DESIGN OF COOLING SYSTEMS FOR 6-AXIS WELDING ROBOT DRIVES

HAMK
UNIVERSITY OF APPLIED SCIENCES

Bachelor’s thesis

Degree Programme in Automation Engineering

Valkeakoski 01.02. 2013

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ABSTRACT

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Subject of Bachelor's thesis Design of cooling systems for 6-axis welding robot drives

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The goal of this thesis work was to design a water-cooling system for a 6-axis welding robot drive, unlike the traditional air/fan cooling system. The purpose was to design a piping and instrumentation diagram for the water-cooling process, to monitor and regulate the running temperature and compare it with the operating temperature of the frequency inverter. The theoretical and practical examination of the functioning of a frequency inverter helped facilitate the new invention. This was conducted in a way to enable the commissioning organization have a smooth and safe operation of the robot.

Ideal Automation Oy in Forssa, Finland commissioned this thesis. In summer 2012, Ideal Automation Oy commissioned installation of a 6-axis welding robot, which needed a frequency inverter to run the axes and the cooling system to cool the inverter. Conventional air-cooling would not be enough for this new robot, so there was a need for a new water-cooling system. However, the system was of new technology, which required extensive research and expertise. The thesis was carried out according to the specifications of the commissioning company and HAMK standards.

In conclusion, as an outcome of the project, a new P&ID design, valves, a pump, pipe size selections and also I/O channels for the P&ID were created.

Keywords piping & instrumentation diagram, input/output, robots, and inverter.

Pages 32 p.

LIST OF ABBREVIATIONS

AC	–	Alternating Current
CPUs	–	Central Processing Units
DC	–	Direct Current
HMI	–	Human Machine Interface
HVAC	–	Heating Ventilating Air-Conditioning
I/Os	–	Inputs and Outputs
IGBT	–	Insulated Gate Bipolar Transistor
P&ID	–	Piping and Instrumentation Diagram
VSDs	–	Variable Speed Drives

DEDICATION

This thesis is dedicated to God Almighty for His grace and wisdom, also to my fiancée Adeola Olubamiji for her support.

1 INTRODUCTION

As the world is exposed to new technologies every day, many researchers are busy working on how to solve problems that are yet to be solved or improvements to the previously solved ones. Different ways of doing things keep appearing, and this thesis work will also take us through another way of cooling systems.

Cooling a system in general is a method of taking heat out of any equipment. This might include homes, offices, industries etc. Cooling is nowadays a very important part in industrial operations because if the wrong cooling system is designed for an operation, the whole operation fails and damage important parts/components in the equipment. Thus, the correct cooling system will save energy, which results in cost saving. It also enhances the performance of the equipment, and makes the operations smooth.

First, we identified the shortcomings and the need for improvements in the old cooling system, and then found the accurate methods to overcome these weaknesses. This could be done by examining the existing cooling system.

The focus of this thesis work was to design and implement a water cooling system for a frequency inverter to drive motor for a 6-axis Motoman welding robot. Today, the use of robots in industries keeps growing faster and the number of tasks performed by these robots increases which consequentially contributes to the increased number of axes in robots. As a result, methods of cooling the frequency inverters that drive the motors in each axis become a headache for manufacturers. A high level of noise during operation and a relatively high operating temperature has been an issue. Industries need a less noisy operation than a fan can provide and they also need to cool the frequency inverters better than what a heat sink can provide.

This might not be 100% new technology since today some industrial computers processing units (CPUs) are operating on a water cooling system but not many frequency inverters use this technology yet. Therefore, this thesis work is an improvement on what has been done before. A successful implementation of this system would provide smooth operation with lesser or no noise and reduce overheating during operation, and also reduce the cost of repair caused by over-heating.

1.1 Objectives of thesis

Frequency inverters need to keep their components cool all the time in order to prolong the life span of the inverters. This brought about the main purpose of this thesis work, which was to design and implement a P&I diagram for a water cooling system (Cold plate mounting) for a frequency inverter used to drive motors in a 6-axis welding robot. It also was to provide a solution on how the water/liquid flow would not affect or have a negative impact on the components during both the operations and the stop modes.

1.2 Thesis outline

This thesis work covers six chapters, with the first chapter as an introduction to the project. The second chapter covers the literature reviews of the topic in question, the theoretical background, types of frequency inverters, other types of cooling systems and their limitations, and Motoman 6-axis welding robot. Chapter three deals with the role of robots. The materials and methods are contained in chapter four. In chapter five, the challenges encountered in the course of the research work were described and the last chapter showcases the conclusion and some recommendations.

1.3 Ideal Automation Oy.

Ideal Automation is a company with vibrant and fresh professionals. Their services include design automation, motion control and implementation service depending on customer's needs. The company's employees are flexible, innovative and also possess client's interest in their minds at all times. The list below indicates some of their areas of specialization;

Design automation services

- Electrical Engineering
- Automation systems, pre-planning and consulting
- Logic programming
- Programming of user interfaces
- Servo motion control systems programming
- Multi-axle synchronous programming

Start-up services

- The introduction of automation systems
- Servo systems introduction
- Drive-up introduction
- The automation systems and the control of the individual components of the mode

Components of delivery services

- Automation components retailer
- Variable Speed Drives
- Programmable Logic Controllers
- HMI panels
- Electric motors and gears (ideal automation, 2012)

1.4 Overview of the research methodology

Using water for cooling electronic devices requires good mathematical skills, proper P&I diagram, and heat conversion. During this thesis work, study was done at the HAMK University of Applied Sciences, Valkeakoski, Finland, and the commissioning company. The expectation for my study included P&I Diagram with all necessary field devices and transmitters and simulation of this P&I Diagram before implementation. The study assessed the effect of both the low and high water temperature role in the process, and proper calculation was needed to ensure right level of temperature throughout the process.

The primary data collection was done by interviewing the commissioning company representatives and the product supplier (B&R automation). Research was done through studying of relevant publications, internet consultation, etc.

