display connected to the Raspberry PI 4 should act as display for different data values from various inputs. The price of the ESBE CRA110 series controller is in 400 EUR price range and Raspberry Pi 4 with extensions and monitor are in 500 EUR price range.

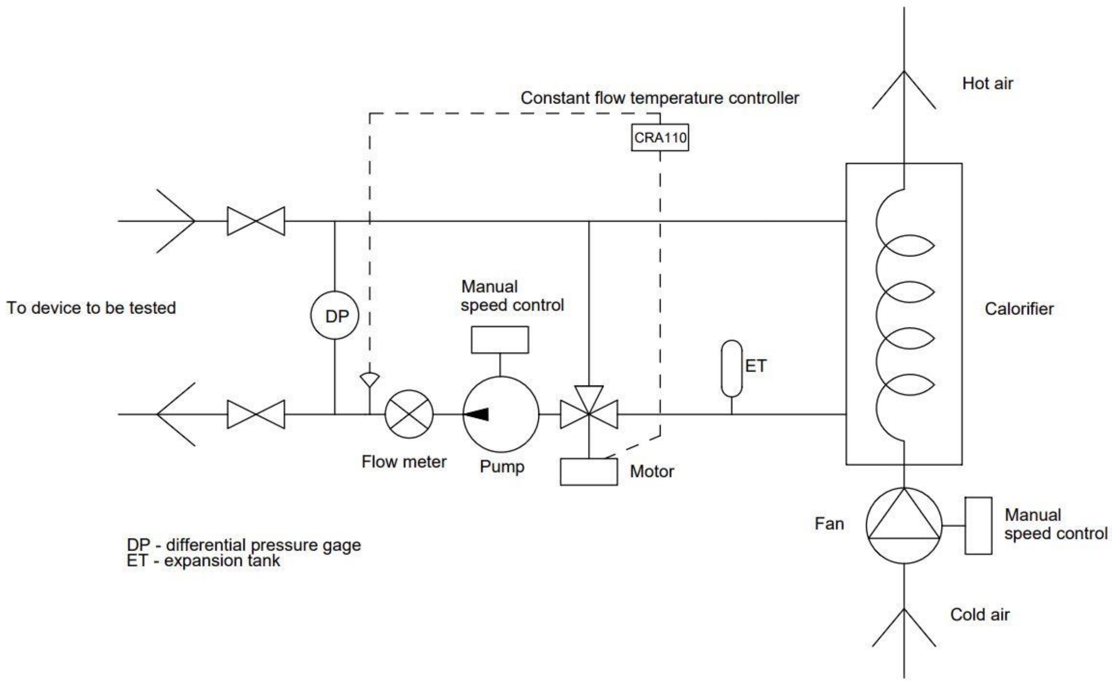
The similar controller solution as from Beckhoff Automation OÜ was presented from Kemeri OÜ, in the basis of Siemens Simatic S7-1200 controller [9] with all the necessary extensions for extra inputs and outputs and 12" Siemens display. The offer can be seen in appendices 2 as offer MP2200321. Delivery time was promised up to 4 weeks for all parts.

After getting the price offer from Kemeri OÜ, MS Balti Trafo was contacted, and two automation options were presented: cheaper partially manually operated with ESBE CRA110 series controller in the price range of 800 EUR and Siemens Simatic S7-1200 based version in the price range of 5000 EUR.

After careful consideration, the decision was to go forward with Siemens automation products, as automatic operation is required – manual operation of some of the key functions of the test device makes the operating harder and the more professional test device operator is needed. The price of the Siemens automation products fits in the allowed budget for all test device, which was 10000 EUR.

After the automation part in product development, the next part is the suitable pump selection with calculating the hydraulic resistance of some of the MS Balti Trafo OÜ example products.

Figure 3.4.3.2 Test device version 2.2 with simple mixing valve controller CRA110



3.4.4 Test device pump selection

The initial requirements from the MS Balti Trafo OÜ for the pump can be seen in table 3.4.4. The overall pipe connections inside test device will be chosen DN15 or equivalent 1/2", as the pipe diameters inside the devices that will be tested do not exceed 12 mm.

Table 3.4.4 Initial requirements for the pump

No	Name of the requirement	Value
1	Flow rate	0.5…10 L/min
2	Liquid	Water
3	Temperature of liquid	80 °C maximum
4	Estimated pressure head	0,3 bar

The initial requirements and some example products from the MS Baltri Trafo OÜ liquid-cooled product range were considered for theoretical hydraulic resistance calculation: water-cooled chokes MS14894 and MS14813. The information brochure for MS14894 can be seen in appendix 3, there can be seen that minimum flow rate for that product is 3 l/min, but pressure drop is "TBD" – to be determined.

Hydraulic resistance range of the products is needed to know for optimal pump selection, as estimated pressure drop is 0,3 bar, but for testing purposes pump with bigger pressure head may be needed to test the products in suboptimal range of flow rate and therefore with much bigger hydraulic resistance in testing purposes.

The products were offered for hydraulic resistance calculation from MS Balti Trafo OÜ, the first one MS14894 has one of the longest hydraulic circuits in the product range – 44 meters and MS14813 has about 2 meters, so they can be considered as two opposite examples from the product range.

The example products hydraulic circuit is analysed, and hydraulic resistance will be calculated using specialized freeware software for hydraulic calculations. After the hydraulic resistance calculations are done for example products, then the pump with suitable parameters can be selected.

3.4.4.1 Hydraulic resistance calculation theory

Hydraulic resistances and therefore pressure losses caused by these resistances are two types: frictional pressure losses and local pressure losses [10], [11]. Frictional pressure losses cause smooth energy line decline, the longer the flow section – the bigger the frictional losses. The local pressure loss causes energy line decline as a step. In a specific flow there can be both types of pressure losses and the total pressure loss is calculated:

$$h_t = \sum h_k + \sum h_l$$

where h_t – total pressure loss, h_l – frictional pressure loss, h_k – local pressure loss.
The equation for calculating frictional pressure loss in a pipe is from the French water engineer Henri Darcy (1803-1858) [10] :

$$h_l = \lambda \frac{l}{d} \frac{v^2}{2g}$$

where h_l – frictional pressure loss, λ – frictional resistance factor, l – the length of the pipe, d – hydraulic diameter of the pipe, v – water speed in the pipe. The frictional resistance factor λ depends on the surface material of the pipe, on the kinematic viscosity of the liquid, on the speed of the liquid in the pipe, as well as the diameter of the pipe and it is found using the Moody chart [10].
The equation for calculating local pressure losses is from Julius Weisbach (1806-1871) [10]:

$$h_k = \zeta \frac{v^2}{2g}$$

where h_k – local pressure loss, ζ – local resistance factor, v – water speed in the pipe.
The local resistance factor ζ can be found for different shapes of local resistances (bend, hole, diffusor etc.) in a suitable handbook [10], [11].
In conclusion when calculating hydraulic resistances, there are a lot of factors to consider that affect the frictional resistance factor and local resistance factor, therefore it is not optimal to do it by hand or in Microsoft Excel for example. There is available different specialized hydraulic calculation software as freeware, and it is reasonable to use them instead.

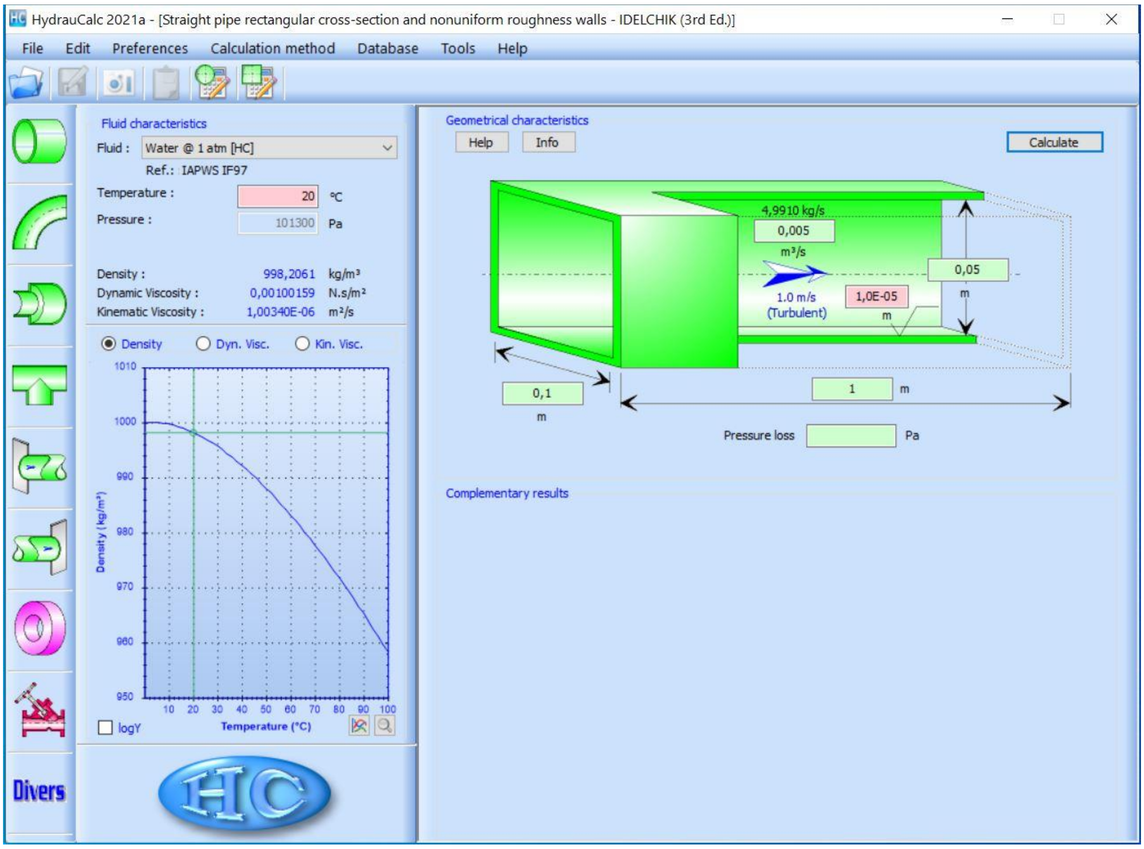
3.4.4.2 Hydraulic resistance calculation software

There is available different freeware software for calculating hydraulic resistances in online form or as downloadable form that can be installed in a PC computer.

HydrauCalc 2021a [12] is one example of PC based French freeware software that is mainly based on well-known and respected references in the field of fluid flow and pressure drop calculation, such as: "Handbook of Hydraulic Resistance", 3rd Edition, I.E Idelchik; "Internal Flow System", 2nd Edition, D.S Miller; "Flow of Fluids Through Valves, Fitting and Pipe" – Crane Technical Paper No. 410; "Pipe Flow: A Practical and Comprehensive Guide", Donald C. Rennels and Hobart M. Hudson.

HydrauCalc 2021a allows accurate modelling and calculating of stabilized flows in piping elements such as bends, pipes, tees, valves etc. The graphical user interface – as seen in figure 3.4.4.2 is available in English, French and Spanish. It allows the user to choose between different elements (pipes, bends etc.) as seen on the left corner of the HydrauCalc main window view, and calculate the hydraulic resistance, choosing other required parameters – for example pipe dimensions and flow rate through pipe.

Figure 3.4.4.2.1 HydrauCalc 2021a main window



The other example is online pressure drop calculator Pressure-drop.online [13], which is offered from the German company Software-Factory Schmitz. Its web page offers less information about on what theory or literature the hydraulic calculations are based on but the user interface is more concise and it offers the opportunity to add together multiple hydraulic parts and calculate their combined hydraulic resistance automatically. The graphical user interface of Pressure-drop.online can be seen in figure 3.4.4.2.2, 3.4.4.2.2 and in figure 3.4.4.2.3.

Figure 3.4.4.2.2 Graphical user interface of Pressure-drop.online

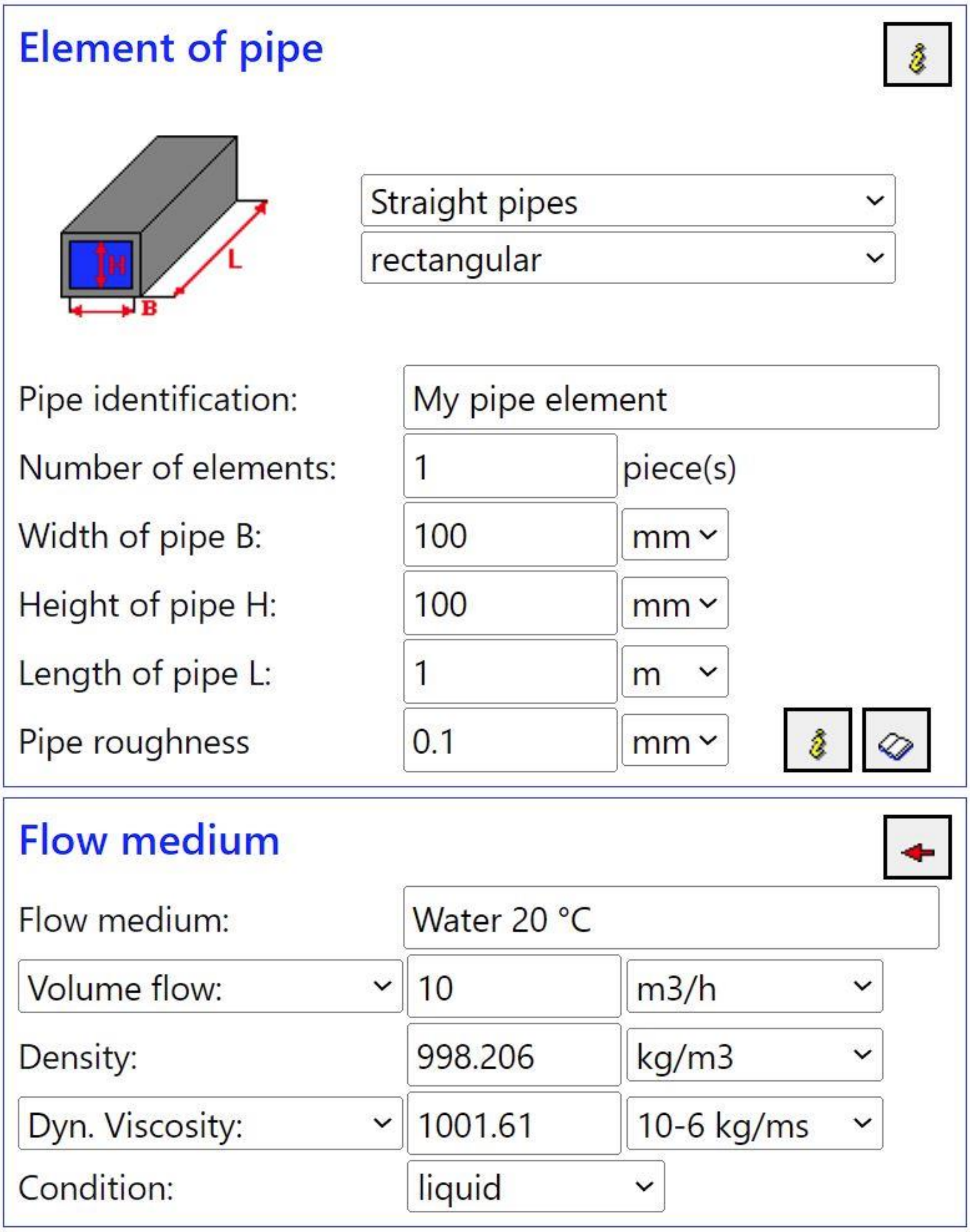


Figure 3.4.4.2.3 Graphical user interface – the result part of the Pressure-drop.online

			☐ 1	2
1	**1. Flow medium**			
2	Flow medium		Water 20 °C	
3	Condition		liquid	
4	Volume flow	m3/h	10.000	
5	Mass flow	kg/h	9982.060	
6	Volume flow branch.pipe	m3/h	---	
7	Density	kg/m3	998.206	
8	Dyn. Viscosity	10-6 kg/r	1001.610	
9	Kin. Viscosity	10-6 m2/	1.003	
-	**2. Additional data for gases**			
11	Pressure (inlet, abs.)	bar	---	
12	Temperature (inlet)	°C	---	
13	Temperature (outlet)	°C	---	
14	Norm volume flow	Nm3/h	---	
15	**3. Element of pipe**			
16	Pipe identification		My pipe element	
17	Element of pipe		rectangular	
18	Number of elements		1	
19	Dimensions of element	SI	Width of pipe B: 100.00 mm	
20			Height of pipe H: 100.00 mm	
21			Length of pipe L: 1.00 m	
22			---	
23			---	
24			---	

Figure 3.4.4.2.4 Graphical user interface of Pressure-drop.online

25	**4. Result of calculation**		
26	Velocity of flow	m/s	0.278
27	Reynolds number		27683.374
28	Velocity of flow 2	m/s	---
29	Reynolds number 2		---
30	Flow		turbulent
31	Absolute roughness	mm	0.100
32	Pipe friction number		0.026
33	Resistance coefficient		0.263
34	Res. coeff. branching pipe		---
35	Press.drop branching pipe	bar	---
36	Pressure drop	bar	0.000
37	**Pressure drop**	bar	0.000
38	**Sum pressure drop**	bar	0.000
39	Remarks		

Altogether there are 39 lines of output information from the online software, some of the lines are empty or not relevant, but pressure drop, and sum pressure drop from the hydraulic resistance is precisely calculated. In addition, there are information available about the mass flow, dynamic viscosity, kinematic viscosity, velocity of flow, Reynolds number, flow type, pipe friction number, resistance coefficient etc.

All in all, the different hydraulic resistance calculation software was compared with the same input parameters and the same results were gained, the decision was to use Pressure-drop.online as it offers the opportunity to add together automatically several hydraulic parts of the circuit. It is very important when you have a long hydraulic circuit which consists of many different types of parts: straight parts, different bends etc.

3.4.4.3 The example liquid-cooled products hydraulic resistance calculation

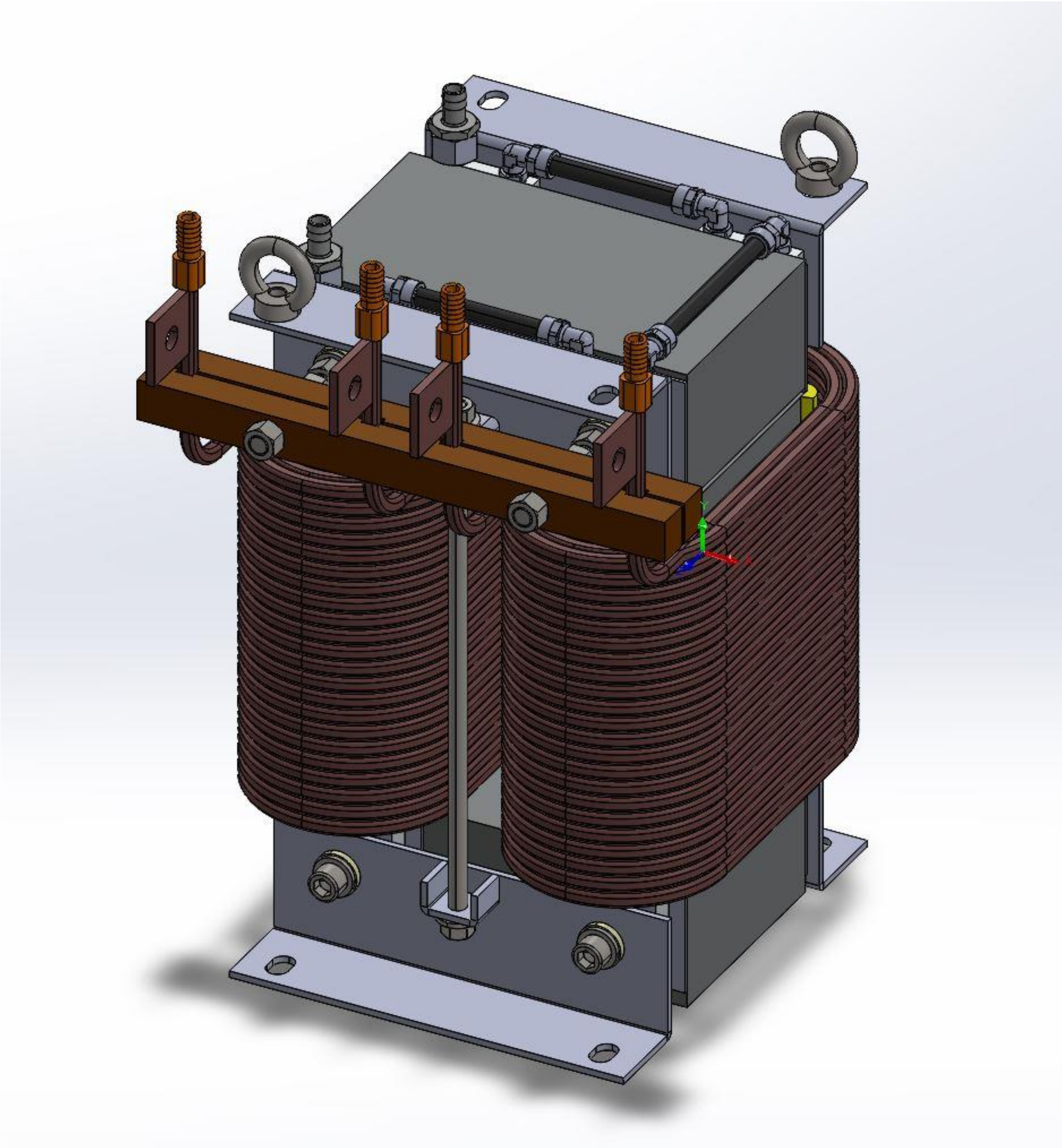
The example liquid-cooled products from MS Balti Trafo OÜ were presented for theoretical hydraulic resistance calculation: choke MS14894 has one of the longest hydraulic contours in the product range and MS14813 has the opposite length of the hydraulic contour.

The hydraulic resistance calculation of the product starts with analysing the product geometry, finding the hydraulic contour and its geometrical shape. When all the different parts of the product hydraulic contour are found, then the data of different parts is entered to the hydraulic resistance calculation software Pressure-drop.online. The geometrical data of the products is available in STEP (Standard of exchange of product data) file format, and it is analysed in Solid Works 2021 software.

The example MS Balti Trafo OÜ product nr. 1 choke MS148924 can be seen on figures 3.4.4.3.1, 3.4.4.3.2, 3.4.4.3.4 and 3.4.4.3.5. The different views of the product are presented to clearly indicate where cooling circuit is located inside the product.

Figure 3.4.4.3.1 Choke MS14894 in MS Balti Trafo OÜ production

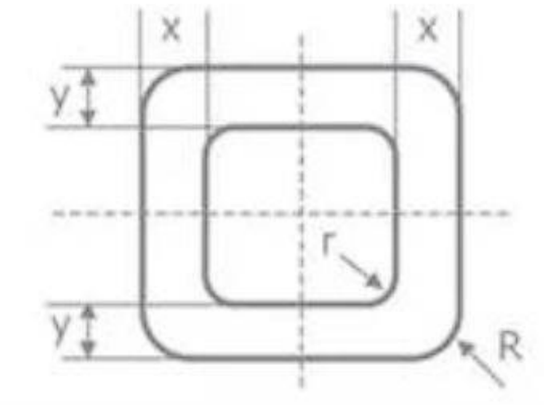
Figure 3.4.4.3.2 Choke MS14894 full assembly in STEP file



As seen in Figure 3.4.4.3.2, the choke MS14894 has two windings, which are made of Finnish company Luvata hollow conductors [14]. In addition, the choke has the third cooling contour made of four cooling plates for core cooling, connected with hoses. In the product MS14894 brochure (Appendix 3) is said that all cooling contours are connected in series, therefore the pressure drops of all 3 hydraulic contours must be added together to get the full pressure drop of the product.

When high magnetic fields are required, then the magnetic winding is produced from internally cooled hollow sections. There is available square hollow conductor with a round or rectangular cooling channel as standard, special shapes are available on demand. Luvata has been making hollow conductors for the most demanding applications for over sixty years. All impurities reduce the electrical conductivity of copper, Luvata hollow conductors are made from OK-OF® (EN CW008A) high purity oxygen-free copper. The direct cooling has challenges as well: potential high pressure drop in the hydraulic cooling system inside the hollow conductors [14].