2 THEORETICAL BACKGROUND TO THE PROJECT

2.1 Heat transfer

Heat transfer is a process whereby heat moves from one substance to another by either conduction or radiation or convention or combination of these methods. Thus means transport of thermal energy due to change in temperature (Peter & Thomas, 2012, 1). This means that whenever there is a temperature difference in a system, heat transfer has taken place.
Heat transfer can be classified by 3 mechanisms:

2.1.1 Conduction

Heat/energy in this form is transferred through a physical object, i.e. solid substance. When the molecules are restricted from moving, this force triggers vibration, the same vibration moved to the next molecule by a chain reaction. Thus, the material transferred heat. This process takes place when steel is heated at one end, sooner or later the other end will get warm.

2.1.2 Radiation

Heat is transferred by means of emission or absorption of electromagnetic radiation. This is neither conduction nor convection, it does not require a medium for transmission and it reflects and refracts the same way as light. This can also transfer heat through vacuum. Example of heat radiation is heat from the sun to the earth.

2.1.3 Convection

It is classified into natural and forced convection (Ari, 2012). Heat transfer by means of heated fluid, it expands when the fluid is heated and thus cause the heat movement from one point to another. Example of this form of heat transfer can be found in domestic hot water system inside hot water cylinder.

There are many applications of heat transfer namely;

- Thermal power plants
- Cooling of machines
- HVAC systems
- Home uses
- Chemical production systems
- Heat pumps and refrigerators
- And lots more

There are fundamental and subsidiary laws that governed the foundation of heat transfer. A Fundamental law depends on the validity of the fact that it has not been proved wrong in the broad area of application of subject at matter. Therefore, these laws are certain in solving any problem. On the other part, a subsidiary laws are depends on experimental evidences and intuitions and these may be a result of fundamental laws.

Laws used in heat transfer Fundamental laws are:

- Newton's laws of motion.
- Laws of thermodynamics.
- Laws of conservation of mass.

The subsidiary Laws that are generally used are:

- Equation of state.
- Laws of thermal radiation.
- Fourier's law of heat conduction.
- Newton's law of cooling/ Newton's of heat flow between a solid surface and a fluid. (Gavhane 2008, 13.)

Most engineers working in the field understands how these laws help in solving today's problems on heat transfer.

2.2 Cooling systems

The history and invention of cooling systems in general could be traced back to the 18th century when Peltier's effect was discovered by French physicist Jean-Charles-Athanase Peltier, His effect states that "The cooling of one junction and the heating of the other when electric current is maintained in a circuit of material consisting of two dissimilar conductors; the effect is even stronger in circuits containing dissimilar semiconductors. In a circuit consisting of a battery joined by two pieces of copper wire to a length of bismuth wire, a temperature rise occurs at the junction where the current passes from copper to bismuth, and a temperature drop occurs at the junction where the current passes from bismuth to copper" (Encyclopedia Britannica Inc., 2012. Web. 29 Jun. 2012). After this great French physicist, many improvements have been made to improve his discovery and many scientists continue working hard to make impact in the field.

A cooling system is an internal combustion engine that is used to maintain the various engine components at temperatures conducive to long life and proper functioning. The thermal efficiency of cooling systems could have power density limitation and thus have direct impact on the cost and the size of the electronic equipment, for these implications, heat removal is one of the major considerations in the development of high density electronic equipment. Previously, convection cooling systems for electronic devices were approached with consideration of material and manufacturing cost, pressure drop and pumping power. (Bergles 1990, 270.)

Cooling is a way of removing heat from an object; it could be in-house appliances, automotives, and electronics and power systems. In the early age, different types of cooling systems were used to achieve this only aim of keeping the equipments or any object that requires cool running at operating temperature. Nowadays, the cost saving project is paramount to organizations and also to individuals, so the choose of right type of cooling systems cannot be over emphasized since many things are associated to it, like power consumptions, maintenance cost etc.

In order to understand what cooling systems is/are, we need to examine the heat transfer principle as mentioned above and this would help to understand better how heat is been transferred in the components.

2.3 Types of cooling system

Cooling systems are of many types and they are based on the principle of their operations which distinguished them from one another. Since the damage caused by cooling components or equipments are enormous, for example the costly repair expenses and unnecessary downtime due to problem originated from wrong cooling system. So choosing right type of cooling systems is important as safety.

The different types of cooling system are listed below;

- Air cooling
- Fluid or Water cooling
- Heat sink
- Fan cooled
- HVAC (Heating, Ventilating and Air conditioning)
- Domestics cooling

2.3.1 Air cooling

Air cooling is a way of removing heat from a system. The system is based on making the object to be cooled have more area surface or using fan to generate air to or unto the objects to be cooled. In some cases, the heat sink is connected with the object to make the cooling more effective, and according to the second law of thermodynamics, the air has to be cooler than the object to be cooled. This application is commonly used in automotive engines back then, but due to high increase in engine sizes, air cooling system is not advisable anymore in most nowadays automobiles. Notwithstanding, air cooling systems are still in use in industrial applications and aircrafts. For example, in computers and CPU cooling, where the computer processors produce large quantities of heat that, if not dissipated, could damage the CPU and other electronic components. In this case air has the advantage of being a good insulator too. However, today, new processors might generate too much heat to be dissipated through direct air cooling and it would follow that such direct cooling for computers and their components will become obsolete. Water cooling is somewhat popular in very high-power situations.

The amount of heat dissipated to air depends on the following:

- Amount of air flowing through the fins.
- Fin surface area.
- Thermal conductivity of metal used for fins.

It is as well important to states the advantages and disadvantages that this type of cooling system offers.

Advantages;

- It is easy to construct.
- It does not require pumps.
- It can be used in cold climates where water could not be used due to lower temperature.
- Pipe corrosion is minima unlike water cooling, so there will be lesser maintenance and thus reduces cost.

Disadvantages;

- Air cooling can only be used where air is exposed directly to the objects e.g. aircrafts.
- It is difficult to control the temperature.
- It is less efficient when there is high temperature.