Figure 3.4.4.3.3 Luvata hollow conductor shape used in choke MS148924



The hollow conductor shape used in choke MS14894 can be seen in figure 3.4.4.3.3. It is a Luvata profile nr. 9095, outer diameter 8,26 x 8,26 mm, inner diameter 5,26 x 5,26 mm, x = y = 1,5 mm, r = 0,5 mm, R = 1,5 mm.

Figure 3.4.4.3.4 Choke MS148924 cooling contour top view

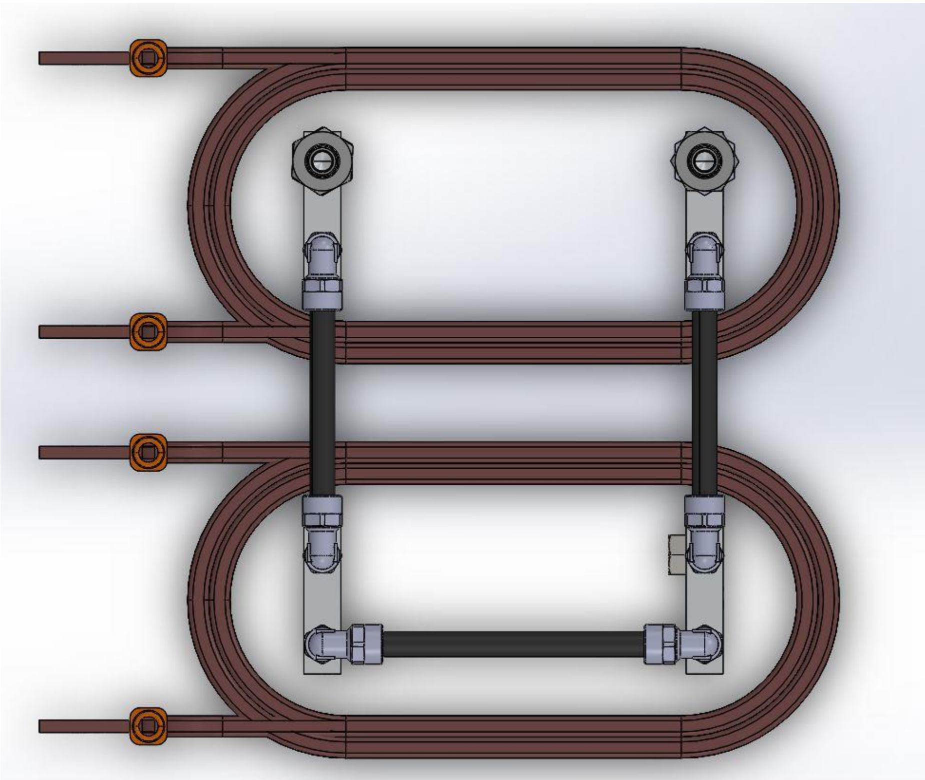
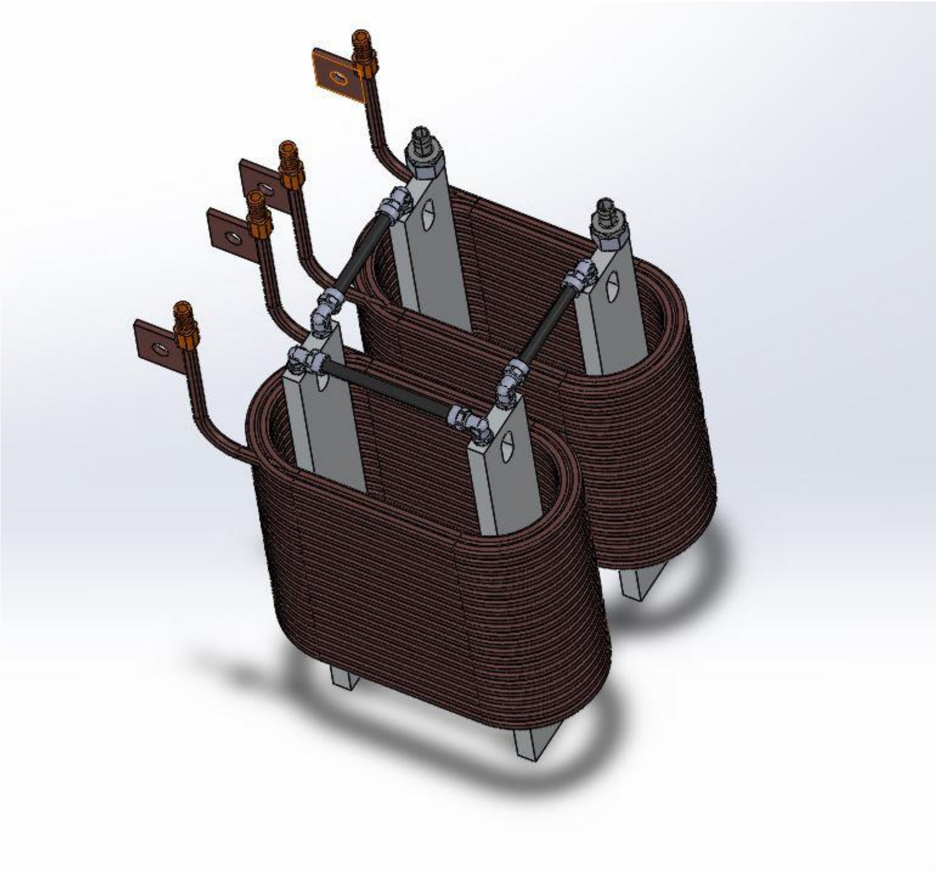


Figure 3.4.4.3.5 Choke MS14894 cooling contour in three-dimensional view



After measuring and analyzing the choke MS14894 in Solid Works 2021, the decision was to use for hydraulic calculations only the two longer hydraulic contours which are inside the hollow conductor, as the third cooling contour with 4 cooling plates for core cooling has bigger diameter (8 mm vs. 5,26 mm) and is so short compared to the 44 meters or windings, that the impact for the total hydraulic resistance value of the product will be minimal.

The measured hydraulic contour components and their parameters can be seen in table 3.4.4.4.1 and they are used in hydraulic calculations with software Pressure-drop.online.

Table 3.4.4.4.1 Choke MS14894 hydraulic contour components

	Choke MS14894	Amount
1	Straight pipe 5,26 x 5,26 mm	24 meters
2	Bend 180 degrees, 5,26 mm x 5,26 mm, r = 51,3 mm	88 pcs
3	Bend 180 degrees, 5,26 mm x 5,26 mm, r = 58,3 mm	88 pcs

The example product nr. 2 choke MS14813 can be seen on figures 3.4.4.3.6...3.4.4.3.8, this product does not have a hydraulic contour inside the conductor, only the core of the choke is cooled with cooling pads.

Figure 3.4.4.3.6 Choke MS14813 in MS Balti Trafo OÜ production

Figure 3.4.4.3.7 Choke MS14813 full assembly in STEP file

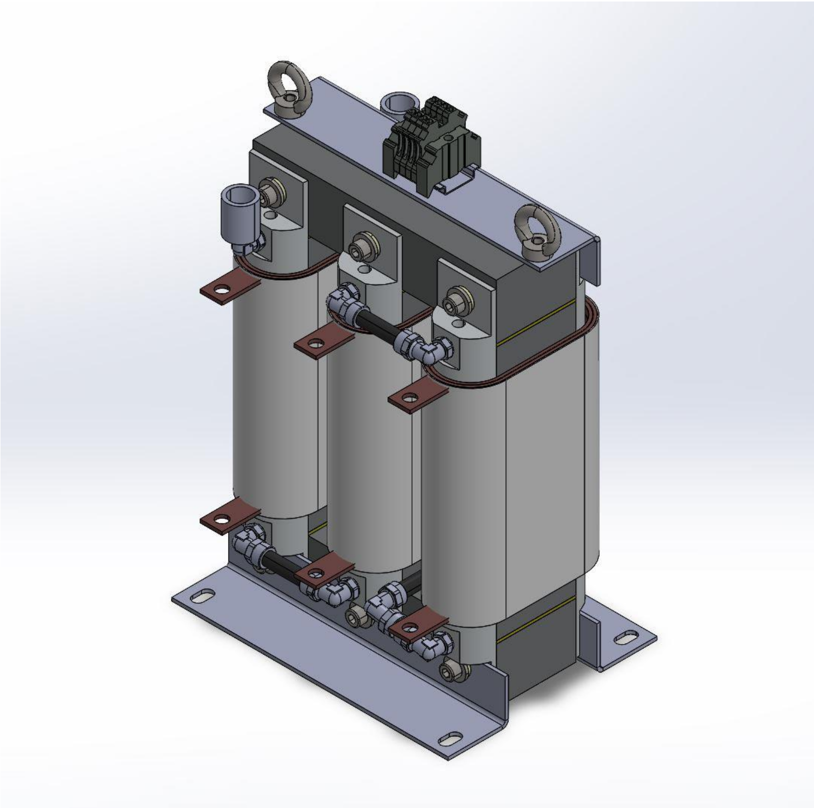


Figure 3.4.4.3.8 Choke MS14813 cooling contour in three-dimensional view

After measuring and analyzing the choke MS14813 in Solid Works 2021, the measured hydraulic contour components and their parameters can be seen in table 3.4.4.4.2 and they are used in hydraulic calculations with software Pressure-drop.online as with first example product choke MS14894.

Table 3.4.4.4.2 Choke MS14813 hydraulic contour components

Choke MS14813		Amount
1	Straight pipe d = 8 mm	1,65 meters
2	Bend 90 degrees, d = 6,5 mm, r = 1d	14 pcs
3	Bend 90 degrees, d = 8 mm, r = 1d	12 pcs

After finding all the hydraulic components of the example products, the hydraulic resistance was calculated with the software Pressure-drop.online. From additional input parameters the flow medium is selected water 20 °C, and roughness of pipe as new drawn/pressed copper 0,0015 mm.

The calculated hydraulic resistance for MS Balti Trafo OÜ products MS14894 and MS14813 can be seen in table 3.4.4.4.3. The choke MS14894 has very high hydraulic resistance, even during flow rates of 4 l/min, the hydraulic resistance is already about 10 bar which is the maximum for standard pressure components, and quite powerful and high-pressure pump is needed for testing. Over 7 l/min is almost impossible to test with this product as the hydraulic resistance is in this range that special reinforced piping and pumps are needed.

The opposite is with the other choke MS14813, where hydraulic resistance is in the projected range of 0,3 bar during the liquid flow rate until 3 l/min and maximum hydraulic resistance is with the flow rate of 10 l/min – 2,2 bar.

Table 3.4.4.4.3 Hydraulic resistance of the MS Balti Trafo OÜ example products

	Hydraulic resistance of the products (bar)									
Flow rate l/min	1	2	3	4	5	6	7	8	9	10
Choke MS14894	0,9	3,5	6,0	9,8	14,4	19,9	26,3	33,3	41,1	49,6
Choke MS14813	0,2	0,2	0,2	0,4	0,6	0,9	1,1	1,4	1,8	2,2

After calculations for hydraulic resistance of the example products were finished, MS Balti Trafo OÜ was contacted for consultations about the testing device parameters update, as the calculated hydraulic resistance of one of the products is extremely high compared to the initial projected need for product nominal hydraulic resistance 0,3 bar. The other tested product MS14813 is in projected hydraulic resistance range with nominal flow of 3 l/min.

From the test device building perspective is clear that, when high pressures (> 10 bar) are needed, then it is possible to build, but several pumps are needed for different pressure ranges and reinforced piping and construction of the test device is required. Altogether it means that new hydraulic circuit is needed, and product development should start over from the beginning.

The overall water speed recommendations in the pipes are for warm water up to 3,0 m/s [15], after that the erosion in the pipes goes high and the energy required for such speed of the water in the pipes is big – it means high costs for pumps, energy etc. For such a small dimensions of a pipe as the hollow conductor of the choke MS14894 5,26 x 5,26 mm, this means maximum reasonable flow rate about 4,9 l/min – then the liquid speed in the pipe is ~3 m/s (liquid is water at 20 °C).

After presenting the above information to the MS Balti Trafo OÜ, it was decided that the maximum pressure head of the pump is in 10 bar range, not more. Then it is possible to build the test device with one pump and with standard components which have maximum pressure rating of 10 bar.

3.4.4.4 Optimal pump selection with updated data

The pump duty point is where pump characteristic and system characteristic are compared on the same graph. A System characteristic is only possible to reduce or to throttle, using tap or similar device for local pressure loss. When the tap is turned to more closed position then the system pressure loss is increased, and flow rate is reduced. The pump characteristic is only possible to change with variable frequency drive.

Therefore, it is optimal to choose a pump with maximum required pressure head in 10 bar range and more than 10 l/min flow rate, as the characteristic of the pump can be reduced with variable frequency drive, in addition system characteristic is possible to reduce as well with a tap. The optimal updated requirements for the pump can be seen in table 3.4.4.4.

Table 3.4.4.4 Optimal updated requirements for the pump

No	Name of the requirement	Value
1	Flow rate	>10 L/min
2	Liquid	Water
3	Temperature of liquid	80 °C maximum
4	Estimated pressure head	10 bar range

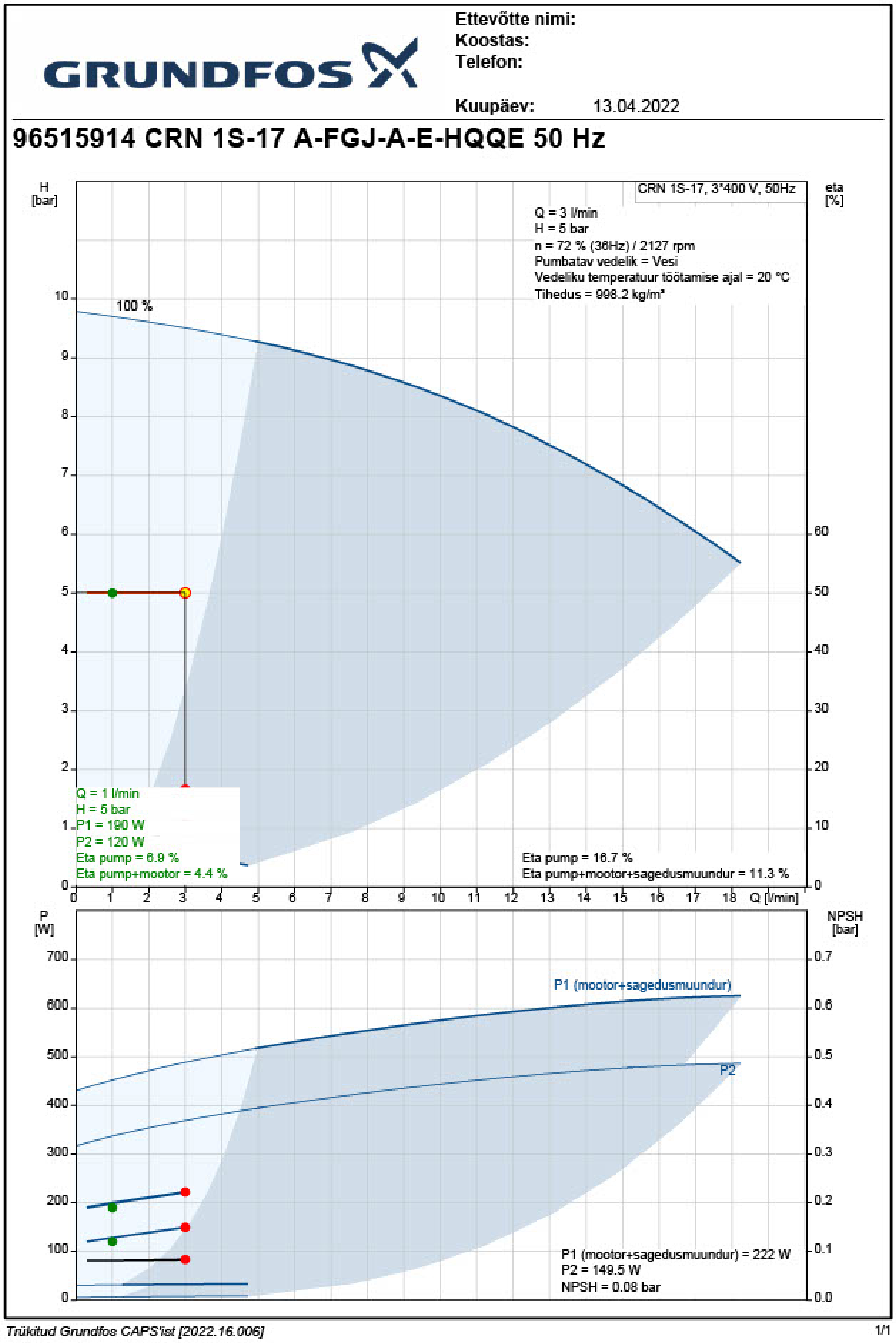
After the updated optimal requirements were clear for the pump selection, a search was conducted what kind of pumps are available in the Estonian retail market. It was found out that one of the world leading pump manufacturers Grundfos offers a wide range of pumps in Estonian market. SIA Grundfos Pumps Baltic Estonian branch was contacted, but it was found out that they do not directly sell to the customers, the consultations and price offers can be done using retailers such as Onninen AS or FEB AS etc.

Onninen AS was contacted for the optimal pump selection from the Grundfos product range and also selection of variable frequency drive was conducted from Onninen AS.

Several pumps were offered by Onninen from the Grundfos product range, finally a pump CRN 1S-17 was chosen with suitable parameters as seen in the figure 3.4.4.4.1 and pump characteristic is seen in figure 3.4.4.4.2.

Figure 3.4.4.4.1 Pump Grundfos CRN 1S-17

Figure 3.4.4.4.2 Pump characteristic of the Grundfos 1S-17 96526914



The pump CRN 1S-17 is from the stainless-steel material AISI 316, has a rated speed of 2856 rpm, rated flow of 15 l/min, rated head of 6,5 bar, maximum head of 9,7 bar, rated power is 0,55 kW, liquid temperature range up to 120 °C, full specifications are available in appendix 4.

In figure 3.4.4.4.2 the pump CRN 1S-17 optimal pressure head to flow working range can be seen in dark blue with variable frequency drive. The light blue area is not optimal range, but short time operation is allowed, for example for testing purposes, this was consulted with pump reseller Onninen AS. Optimal range is intended for long time continuous operation, there are pump efficiency and other parameters optimal for long time operation.

After the pump selection, suitable variable frequency drive was selected from the Grundfos product range: CUE 3X380-500V 0,55 kW 99616756 as can be seen in figure 3.4.4.4.3. The drive is the simplest one in Grundfos product range, nevertheless it offer several analogue and digital inputs, for instance for controlling the speed of the motor and for emergency stop function. The full specification of the CUE variable frequency drive can be seen in appendix 5.

Figure 3.4.4.4.3 Variable frequency drive Grundfos CUE 0,55 kW

3.4.5 Test device calorifier selection

The initial requirements for the calorifier selection are the cooling capacity of 10 kW and the possibility to change the speed of the calorifier fan via analogue or digital input.

The Volcano [16] range of standard type calorifiers were investigated from the Onninen AS product range. The principle of operation is that the heating liquid gives up heat to the heat exchanger, where highly effective axial fan draws air from the room, pumps it through the heat exchanger and then sends it back into the room. The maximum operating pressure of the medium for water coils of the calorifier is 16 bar, so it meets the 10-bar requirement. The model with EC designation is selected, that have 0-10 V DC analogue input for speed control of the fan. The Volcano type of Calorifier can be seen in figure 3.4.5.1 and the technical data for the calorifier Volcano VR2 can be seen in Figure 3.4.5.2.

Figure 3.4.5.1 Volcano type calorifier

Figure 3.4.5.2 Volcano VR2 calorifier technical data [16]

		Volcano VR2															
		Parameters T_z/T_p [°C]															
		90/70 [°C]				80/60 [°C]				70/50 [°C]				50/30 [°C]			
T_{p1} [°C]	Q_p [m³/h]	P_g [kW]	T_{p2} [°C]	Q_w [m³/h]	Δp [kPa]	P_g [kW]	T_{p2} [°C]	Q_w [m³/h]	Δp [kPa]	P_g [kW]	T_{p2} [°C]	Q_w [m³/h]	Δp [kPa]	P_g [kW]	T_{p2} [°C]	Q_w [m³/h]	Δp [kPa]
0	4850	50.1	30.7	2.21	23.8	43.1	26.5	1.9	18.3	36.2	22.3	1.59	13.5	22.3	13.7	0.97	5.7
	3600	41.9	34.7	1.86	17.2	36.5	30	1.6	13.3	30.5	25.3	1.34	9.8	18.8	15.6	0.82	4.2
	2400	32.7	40.6	1.45	10.8	28.3	35.2	1.25	8.4	23.9	29.7	1.05	6.2	14.8	18.4	0.64	2.7
5	4850	46.7	33.7	2.07	21.1	39.9	29.5	1.76	15.9	33.1	25.3	1.45	11.4	19	16.7	0.83	4.3
	3600	39.3	37.5	1.74	15.2	33.6	32.8	1.48	11.5	27.9	28.1	1.22	8.3	16.1	18.3	0.7	3.1
	2400	30.6	43.1	1.36	9.6	26.2	37.6	1.16	7.3	21.8	32.1	0.96	5.3	12.6	20.7	0.55	2
10	4850	43.6	36.8	1.93	18.5	36.7	32.6	1.62	13.6	29.8	28.4	1.31	9.4	15.6	19.6	0.68	3
	3600	36.6	40.4	1.62	13.4	30.9	35.6	1.36	9.9	25.2	30.9	1.11	6.8	13.2	21	0.58	2.2
	2400	28.6	45.5	1.27	8.4	24.2	40	1.07	6.3	19.7	34.5	0.87	4.4	10.4	22.9	0.45	1.4
15	4850	40.4	39.8	1.79	16	33.5	35.6	1.48	11.5	26.6	31.3	1.17	7.6	12.2	22.5	0.53	1.9
	3600	34	43.1	1.51	11.6	28.2	38.4	1.25	8.3	22.4	33.6	0.99	5.5	10.3	23.5	0.45	1.4
	2400	26.5	48	1.18	7.3	22.1	42.5	0.98	5.3	17.6	36.9	0.77	3.5	8	25	0.35	0.9
20	4850	37.2	42.8	1.65	13.7	30.3	38.6	1.34	9.5	23.3	34.3	1.02	5.9	8.4	25.2	0.37	1
	3600	31.3	45.9	1.39	10	25.5	41.1	1.13	6.9	19.7	36.3	0.86	4.3	7	25.8	0.31	0.7
	2400	24.5	50.4	1.09	6.3	20	44.8	0.88	4.4	15.5	39.2	0.68	2.8	5.3	26.6	0.23	0.4

From the Volcano range of calorifiers Volcano VR2 is selected as it offers powerful cooling capacity even with inlet air temperature 20 °C – marked as T_{p1} in figure 3.4.5.2, the maximum cooling capacity is in 8,4…30,3 kW range depending on the inlet water temperature of 50…80 °C. In projected extreme testing conditions, where outgoing temperature of the device to be tested is 80 °C, the cooling capacity is >30 kW. Nevertheless, it is worth mentioning that the cooling capacity is depending on the outside environment temperature – for example when outside is extreme hot temperature 35 °C, then cooling capacity of the test device is reduced. For the standard operation of the test device is presumed indoors recommended temperature ~20 °C.

3.4.6 Test device 3-way valve selection with motor

The 3-way mixing valve VRG130 from ESBE is selected as it is suitable for mixing and diverting operations. The valves are made of high high-performance brass allowing it to use in heating applications. The VRG series is available in DN15 size and it perfectly together with ESBE actuators, the ESBE VRG130 3-way valve can be seen in figure 3.4.6.1. For the actuator what goes along with the 3-way valve – ESBE actuator 600 Proportional is selected as it is suitable for mixing operations and can be seen in Figure 3.4.6.2.

Figure 3.4.6.1 ESBE VRG130 3-way valve

Figure 3.4.6.1 ESBE VRG130 3-way valve

ESBE Series 600 is controlled with proportional voltage/current signal, in these mixing applications can any position of the actuator range be used to get the desired mix level. The actuator is controlled with a voltage or current control signal and offer precise operation of the actuator and valve.