2.3.2 Water/liquid/fluid cooling

This is very important section, since this project work is based on water cooling system for a frequency inverter used to drive 6-axes Motoman welding robot, though more about this would be discussed more in the next chapters.
Water/liquid/fluid cooling systems are nowadays preferred way of taking heat out of our domestics and industrial equipment. Research has shown that, liquid cooling system is more preferred as a better option in cooling heavy equipment and because of the high water density, it provides greater efficiency compared to air cooling system. It also addresses easy control on temperature passing through components. Nevertheless, it does present its shortcomings too in the area of maintenances and cost of installation.

2.3.3 Heat sinks

Heat sinks are device made of fins and spines. The component is used to effectively dissipate heat (thermal energy) from the air using extended surfaces (Ho-Sung Lee, 2010, 34). Heat sinks are used in a wide range of applications where efficient heat dissipation is needed such as high-power semiconductor devices, examples can be found in CPUs and many industrial devices.
This metal device with many cooling fins array designed to increase the surface area in contact with the cooling medium surrounding it. As such, the heat sinks are also heat exchangers like radiator in an automobile. Fans are usually connected with the heat-sinks, especially in CPUs in order to remove excess heat generated by the chips.

Figure 1 Heat sink fin array (Ideal automation)

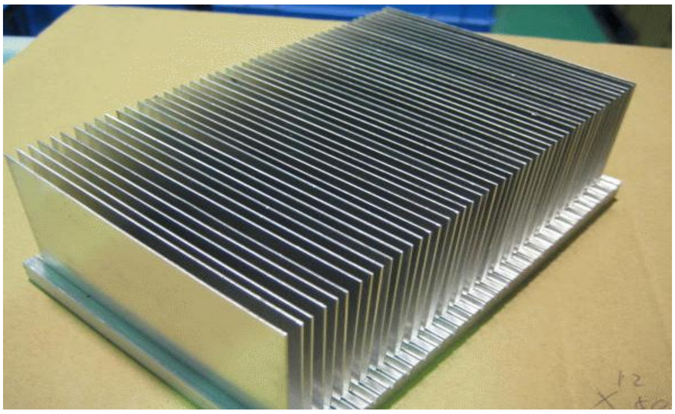


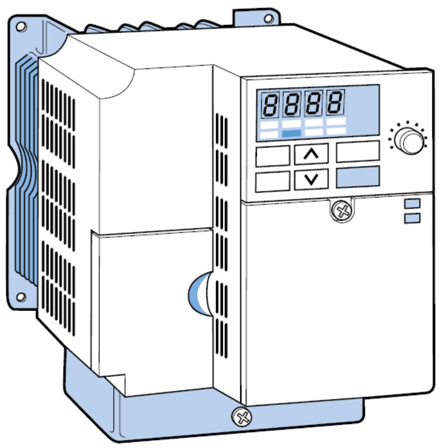
Figure 2 Heat sink fan

2.4 Frequency inverters/variable speed drive

Frequency inverter (variable speed drive) is a device that is used to control torque and motor speed by adjusting motor input voltage and frequency, it achieves a good match with the process requirements of the machine it is driving. When variable speed drive is used in reducing motor speed, this reduces energy used substantially. So, VSD is used to achieve different motor speed output. While some equipment may be good with a fixed speed, there are many other applications which are better suited to running at adjusting speeds, since the speed of induction motor is directly proportional to frequency of the supply. Examples are pumps, fans, precision tools and etc. VSDs are used in applications ranging from small appliances to the huge mine mill drives and that makes it one of the most used devices in the modern day domestics and industrial applications.

A VSD or Frequency inverter works by converting the incoming electrical supply of fixed frequency into a variable frequency output. This change in frequency allows the drive to be controlled the way which the motor operates, meaning the higher the frequency the faster the motor speed or vice versa. The output can be changed to enable the motor to generate more or less torque when required.
There are various sizes of VSDs in terms of the power rating which range from hundreds of Watts to MWs and it can be optimized to suit certain applications. The efficiency of VSDs is very high and could range between 89-95%. It is important to note that most of the losses are due to heat, so it is advisable to place the drive to a suitably protected area which is clean with adequate ventilation and dry, since larger drives generates quite a lot of heat and this could cause overheat and subsequently the unit will malfunction.

Figure 3 Frequency inverter or VSD (google pictures)



2.4.1 Principle of operation of VSDs

In the studying of VSDs principle of operation, the understanding of the four basic sections of VSDs is important, the sections are; rectifier, dc bus, control unit and inverter.
The voltage on an alternating current power supply move in form of sine wave (see figure 4). Current flows in accordance with voltage position i.e. positive or negative. “This type of power system enables large amounts of energy to efficiently transmit over great distance”. (Operation of VSDs: https://hvacpartner.com)

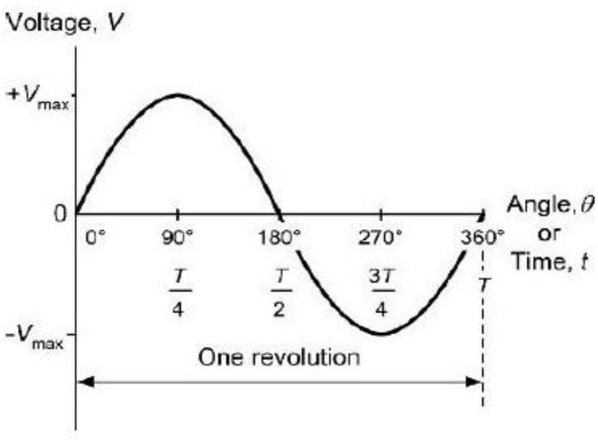


Figure 4 AC power sine wave (Dayo 2012)

The ***rectifier*** is used to convert the incoming alternating current (AC) supply to direct current (DC) supply. The uses of rectifiers vary depending on the type of performance required from the drive. After the power conversion, the power is stored on a ***dc bus,*** this normally comprises of capacitors and inductors which allow the storage of power and later deliver the power through the inverter section. The ***inverter*** converts the rectified and conditioned DC back into an AC supply of variable voltage and frequency, this contains transistors or semi-conductors switch that transfer power to the motor. Insulated Gate Bipolar Transistor (IGBT) is commonly used in today's VSD because of its **pulse width modulation** property. Then the ***Control unit*** gives and receives signals to the rectifier, the intermediate circuit and the inverter to correctly operate the equipment. (Carbon trust, 2007).