3.4.7 Test device sensors selection

Different types of sensors were considered for the test device, information about their properties and specifications were investigated in the literature [17], [18], [19], [20].

From the requirements of the MS Balti Trafo OÜ k-type thermocouples and PT 100 type temperature sensors are required to connect to the industrial controller to log temperature data of the product to be tested. Thermocouples are based on Seebeck effect, it means that when two different types of electrical conductors are soldered together, and the soldered point is heated, then electromotive force is created. The size of the force depends on the materials used and from the temperature of the soldered joint. Thermocouple has two soldered joints; one is working joint which measures temperature and the other one must be held in a stabile temperature environment – usually just in the outside environment of the device measuring temperature. In nowadays, the temperature measuring devices that are intended for measuring temperature with thermocouples, the reference soldering point is added electronically. This type of temperature measuring devices has the company already available in their stock, the example k-type thermo-couple can be seen in figure 3.4.7.1.

Figure 3.4.7.1 k-type thermocouple

The other required temperature sensor type by the MS Balti Trafo OÜ is PT100 type resistive temperature sensor – RTD. It means from the suitable material electrical resistance body is used with assumption that its electrical resistance is depending on the temperature and the temperature dependence is known. PT100 type RTD-s are used with output transmitters that convert the output signal in the range of 4…20 mA or 0…10 V. This type of temperature measuring devices has the company also available in their stock, the example PT100 type resistive temperature sensor can be seen in figure 3.4.7.2.

Figure 3.4.7.2 PT100 type resistive temperature sensor

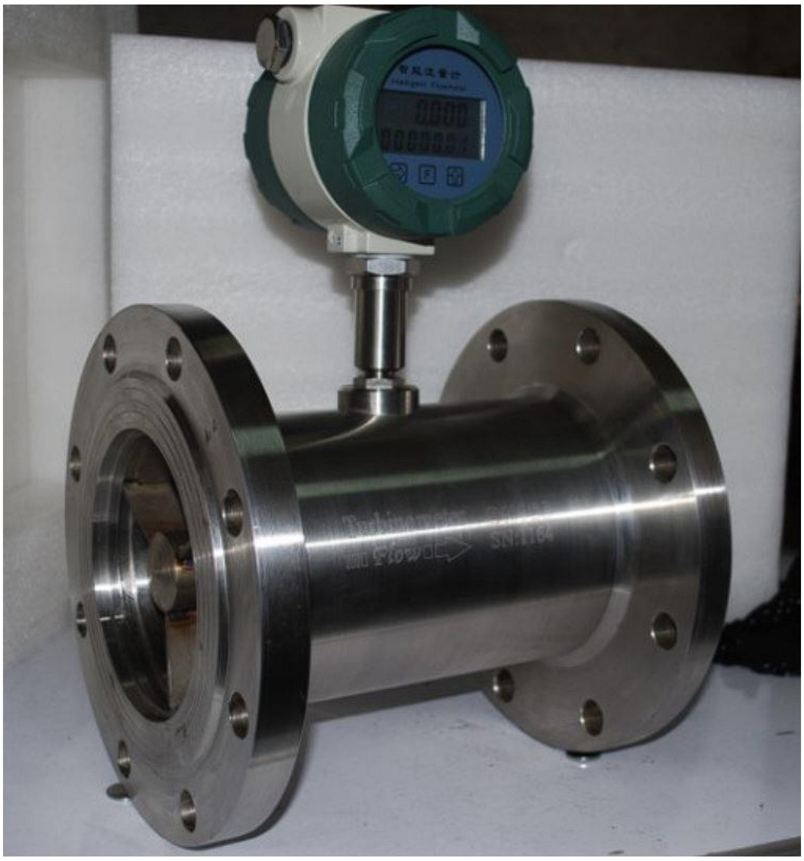
Electrical pressure sensors are widely used in boiler houses, thermal power plants also in building automation, food production etc. They are very widespread devices, there are a lot of different types: without local reading and with analogue output, with local analogue reading and analogue output etc. Differential pressure gauges are not available in Onninen AS product range; therefore, the decision was to use two pressure sensors instead and the controller computes the pressure difference, and it is displayed and logged on the HMI. The Danfoss MBS1700 0-10 bar pressure transmitter can be seen in Figure 3.4.7.3, it has the analogue output of 4…20 mA.

Figure 3.4.7.3 Danfoss MBS1700 0-10 bar pressure transmitter (sensor)

Flow meter selection: magnetic inductive flow meters are available and recommended for industrial process liquids and are based on Faraday principle, by which a conductor which traverses a magnetic field generates a potential oriented perpendicular to that field. The magnetic field which is generated by the electric current running through the coils induces a potential difference in the electrodes that are proportional to the flow being measured. The perspective option WIKA FLC 2200EL for flow metre can be seen in Figure 3.4.7.4, it can measure flow from about 1 l/min and DN15 connections are available. Nevertheless, with ultra-pure liquids magnetic inductive flow metres may not work as intended and some special solution may be needed, therefore more research and consultations have to be done with the MS Balti Trafo OÜ, one perspective flow metre for deionized water from Silver Automation Instruments can be seen in Figure 3.4.7.5.

Figure 3.4.7.4 WIKA magnetic inductive flow metre FLC2200EL

Figure 3.4.7.5 Special ordered flow metre for deionized water from Silver Automation Instruments



3.5 The price calculation of the test device

After that, when most of the parts of the test device for liquid-cooled transformers were known, a price calculation was done to verify if the desired budget by the MS Balti Trafo OÜ for the device – 10000 EUR – was in the limits.

The price calculation includes the price for the Siemens S7-1200 controller, all the extensions for additional analogue inputs and outputs, 12" Siemens display (HMI), a necessary Siemens software licence for automation, power supply, 3-way valve, pump with variable frequency drive and calorifier.

Also, the estimated cost for building the test device was added to the calculations, as some work (piping) may have to order outside the company.

All in all, the price of the components will be below the recommended budget of 10000 EUR, at the end it depends on the additional works or parts that needed to develop for the test device as some product development has to be done more, especially considering mechanical design. The price calculation can be seen in table 3.5.1.

Table 3.5.1 The price calculation of the test device

		Comment	Price EUR
1	SIMATIC S7-1200, CPU 1214C, DC/DC/DC	Controller	590
2	Analog output, SM 1232, 4 AO, +/-10 V	Extensions analogue output valve/pump/vent	429
3	Analog input, SM 1231, 8 AI	Extensions analogue input temp/pressure/flow	389
4	Analog input, SM 1231 TC, 8 AI thermocouples	Extensions thermocouple k-type	578
5	Analog input, SM 1231 RTD, 8xAI RTD module	Extensions to PT-100 thermo sensors	635
6	12" Siemens display		1920
7	Siemens controller software license	Simatic Step 7 V17	319
8	Power supply Siemens 24V 5A		149
9	3-way valve ESBE		73
10	3-tee valve actuator ESBE		182
11	Pump Grundfos CRN 1S-17		760
12	Variable frequency drive Grundfos CUE		510
13	Calorifier Volcano VR2		440
14	Additional sensors		1000
15	The cost of building test device - the cost of staff		3000
			10974

SUMMARY

The content of this master's thesis was to develop a promising liquid-cooled transformer testing device for MS BALTI TRAFO OÜ, analyzing the liquid-cooled products of MS BALTI TRAFO OÜ, considering the company's own wishes and requirements for the device.

The master's thesis gave an overview of the company and its products, introducing the field of liquid-cooled products separately. Then product development was started, various concepts were developed, and a suitable version was selected for further development.

The master's thesis ended with the selection of the hydraulic circuit and automation components of the test equipment and the preparation of the price calculation.

In conclusion it can be said that the work was very extensive and in 3 months the building of the test device will not be completed, the mechanical design and and the real construction of the machine will be in the future.

KOKKUVÕTE

Käesoleva magistitöö sisu oli töötada välja ettevõtte MS Balti Trafo OÜ jaoks perspektiivne vedelikjahutusega trafode testimise seade, analüüsides MS Balti Trafo OÜ vedelikjahutusega tooteid, arvestades ka ettevõtte enda soove ning nõudmisi seadmele.

Magistritöös anti ülevaade ettveõttest ja tema toodetest, eraldi tutvustades vedelikjahutusega toodete valdkonda. Siis alustati tootearendusega, töötati valja erinevaid kontseptsioone, valiti valja sobiv milda edasi arendada.

Magistritöös uuriti vedelikjahutusega toodete optimaalse hüdraulise takistuse leidmise teooriat ja viise, arvutati valja näidistoodete hüdrauliline takistus. Pärast hüdraulilise takistuse välja arvutamist, täpsutati testmasina hüdraulisi parameetrid ja koostati uuendatud hüdraulika skeem ning automaatika skeem.

Magistritöö lõppes testseadme hüdraulika ja automaatika komponentide valikuga ning hinnakalkulatsiooni koostamisega.

Kokkuvõttes võib öelda, et töö oli väga mahukas ja 3 kuu perspektiivis masinat ehitada valmis ei jõua, mehaaniline disain ja masina realne valmis ehitamine jääb tulevikku.

LIST OF REFERENCES

[1] "Tallinna Vesi homepage", [Online], Available: https://tallinnavesi.ee/tehnilised-nouded/ehitamine-2-2/hudraulilise-surveproovi-teostamine/ [Accessed 26.04.2022].

[2] "MS Balti Trafo homepage", [Online], Available: www.msbaltitrafo.ee [Accessed 27.04.2022]

[3] "Lenntech water treatment solutions homepage", [Online], Available: https://www.lenntech.com/applications/ultrapure/conductivity/water-conductivity.htm [Accessed 28.04.2022]

[4] Directive 2006/42/EC on Machinery, [Online], Available: https://eur-lex.europa.eu/eli/dir/2006/42/2009-12-15 [Accessed 29.04.2022]

[5] EVS EN 12100:2010, Safety of machinery – General principles for design – Risk assessment and risk reduction, [Online], Available: https://www.evs.ee/Download/ViewBrowsingServiceSubscription?productId=28122&language=EnglishLanguage [Accessed 29.04.2022]

[6] "Beckhoff Automation OÜ homepage," [Online], Available: https://www.beckhoff.com/et-ee/ [Accessed 20.02.2022]

[7] "ESBE homepage," [Online], Available: https://esbe.eu/group/products/controllers/cra110 [Accessed 20.02.2022]

[8] "Raspberry Pi 4 homepage," [Online], Available: https://www.raspberrypi.com/products/raspberry-pi-4-model-b/ [Accessed 20.02.2022]

[9] "Siemens Simatic S7-1200 controller," [Online], Available: https://mall.industry.siemens.com/mall/en/WW/Catalog/Product/6ES7214-1AG40-0XB0 [Accessed 13.04.2022]

[10] K. Laigna, Hüdromehaanika, Tallinn: EMK Kirjastusgrupp, 1997.

[11] A. Maastik, H.Haldre, T.Koppel, L.Paal, Hüdraulika ja Pumbad, Tartu: Greif, 1995.

[12] "HydrauCalc homepage," [Online], Available: https://www.hydraucalc.com/ [Accessed 10.02.2022]

[13] "Pressure-drop.online homepage," [Online], Available: http://www.pressure-drop.online/ [Accessed 11.02.2022]

[14] "Luvata hollow conductors homepage" [Online], Available: https://www.luvata.com/products/hollow-conductors [Accessed 12.02.2022]

[15] V. Suurkask, Hoonete veevärk ja kanalisatsioon, Tallinn: TTÜ kirjatus, 2012.

[16] "Volcano calorifier product page in Onninen AS home page" [Online], Available: https://www.onninen.ee/onnline-ohkkutteagregaat-volcano-vr1-ec/p/CCT178?term=volcano [Accessed 01.05.2022]

[17] K. Ingermann, Soojustehnika mõõtevahendid, Tallinn: TTÜ kirjastus, 2015.

[18] K. Ingermann, Temperatuuri mõõtmine. Tallinn: TTÜ kirjastus, 2015.

[19] A.Ots, Soojustehnika algkursus, Tallinn: TTÜ kirjatus, 2011

[20] Z. Nenova, S.Ivanov, T.Nenov, Andurid tööstusautomaatikas, Tallinn: TTÜ kirjastus 2011.

[21] "Wika homepage, model FLC 2200 EL" [Online], Available: https://www.wika.com/en-en/flc_2200el.WIKA [Accessed 01.05.2022]

[22] E. Brindfeldt, E.Pettai, H.Hõimoja, V.Beldajajev, Täiturid tööstusautomaatikas, Tallinn: TTÜ kirjastus, 2011.

[23] M.Müür, E.Pettai, U.Lepiksoo, Programmeeritavad kontrollerid tööstusautomaatikas, Tallinn: TTÜ kirjastus, 2011.

[24] A.Rashidov, S. Jordanov, Tööstuslikud võrgud ja liidesed automatiseerimis-süsteemis, Tallinn: TTÜ kirjastus, 2011.

[25] A. Rosin, Programmeeritavad kontrollerid Simatic S7, Tallinn: TTÜ kirjastus, 2000.

[26] F.Lamb, Industrial Automation: hands-on, New York: bMcGraw-Hill Education, 2013.

[27] V. Vodovzonov, Electrical Drive: Performance, Design and Control, Saarbrücken: LAP Lambert Academic Publishing, 2014.

[27] R.Sell, M.Leini, R.Ellermaa, AVR mikrokontrollerid ja praktiline robootika, Tallinn: Robolabor kirjastus, 2015.

[28] T.Lehtla, Elektriajamid, Tallinn: TTÜ kirjastus, 2007.

APPENDICES

1. Appendix 1 – Beckhoff Automation OÜ offer nr. 805
2. Appendix 2 – Kemeri OÜ offer nr. MP220030201
3. Appendix 3 – MS Baltri Trafo OÜ product MS 14894 info brochure
4. Appendix 4 – Grundfos CRN 1S-17 96515914 brochure
5. Appendix 5 – Grundfos CUE 99616756 variable frequency drive brochure

Appendix 1

BECKHOFF
New Automation Technology

Offer

CONFIDENTAL
1 / 3

Number 805
Date 22.3.2022

Tallinn University of Technology

Ehitajate tee 5

19086 Tallinn

Contact person Mario Einama

Valid 21.4.2022
Payment terms 14 days net
Delivery method
Delivery terms
Seller Petrov Ilja
Your reference
Our reference
Deliv. date

Pos.	Code	Item	Amount	Unit	Unit price	Total
01	227058	CP2213-0030 Multitouch Built-in Panel PC housing - aluminium housing with glass front - all connectors at the bottom of the rear side - PC to be opened from the back side - all components easily accessible - 1 slot for one 2½-inch hard disk or SSD and 1 slot for one CFast card, accessible from outside - 2 connector brackets to lead out interfaces of the motherboard at the connection section - fan cartridge at the PC top side, accessible from outside - protection class front side IP 65, rear side IP 20 - operating temperature 0...55 °C Front panel - 12.1 inch display 1280 x 800 - multi finger touch screen Features – processor Intel® Celeron® G4900 3.1 GHz, 2 cores (TC3: 50) – 3½-inch motherboard for 8th and 9th generation Intel® Celeron®, Pentium®, Core™ i3, Core™ i5 or Core™ i7 - 4 GB DDR4 RAM, expandable to 64 GB - Graphic adapter integrated inside the Intel® processor, 1 DVI-D port occupied by the display in the front and 1 DVI-D connector free – on-board dual Ethernet adapter with 2 x	1,00	pcs	2 534,40 €	2 534,40 €
02	177357	EK1000 EtherCAT Coupler for standard and TSN networks	1,00	pcs	520,44 €	520,44 €
03	68992	EL3058 8-channel-analog-input terminal 4...20 mA, single-ended, 12 Bit 1-wire system CTN: 85369010 COO: DEU	1,00	pcs	206,88 €	206,88 €
04	68969	EL3008 8-channel-analog-input terminal -10 V...10 V, single-ended, 12 Bit 1 wire system	1,00	pcs	206,88 €	206,88 €

Beckhoff Automation OÛ
Valukoja 8, Õpiku 2
11415 Tallinn
Estonia

+ 372 588 03238
+ 372 588 12547
info@beckhoff.ee
www.beckhoff.ee

VAT no.
EE102171552 / LT100014516210
Domicile Tallinn
Business ID 14718089

Pos.	Code	Item	Amount	Unit	Unit price	Total
		CTN: 85369010 COO: DEU				
05	55002	EL3202 2-channel input terminal PT100 (RTD) for resistance sensors, 16 bit 2-, 3-wire system CTN: 85369010 COO: DEU	3,00	pcs	181,80 €	545,40 €
06	125396	EL3208 8-channel input terminal PT100 (RTD) for resistance sensors, 16 bit, 2-wire system CTN: 85369010 COO: DEU	1,00	pcs	323,52 €	323,52 €
07	56232	EL3314 4-channel thermocouple input terminal, preset to type K with wire breakage detection, 16 bit CTN: 85369010 COO: DEU	2,00	pcs	231,96 €	463,92 €
08	26845	EL9010 E-bus end terminal CTN: 85369010 COO: DEU	1,00	pcs	11,94 €	11,94 €
09	55	Shipping costs	1,00	pcs	35,00 €	35,00 €
10	68	Typical Lead Times Automation TwinCAT licenses 1-2 working days I/O (updated 28.02.2022) Terminals EL1,EL2: 22 weeks Terminals EL3,EL4: 20 weeks Terminals EL5,EL6: 20-21 weeks Terminals EL7: 19 weeks EtherCAT Couplers EK: 20 weeks EtherCAT Boxes: 28-30 weeks TwinSAFE: 38 weeks Terminals KL/BK: 18-19 weeks Industrial PC (updated 09.03.2022) C60xx Control Cabinet IPC: 33 weeks C69xx Control Cabinet IPC: 29 weeks C66xx Control Cabinet IPC: 24 weeks CP66xx PanelPC: 31 weeks CP26xx PanelPC: 31 weeks CP29xx Multi-touch panel: 31 weeks, wo options 1 week except CPX29 CP39xx Multi-touch IP65 panel: 31 weeks, wo options 1 week Embedded PC (updated 14.03.2022) CX10x0: 15 weeks CX20x0: 25 weeks CX50x0: 18 weeks	1,00	pcs		

Pos.	Code	Item	Amount	Unit	Unit price	Total

CX51x0: 35 weeks
CX80xx: 32 weeks
CX90x0: 18 weeks

Motion (updated 10.03.2022)
AX5000: 24 weeks
AX8000: 40 weeks

AM3xxx: 30 weeks
AM80xx: 24 weeks
AM81xx: 24 weeks (only for high runner, otherwise lead times like AM8xxx)
AS1xxx: 52 weeks

AG2300: 8 weeks
AG2800: 4 weeks
AG2250: 9 weeks

Prices of the offer are without VAT. We reserve the right to update the payment terms with your order.

TKL's delivery conditions for products and services are valid. Conditions **here.**
TwinCAT software license deliveries are based on the license agreement for TwinCAT software products. Conditions **here.**

Terms of delivery: Shipping and handling costs will be charged separately. If the shipment is wanted in more than one delivery, expenses will be charged from each batch.

Warranty: 12 months

We hope that offer meets the expectations of your request. We are happy to answer for your questions.

	Total, VAT 0%
	4 848,38 €

Beckhoff Automation OÛ
Valukoja 8, Öpiku 2
11415 Tallinn
Estonia

+ 372 588 03238
+ 372 588 12547
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www.beckhoff.ee

VAT no.
EE102171552 / LT100014516210
Domicile Tallinn
Business ID 14718089

Appendix 2

Klient
Tallinna Tehnikaülikool
KMKR nr: EE100224841
Ehitajate tee 5
19086 Mustamäe linnaosa, Tallinn Harju maakond
Eesti Vabariik

Pakkumine nr MP2203021

Kuupäev:	13.04.2022
Pakkumine kehtib:	20.04.2022
Maksetähtaeg:	0 päeva

Makse saaja:
KEMERI OÜ
Swedbank: EE952200221069024026
PayPal:

Pakkumine kokku: 6010.80

Kirjeldus	Kogus	Hind	Ah %	Summa	KM	Kokku (EUR)
6ES7214-1AG40-0XB0 - SIMATIC S7-1200, CPU 1214C, compact CPU, DC/DC/DC, onboard I/O: 14 DI 24 V DC; 10 DO 24 V DC; 2 AI 0-10 V DC, Power supply: DC 20.4-28.8V DC, Program/data memory 100 KB 85389000 IN W: 0,358 kg	1 tk	590.00		590.00	118.00	708.00
6ES7231-4HF32-0XB0 - SIMATIC S7-1200, Analog input, SM 1231, 8 AI, +/-10 V, +/-5 V, +/-2.5 V, or 0-20 mA/4-20 mA, 12 bit+sign or (13 bit ADC) w.0.17kg 85371000 DE	1 tk	389.00		389.00	77.80	466.80
6ES7231-5QF32-0XB0 - SIMATIC S7-1200, Analog input, SM 1231 TC, 8 AI thermocouples	1	578.00		578.00	115.60	693.60
6ES7231-5PF32-0XB0 - SM 1231 RTD, 8 AI	1	635.00		635.00	127.00	762.00
6AV2123-2MB03-0AX0 - SIEMENS 6AV21232MB030AX0 / 6AV2123-2MB03-0AX0 SIMATIC HMI, KTP1200 Basic, Basic Panel, Key/touch operation, 12" TFT display, 65536 colors, PROFINET interface, configurable from WinCC Basic V13/ STEP 7 Basic V13, contains open-source software, which is provided free of charge see enclosed CD	1	1920.00		1920.00	384.00	2304.00
6ES7232-4HD32-0XB0 - SIMATIC S7-1200, Analog output, SM 1232, 4 AO, +/-10 V, 14-bit resolution, or 0-20 mA/4-20 mA, 13-bit resolution DE 85389000 0.180 kg	1 tk	429.00		429.00	85.80	514.80
6EP1333-3BA10 - SITOP PSU200M 5 A stabilized power supply input: 120/230-500 V AC output: 24 V DC/5 A *Ex approval no longer available*	1	149.00		149.00	29.80	178.80
6ES7822-0AA07-0YA5 - SIMATIC STEP 7 Basic V17; Floating License; engineering software in TIA Portal; software and documentation on DVD; license key on USB flash drive; class A; 9 languages: de,en,zh included, fr,sp,it,ru,jp,kr as download; executable in Windows 10, Windows Server 2016/2019; for configuration of SIMATIC S7-1200 SIMATIC Basic Panels ******************************** content: set (4x DVD + 1x USB)	1	319.00		319.00	63.80	382.80
Pakkumine nr MP2203021 sh.				**5009.00**	**1001.80**	**6010.80**

KEMERI OÜ

Reg nr: 14458085
KMKR nr: EE102084380
Aadress: Savi 7
80041 Pärnu Pärnumaa
Eesti Vabariik

E-post: info@kemeri.ee

Swedbank: EE952200221069024026, SWIFT: SWIFT kood/BIC HABAEE2X
PayPal:

1 / 2

Käibemaks 20%	5009.00	1001.80	6010.80

Appendix 3

MS BALTI
TRANSFORMERS

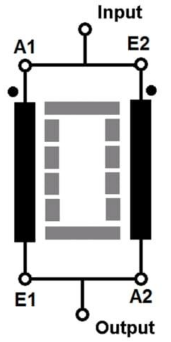
Type:	**UI240/140**	**Output power:** **approvals:**	**405J Ta 40˚C/F**
Model No:	**MS 14894**		Date: 28.04.20

General:

- Water cooled DC-choke
- Insulation class F,
- protection system, IP00, vacuum impregnated + finishing varnish Voltatex 4001
- cooling method: water cooled, all cooling contures connected in series, core cooling added
- Total weight. ~102kg
- Copper weight ~20kg
- Fixing method by mounting brackets.
- Cooling water connectors for 12mm hose
- Minimum flow rate 3 l/min
- Pressure drop: TBD

Electrical data:	Nominal load	405J
	Max. ambient temperature	40°C
	Insulation class IEC:	H (180°C)
	Thermal cutoff (on the core)	2 x 155° NC + 2 x 110° NC
	Dielectric test:	3,5 kV : between windings 3,5 kV: windings against core
Input:	Connections:	40x40x5mm Busbar, 200mm^2, hole 13,5mm
	Voltage:	750V
	Nominal frequency:	DC+200Hz
	Inductance	0,5mH ± 5%
	Nominal input current:	900Adc
	Resistance +-10% @ 20°C:	5 mΩ (windings connected in parallel)