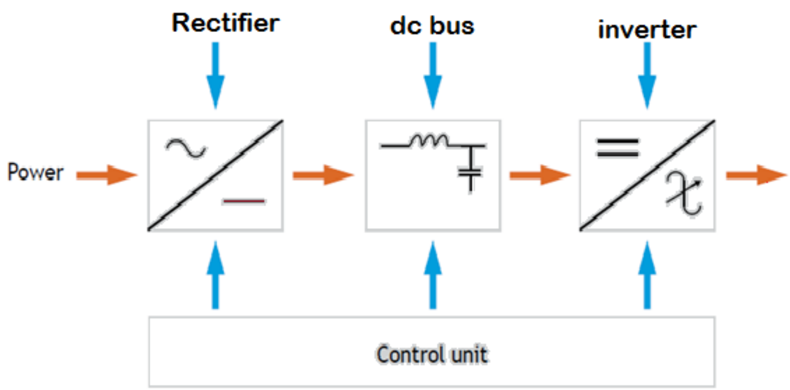


Figure 5 Schematic diagram of VSDs (carbon trust, 2007)

2.4.2 Cooling systems in frequency inverters

Cooling of frequency inverters require precision and it is more challenging when dealing with high power frequency inverters since the heat loss generate in high power VSDs is really huge and so, if wrong selection is made it renders the system malfunctioning. Before now, air cooling is very common in VSDs but due to low air density and research and development, the discovery of new methods emerged and nowadays, there are liquid cooling VSDs, which apparently became famous in the industries because of its numerous benefits compared with air or fan types. Using a liquid for transporting the heat losses offers a different solution to the problem. Due to the higher thermal capacity of the liquid used, typically a water or a water/glycol mix, the amount of cooling media is much lower. The first generation of liquid cooled drives were created by converting air cooled drives for liquid cooling by replacing the air cooled heat sinks with liquid cooled heat sinks. In these types of hybrid solutions the power loss into the air is still quite high as many components, not mounted on the heat sink, still dissipate their heat into the air. It is also not easy to gain size advantages compared to air cooled solutions with such a design, but the latest designs are fully liquid cooling optimized. An optimized design makes it possible to increase the amount of internal components that are cooled by liquid, which in turn reduces the amount of heat dissipated into the air. Moreover, it gives a better and more reliable design of the product (vacon AC drive). The study of this thesis work was based on water cooling discovering for a new system called ACOPOSmulti (cold plate mounting) by B&R automation.

3 ROBOT

The history of robots could be traced back to eighteen century but it later became industrious is late 1960s since then there is no basic definition for it, but I defines it as an automatic machines that are capable of performing tasks at a given instruction. Britannica Encyclopedia gives definition of a robot as “An instrumented mechanism used in science or industry to take the place of a human being. It may or may not physically resemble a human or perform its tasks in a human way, and the line separating robot devices from merely automated machinery is not always easy to define. In general, the more sophisticated and individualized the machine, the more likely it is to be classed as a robot device"
Other definitions have been proposed in "A Glossary of Terms for Robotics," prepared for the Air Force Materials Laboratory, Wright-Patterson AFB.

These definitions are listed below;
Robot: “A mechanical device, which can be programmed to perform some task of manipulation or locomotion under automatic control." [Note: Programs can differ in their nature]
Industrial robot: “A programmable, multi-function manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks."
Pick and place robot: “A simple robot, often with only two or three degrees of freedom, which transfers items from place to place by means of point-to-point moves. Little or no trajectory control is available. Often referred to as a 'bang bang' robot."
Manipulator: “A mechanism, usually consisting of a series of segments, jointed or sliding relative to one another, for the purpose of grasping and moving objects usually in several degrees of freedom. It may be remotely controlled by a computer or by a human."
Intelligent robot: “A robot that can be programmed to make performance choices contingent on sensory inputs."
Open-loop robot: “A robot which incorporates no feedback, i.e., no means of comparing actual output to command input of position or rate."
Close-loop robot: “A robot which incorporates feedback to improve”
Mobile robot: “A robot mounted on a movable platform."
Limited-degree-of-freedom robot: “A robot able to position and orient its end effector in fewer than six degrees of freedom." (Ben-Zion. 1999).

3.1 Parts of robot

The following parts are what make a basic robot but it is not limited to these parts alone rather depends on specifications or tasks to perform by the robot.

- ***Sensor***: This part measures attributes and interact with external events. In robotics, some of the parameters sensors measures are orientation, speed, paths, and proximity of other objects.

  –

- ***Controller***: This control and regulating device initiates one or more functions of operation in the robots' arms, examples are starting, reversing, stopping and varying speeds by issuing preset lists of commands.
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- ***Actuator***: There are many types of actuators. The actuators are the drives and motors inside the robot compartment that are used to create and control motion.

- ***Mechanisms and Kinematics:*** The mechanism is the arrangement of the connected parts. The kinematic structure of a robot refers to the identification of the joint connection between its links. Diagrams can usefully represent it. (robot.com/education/robot-parts-type accessed 1.12.2012)

Designs of robots required good knowledge of mathematics and programming skills and also planning of path and trajectory is very important because these are what makes the whole way from one point to another and also how to avoid the obstacles while its (robot) performing the programmed tasks. There are two constraints facing the movement of robots, these are **path constraints** and **obstacle constraints.** To move between point A and B, different tasks must be deciphered. The best trajectory must be achieved, collisions and obstacles must be avoided and the work productivity and efficiency must be attained.
Industrial robots should possess high flexibility to execute different operations, and follows the three laws of robotics by *Isaac Asimov* which states that;

I. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
II. A robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law.
III. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

From the laws, Isaac Asimov indicated how important human safety is, and also human love for their robots. (Isaac, 1942)

3.2 Types of robots

Classifications of robots are mainly defined by the tasks performed by the robots and nowadays, almost every aspect of our lives involves robot applications, ranging from domestics to difficult areas inaccessible to human. The lists below are the most commonly use types of robots and each one of these types has numerous examples

- Industrial/Factory robots
- Mobile robots
- Service robots
- Modular robots
- Collaborative robot s
- Military robots
- Telerobots
- Healthcare robots

- Research robots etc.