Electrical connections:



● **Electrical polarity**

MS Balti Trafo OÜ
Vihtra tee 3a // 87701 Vändra, Estonia
Phone: +372 44 71 660 // Fax: +372 44 71 667
info@msbaltitrafo.ee // www.msbaltitrafo.ee

Commercial register: 10153561
VAT: EE100135736

Swedbank AS
SWIFT: HABAEE2X
IBAN: EE77 2200 0011 2023 7354

SEB Pank AS
SWIFT: EEUHEE2X
IBAN: EE92 1010 2200 2090 3229

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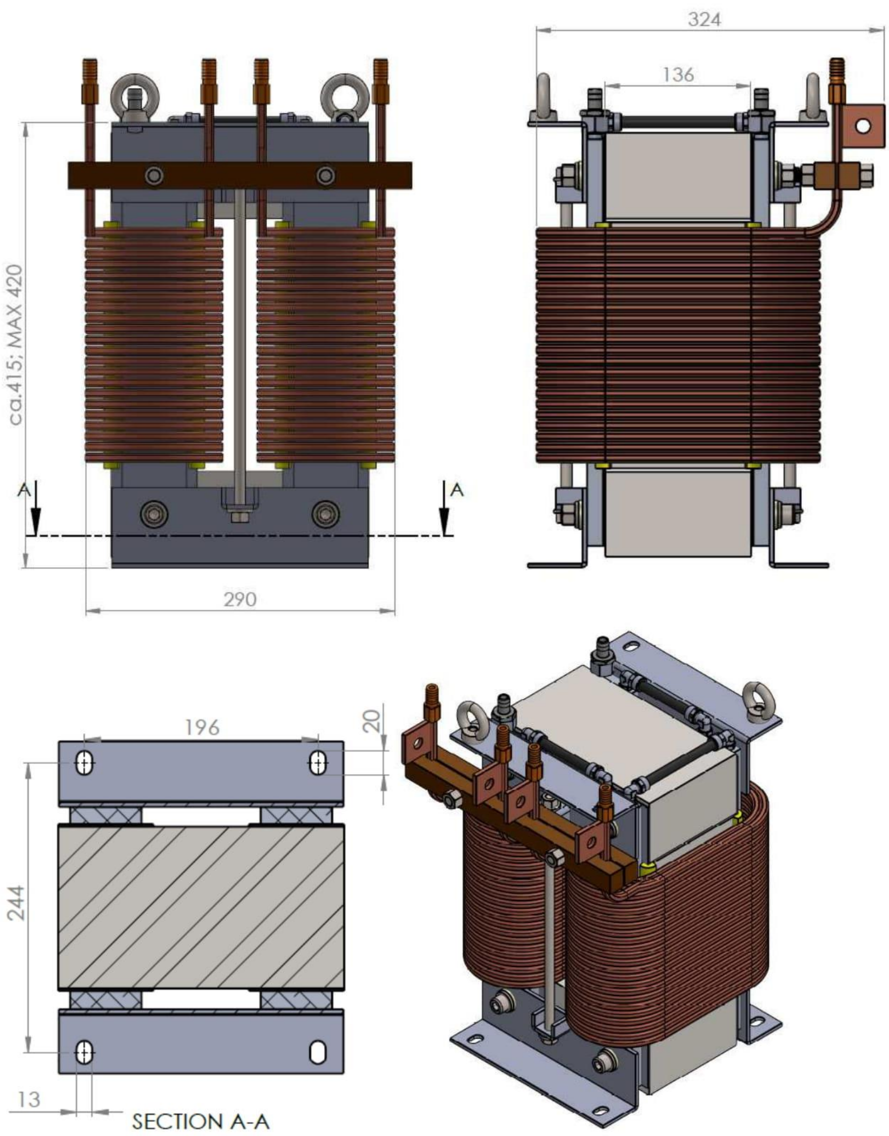
Dimensions:



Date: 30.03.20	Version 1	Created by: Luik
Date: 16.04.20	Version 2	Created by: Luik
Date: 28.04.20	Version 3	Created by: Luik

MS Balti Trafo OÜ
Vihtra tee 3a // 87701 Vändra, Estonia
Phone: +372 44 71 660 // Fax: +372 44 71 667
info@msbaltitrafo.ee // www.msbaltitrafo.ee

Commercial register: 10153561
VAT: EE100135736

Swedbank AS
SWIFT: HABAEE2X
IBAN: EE77 2200 0011 2023 7354

SEB Pank AS
SWIFT: EEUHEE2X
IBAN: EE92 1010 2200 2090 3229

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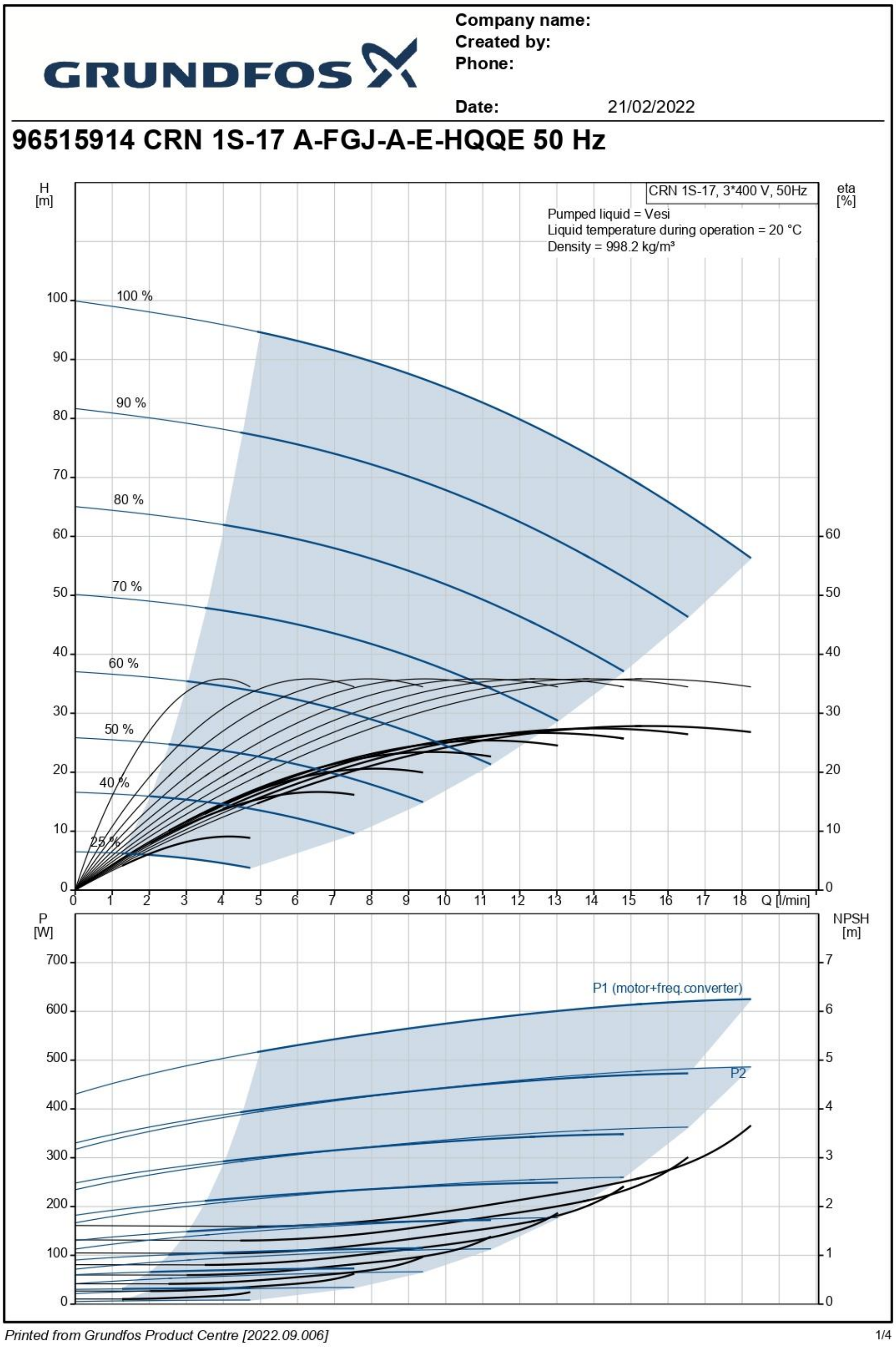
Appendix 4

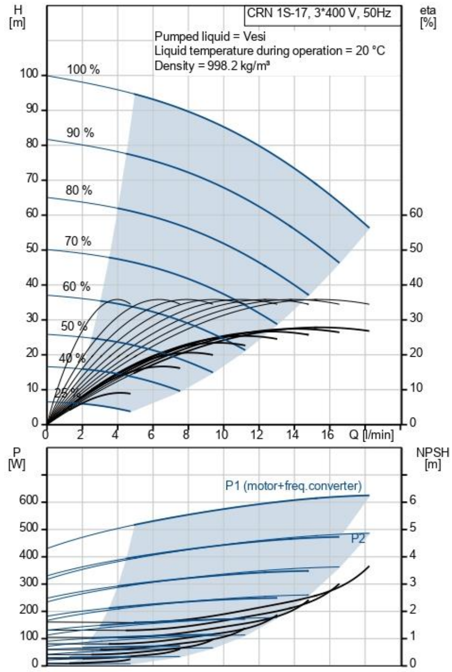


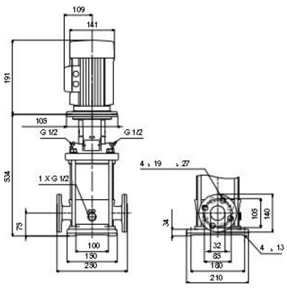
GRUNDFOS
Company name:
Created by:
Phone:
Date: 21/02/2022
96515914 CRN 1S-17 A-FGJ-A-E-HQQE 50 Hz
CRN 1S-17, 3*400 V, 50Hz
Pumped liquid = Vesi
Liquid temperature during operation = 20 °C
Density = 998.2 kg/m³
H [m]
eta [%]
100 %
90 %
80 %
70 %
60 %
50 %
40 %
25 %
Q [l/min]
P [W]
NPSH [m]
P1 (motor+freq.converter)
P2
Printed from Grundfos Product Centre [2022.09.006]
1/4

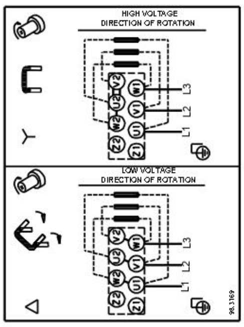
Company name:
Created by:
Phone:

Date: 21/02/2022

Description	Value
General information:	
Product name:	CRN 1S-17 A-FGJ-A-E-HQQE
Product No:	96515914
EAN number:	5700396733722
Price:	
Technical:	
Pump speed on which pump data are based:	2856 rpm
Rated flow:	15 l/min
Rated head:	66.5 m
Maximum head:	99.1 m
Stages:	17
Impellers:	17
Number of reduced-diameter impellers:	0
Low NPSH:	N
Pump orientation:	Vertical
Shaft seal arrangement:	Single
Code for shaft seal:	HQQE
Approvals:	CE,EAC,UKCA
Approvals for drinking water:	WRAS,ACS
Curve tolerance:	ISO9906:2012 3B
Pump version:	A
Model:	A
Materials:	
Base:	Stainless steel
Base:	EN 1.4408
Base:	AISI 316
Impeller:	Stainless steel
Impeller:	EN 1.4401
Impeller:	AISI 316
Material code:	A
Code for rubber:	E
Bearing:	SIC
Installation:	
t max amb:	60 °C
Maximum operating pressure:	25 bar
Max pressure at stated temp:	25 bar / 120 °C
Max pressure at stated temp:	25 bar / -20 °C
Type of connection:	DIN / ANSI / JIS
Size of inlet connection:	DN 25/32
Size of outlet connection:	DN 25/32
Pressure rating for connection:	PN 25
Flange rating inlet:	300 lb
Flange size for motor:	FT85
Connect code:	FGJ
Liquid:	
Pumped liquid:	Vesi
Liquid temperature range:	-20 .. 120 °C
Selected liquid temperature:	20 °C
Density:	998.2 kg/m³
Kinematic viscosity:	1 mm2/s
Electrical data:	
Motor standard:	IEC
Motor type:	71B
IE Efficiency class:	IE3
Rated power - P2:	0.55 kW
Power (P2) required by pump:	0.55 kW