This work focused on 6-axis welding robot, a sub-type of industrial robots;

Implication of robots on society

Robotics have both positives and negatives impacts on society. However, Industries quickly adopted robotic technologies in the interests of perceived safety, economy and efficiencies. Robots can work 24hrs a day, does not required staff amenities, easier to repair and can work in most dangerous areas where people could not access. The replacement of automated systems might contribute to unemployment in society especially unskilled workers. Robots also created new jobs directly and can create wealth, leading to the development of new industries and jobs.

Negative impacts
Unemployment: The use of robots resulting to productivity improvements and related technology can affect labor in several ways. According to V. Daniel Hunt, these effects depend on factors such as the following:

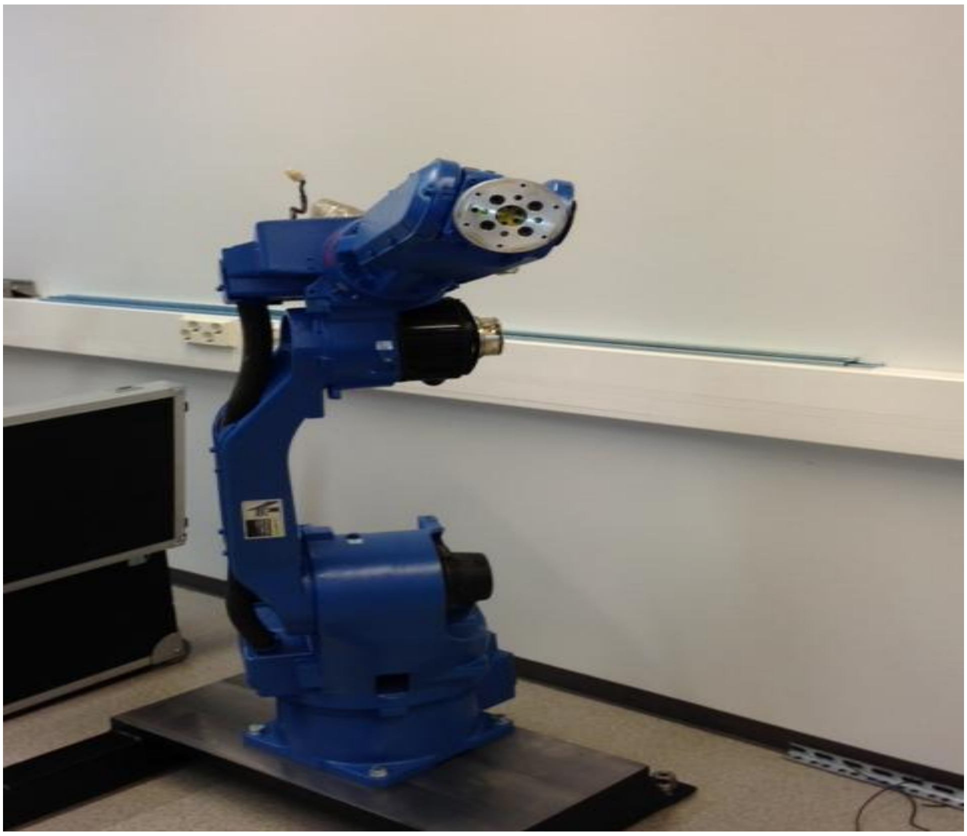
- The effects of new technology on the relative proportion of machinery to workers in a given industry
- The extent of change in prices and production volumes
- The supply of qualified workers with specific job skills in a given industry. (Hunt, 2005.)

Education and Training: Numerous education and training issues are raised by robotics in robot installation, programming and maintenance. There are needs for more technologically literate work force which result into more spending for companies. But it would be unfair to say, this is an issue because improved technological literacy would provide more benefits for the company and the employees.

3.3 Welding robots

From manufacturing of cars to production of very small products, welding is now one of the widespread and successful applications of industrial robotics. Even though industrial robots were introduced in 1960s into US industries, the use of robots in welding did not start until 1980s. However, it covers over 20% of industrial robot applications. These are as a result of several improvements in productivity and precision of welding.
In today’s market, welding robots varies in models and manufacturers, for this thesis work, a 6-axis Motoman arc welding robot was used and re-modified with reference to client specifications.

Figure 6 6-axis welding robot (ideal automation Oy.)



4 MATERIALS AND METHODS FOR THE WATER COOLING SYSTEM

Accuracy and precision are most important part of automation systems and to achieve these, special attention, and research has to be carried out to get the right parameters for the automation systems. This research work was based on getting the right flow, temperature range, and signal communication for a water cooling system. Also designing and implementing piping and instrumentation diagram for the water cooling system, and I/O channeling and diagram.

4.1 Materials

Material used for this thesis work was Cold-plate mounting by B&R Automation for ACOPOSmulti drive, since we were dealing with 6-axis robot, ACOPOSmulti gives a higher level of efficiency for multi-axis machine that are commonly used in industries. I choose this system because it gives a better free space for conventional heat dissipation in the switching cabinet and a feed-through cooler with IP65. The systems use groundbreaking power distribution, which prevent accidental touching of the unit. It is also designed with integrated distribution of the power and auxiliary supply voltage.

Figure 7 ACOPOSmulti drive (br-automation)

Figure 8 Cold-plate mounting

Figure 9 Dimension diagrams and installation dimensions for cold-plate mounting (br-automation 2012)

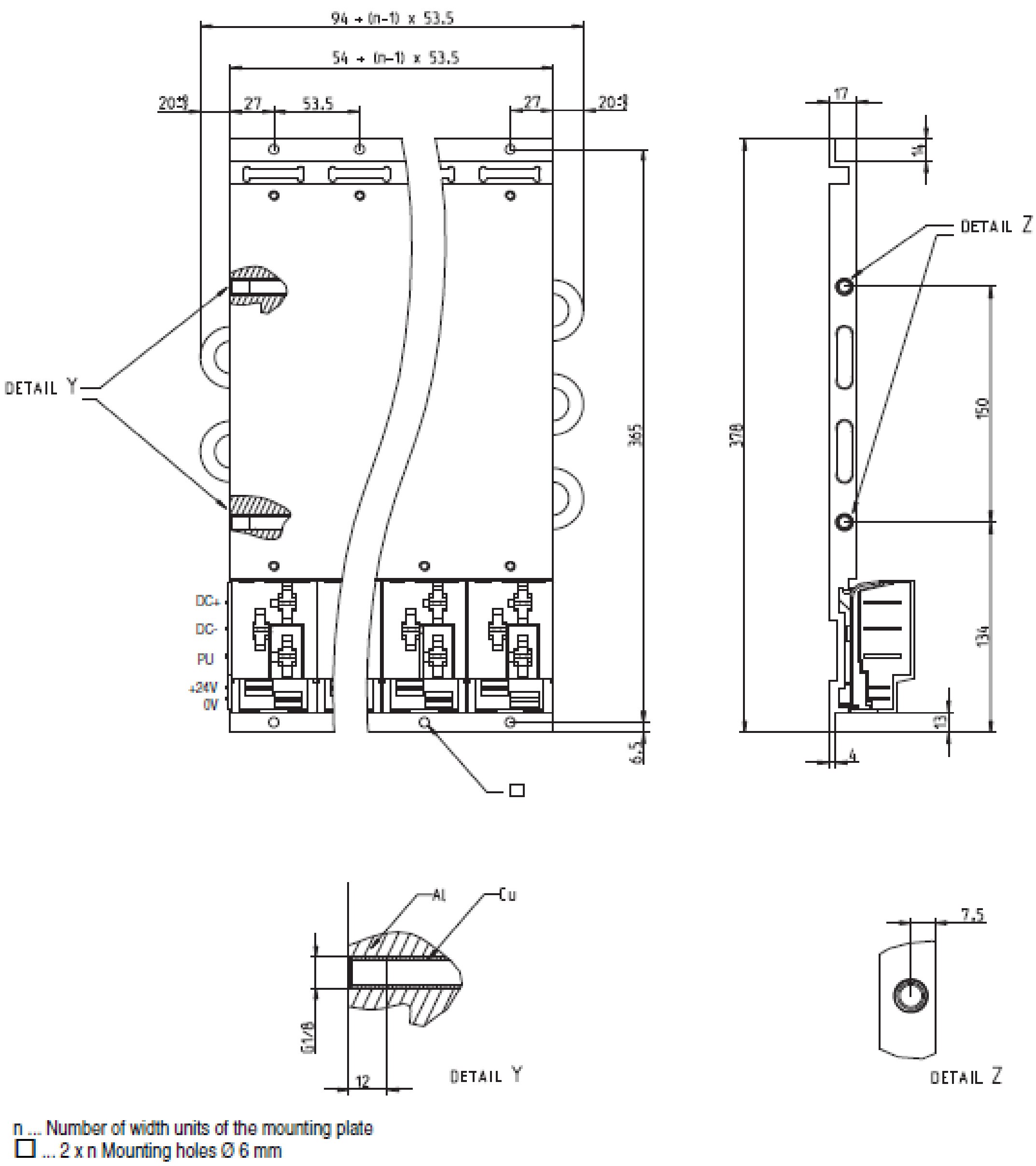


Table 1 Specifications for cold-plate mounting 6-slots type ACOPOSmulti. (br-automation)

Number of slots	6
Cooling and mounting method	Cold-plate mounting
Certification c-UL-us	 Yes
DC bus connection	
Voltage Rated	 750VDC
Continuous power	200kW
Reduction of continuous power according to ambient temperature above 40 °C	In Preparation
Reduction of continuous power depending on installation altitude Starting at 500m above sea level	 20kW per 1,000m
Cross section DC+, DC- PE	 72mm2 72mm2
24 VDC auxiliary supply	
Voltage	25 VDC ±1.6%
Continuous power	1500W
Reduction of continuous power according to ambient temperature above 40 °C	In preparation
Reduction of continuous power depending on installation altitude Starting at 500m above sea level	 150W per 1,000m
Cross section 24 VDC, COM	 21.3mm2
Operating conditions	
Permitted mounting orientations Hanging vertically Lying horizontally Standing horizontally	 Yes Yes No
Installation at altitudes above sea level Rated Maximum	 0 to 500m 4000 m
Degree of pollution in accordance with EN 60664-1	2 (non-conductive pollution)
Overvoltage category in accordance with IEC 60364-4-443:1999	III
Smoothness of the mounting surface	Smoothness of 1 mm over the entire mounting surface
Flow volume Minimum Maximum	 3 l/min 6 l/min
Pressure drop depending on the flow volume 3 l/min	 Typically 0.3 bar

6 l/min	Typically 0.7 bar
Test pressure	10 bar for 1 minute, air inside, water outside
Max. continuous pressure	5 bar
Max. ambient return temperature	60°C
EN 60529 protection	IP20
Environmental conditions	
Temperature Operation Rated Maximum Storage Transport	 5 to 40°C 55°C -25 to 55°C -25 to 70°C
Relative humidity Operation Storage Transport	 5 to 85% 5 to 95% Max. 95% at 40°C
Mechanical characteristics	
Dimensions Width Height Depth	 361.5 mm 378 mm 17 mm
Weight	5.6kg

4.2 Operation of the water cooling VSDs

Liquid cooling system for a variable speed drives works on the basic principle of thermodynamics, by transferring heat from warmer objects to cooler objects. Whenever there is contact between cool and warm objects, heat transfer takes place and makes the warmer components becomes cooler. This principle could be experimental through firsthand by placing hand flat on a cool spot of a desk for a couple of seconds, after removing the hand, the spot gets a bit warmer. The same principle is applicable in automobile cooling system.