GRUNDFOS

Company name:
Created by:
Phone:

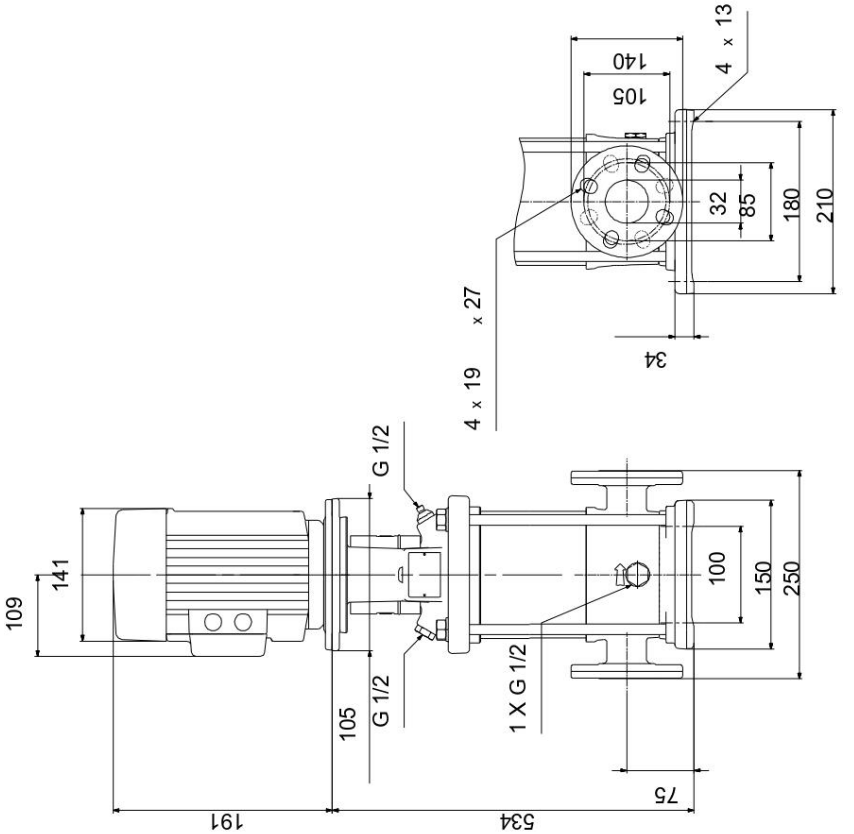
Date: 21/02/2022

Description	Value
Mains frequency:	50 Hz
Rated voltage:	3 x 220-240D/380-415Y V
Rated current:	2.50/1.44 A
Starting current:	580-620 %
Cos phi - power factor:	0.80-0.70
Rated speed:	2830-2850 rpm
Efficiency:	IE3 77,8%
Motor efficiency at full load:	77.8 %
Motor efficiency at 3/4 load:	81.5 %
Motor efficiency at 1/2 load:	79.5 %
Number of poles:	2
Enclosure class (IEC 34-5):	55 Dust/Jetting
Insulation class (IEC 85):	F
Built-in motor protection:	NONE
Motor No:	85805103
Controls:	
Frequency converter:	NONE
Others:	
Minimum efficiency index, MEI ≥:	0.54
Net weight:	25.8 kg
Gross weight:	29.8 kg
Shipping volume:	0.092 m³

Company name:
Created by:
Phone:

Date: 21/02/2022

96515914 CRN 1S-17 A-FGJ-A-E-HQQE 50 Hz



Note! All units are in [mm] unless others are stated.
Disclaimer: This simplified dimensional drawing does not show all details.

Appendix 5

Ettevõtte nimi:
Koostas:
Telefon:

Kuupäev: 13.04.2022

Kogus	Kirjeldus
1	**CUE 3X380-500V IP55 0,55KW**

Märkus! Reaalse toote väljanägemine võib erineda pildil kujutatust.

Toote kood:: 99616756

CUE is a complete range of external frequency converters designed for speed control of a wide range of Grundfos pumps. CUE has a built-in PI controller and offers the same functionality and user-interface as Grundfos E-pumps. CUE solutions can thus be seen as an extension to the E-pump range.

By choosing a CUE-solution, you will get the following benefits:

- Grundfos E-pump functionality and user-interface
- application- and pump-family-related functions
- increased comfort compared to fixed-speed pumps
- very easy installation and commissioning compared to standard frequency converters
- speed control of pumps up to 250 kW
- speed control of pumps installed in potentially explosive environments.

CUE offers the following inputs and output:

- RS-485 GENIbus
- an analog 0-10 V input for external setpoint
- an analog 0/4-20 mA input for sensor
- four digital inputs for various functions, for instance external start/stop
- two signal relays (C/NO/NC).

Accessories:
Input/output add-on board
Provides additional input:

- one 0/4-20 mA analog input for an additional sensor
- one 0-20 mA analog output
- two inputs for Pt100/Pt1000 temperature sensors, for instance for bearing monitoring.

Motor filters:
For reduction of dU/dt and peak voltages to the motor windings and for reduction of the acoustic noise generated in the motor, a number of motor filters are offered:

- dU/dt filters , 11-250 kW
- Sine wave filters, 0.55-250 kW.

Tehnilised:

Tunnustused sildikul:	CE, CULUS, C-TICK

Paigaldamine:

Ümbritseva temperat. vahemik:	0 .. 45 °C
Suhteline niiskus:	5-95 %

Elektriandmed:

Nimivõimsus - P2:	0.55 kW
Vooluvõrgu sagedus:	50 / 60 Hz
Nimipinge:	380-440/441-500 V
Nimivool:	1.8-1.6 A
Maksimaalne voolutarve:	1.8 A
Efficiency at full load:	95 %
Kaitseklass (IEC 34-5):	IP55

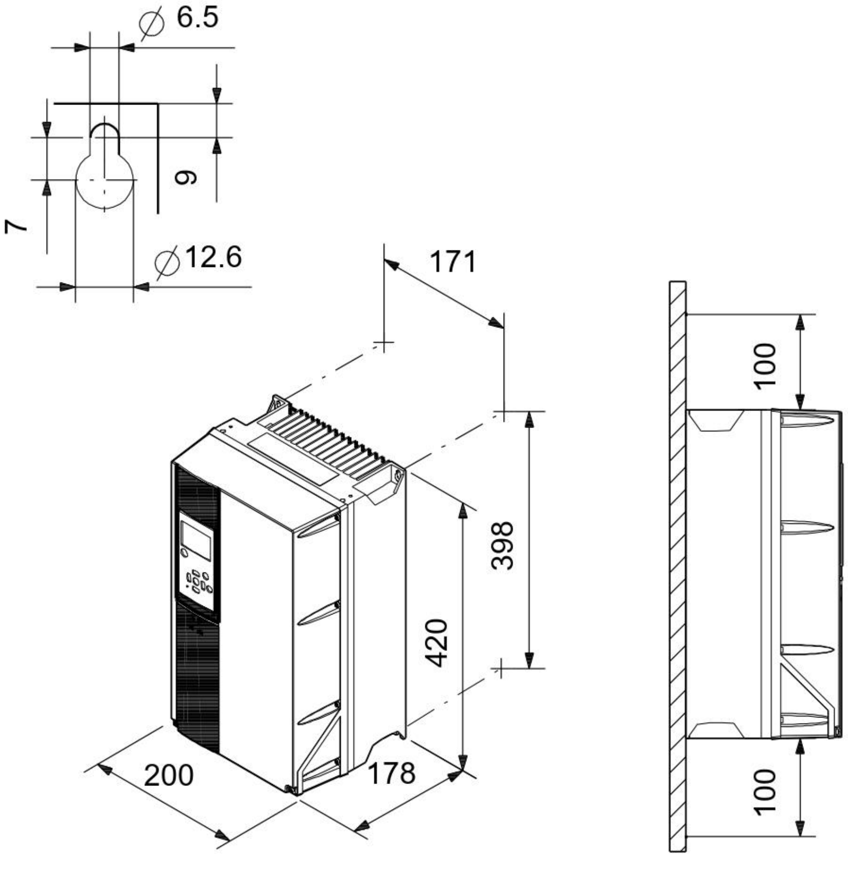
	Ettevõtte nimi:
GRUNDFOS	**Koostas:**
	Telefon:
	Kuupäev: 13.04.2022

Kogus	**Kirjeldus**	
	Muu:	
	Nettokaal:	9.2 kg
	Danish VVS No.:	382996005

Ettevõtte nimi:
Koostas:
Telefon:

Kuupäev: 13.04.2022

99616756 CUE 3X380-500V IP55 0,55KW

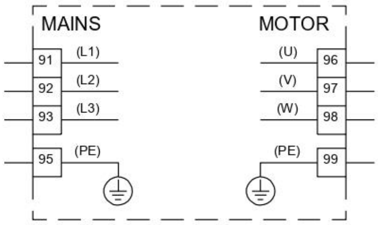


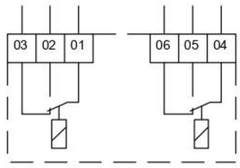
Märkus! Kõik mõõdud on [mm] kui pole teisiti tähistatud.
Lahtiütlus: see lihtsustatud mõõtjoonis ei näita kõiki detaile.

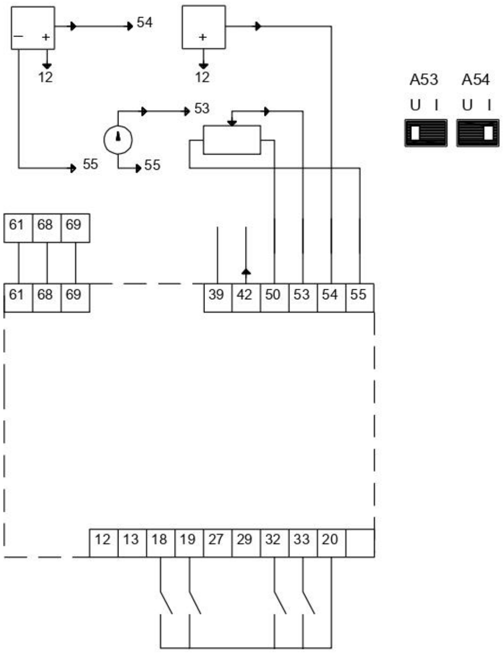
Ettevõtte nimi:
Koostas:
Telefon:

Kuupäev: 13.04.2022

99616756 CUE 3X380-500V IP55 0,55KW







Märkus! Kõik mõõdud [mm] kui pole teisiti tähistatud.

Appendices complement the thesis main body. They may contain, in order to keep the main body concise, the following:

- all larger data volumes (tables of initial parameters, drawings of A3 and A4 size, specification, bills of materials, raw experimental data, etc.),
- repeatedly needed calculations of standard nature, computer programmes, their printouts or descriptions,
- text material of lower importance and/or supportive and/or illustrative nature,
- voluminous mathematical deriving's, etc.

In the case of many appendices, it is allowed to position a page, titled **APPENDICES,** before the first appendix. Each appendix must start on a new page. The word Appendix together with is number and title should be written in upper right corner of each appendix' first page, e.g.: Appendix 1 Form of title page. When an appendix is structured into divisions, their numbers should begin with letter A, in order to distinguish them from divisions of thesis main body, e.g. A3.2, A5.3.1, etc.

GRAPHICAL MATERIAL

In the case, that thesis contains graphical materials, such as drawings, schemes, posters etc., that have size A3 or larger, it is allowed to:

- print it out as reduced, assuming that the texts remain readable, and bind them in thesis appendices or
- put together graphical part, place them (in original size and folded) into an envelop attached onto the inside of thesis back cover or into a separate folder, equipped with title sheet. Graphical material shall be folded after the thesis defence (see Appendix 4).

List of graphical materials shall be given in the end of thesis contents.

Formatting of all drawings must comply with valid standards (ISO etc).