It is important to note that VSDs can also be air-cooled or air-conditioned and also can dissipate heat to surface via heat sink. However, the fans inherent to the air-cooled drives tend to generate noise during operation and that was why water-cooled drives get involved. (Carrow, 2001). Water-cooled drives require pump, piping, valves, control systems, and heat exchanger systems in conjunction with the drive’s converter and inverter. Special attention should be given to the heat generated by the drive since the drive has current running through it that produces heat and this heat has to go somewhere. It can dissipate naturally if there is a light-duty cycle. If the loading is heavy, then provisions for cooling or ventilating are necessary.

The advantages of water-cooled drives over air-cooled or heat dissipate drives;

- It moves heat faster than air because of its higher thermal conductivity.

- Water also has a higher specific heat capacity that allows it to absorb more heat before it starts to feel hot.
- It is very effective at deadening mechanical noise, which makes the system quieter.
- It is efficient and easy to maintain.
- Cost effective.

Disadvantages

- From a control point of view, water cooling can be more difficult to handle since the change in temperature occur rapidly as soon as water cooling is activated. (Rauwendaal, 2002).
- It is relatively expensive to implement.
- Water accelerates corrosion of metal parts and is a commending medium for biological growth.

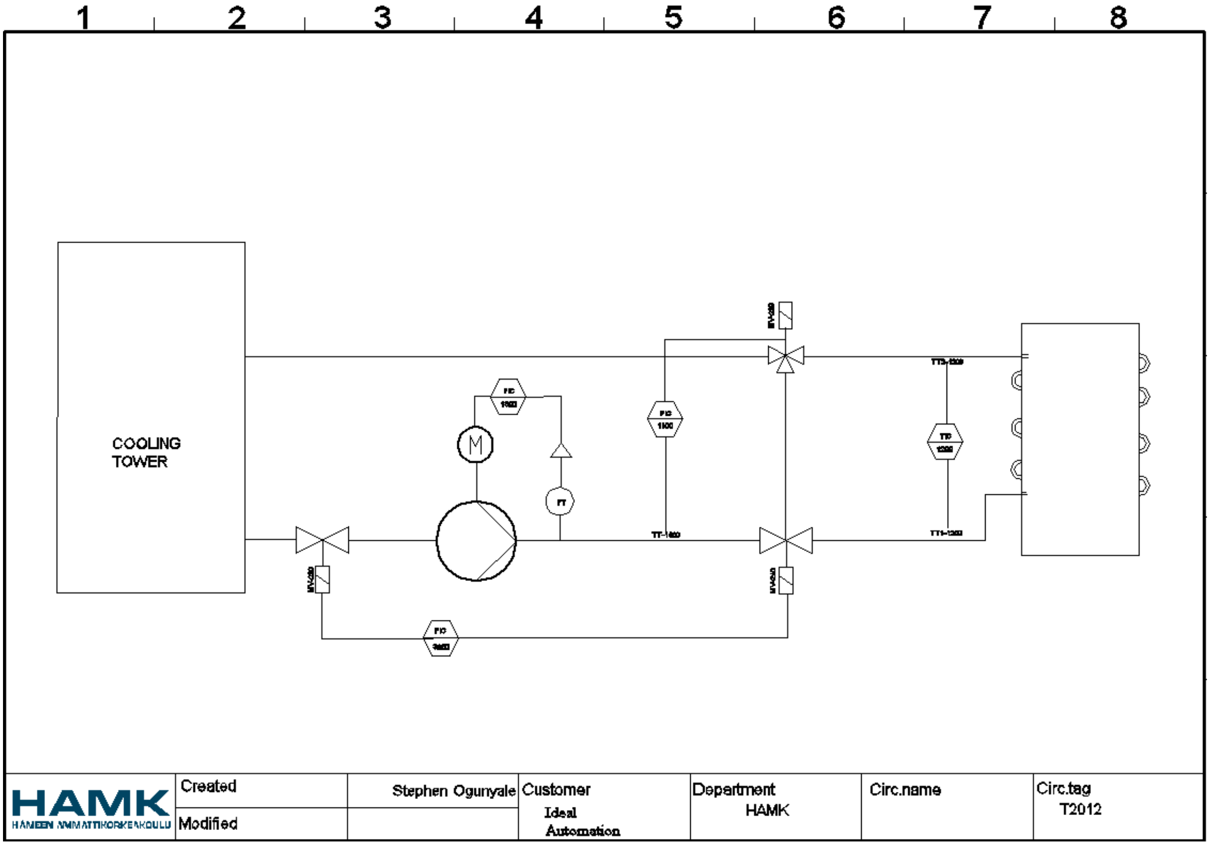
4.3 Project design

Piping and instrumentation diagram (P&ID) are schematic analogy of working relationship of piping, instrumentation and system equipment components. P&ID indicates all the piping with physical sequence of branches, valves, instrumentation, equipment and control interlocks. A P&ID is a key source of data document for process automation design, and it is also necessary for later process alterations, maintenance functions and outlining an overview of both process and automation systems. (Tikka, 2007).

In P&IDs control, position numbers are used to indicate the command and measurement circuit functions and various locking and alarm requirements. The position number is a letter-number combination, which is shown inside an instrument circle. The upper half of the circle contains the instrument circuit function indicated using the standard initials and the lower half contains a numerical identifier indicating the specific circuit. The numerical identifier can be a sequential number as well as a plant-specific symbol series, which indicates the circuit's position in the process. P&IDs position markings must comply with standard SFS-ISO 14617-6 (Graphical symbols for diagram).

If a programmable device or a computer is processing information, the instrument circle is replaced by a hexagon if necessary it can be elongated. The amount of quality time spent preparing P&ID can easily result in cost savings, efficient plant layout and safe operation.

Figure 10 Piping and Instrumentation diagram for the system. (Dayo 2012)



4.3.1 Cooling tower

Cooling tower is a simple device used by industries to remove heat from the water. The internal design of the cooling tower ensures good air and water contact. Hot water transfers heat to cooler air as it passes through the internal components of the tower. This type of heat is called sensible heat, the heat can be measured, and it accounts for only few percent of the heat transfer in a cooling tower. However, the evaporation accounts for about 85% of the heat transfer in a cooling tower. Heat energy is resulted when water changes to vapor and left over the cooler liquid. Cooling tower efficiency is basically dependent on the principle of evaporation.

Cooling towers are classified by how its produces airflow and the direction the airflow takes in relation to the downward flow of water. Airflow may be produced mechanically or naturally. Fans located on the top or side of the cooling tower creates mechanical drafts. Flow direction into a tower is either cross flow or counter flow. The designs of cooling towers are based on the airflow principle and come in the following designs:

Natural drafts

- Atmospheric draft - simple counter flow
- Hyperbolic (Chimney towers) draft – counter or cross flow

Mechanical drafts

- Forced draft – counter flow
- Induced draft – counter or cross flow

The components of a cooling tower include a water basin, water make-up system at the base of the cooling, pump, fan, and pressure-treated woods or plastics what are designed to support the internal components of the cooling tower. (Thomas 2010, 148).

The application of atmospheric draft was used for this thesis work, which allows forced air to move vertically against the downward water flow.

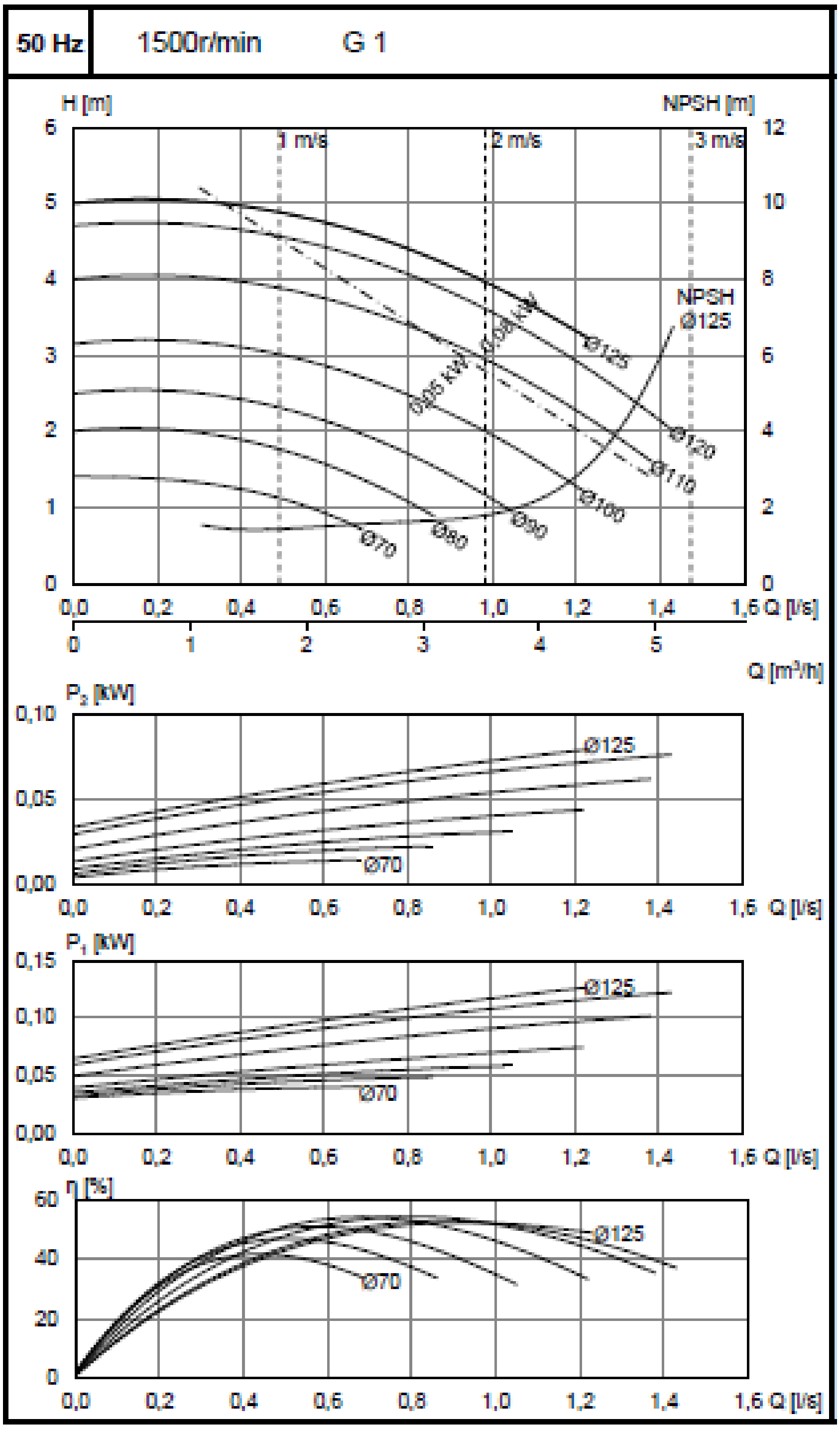
4.3.2 Pump

Pumps are simple devices that transfer the fluid from one place to another, by mechanical action. They are usually configured to use the rotational (kinetic) energy from an impeller to impart motion to a fluid. The impeller is located on a shaft; shaft and impeller(s) make up the rotor. Many process pumps are designed and constructed to facilitate field repair. Although, operating a hydraulic end, the impeller remains energized during removal from the field (Bloch, 2011). There are many types of pumps in process industries, and they are classified into three main groups according to the method they use to move the fluid namely:

- Displacement pumps
- Direct lift pumps, and
- Gravity pumps.

The pump selection was based on the specification of the cold-plate mounting maximum fluid flow of 6 l/m or 0.1 l/s. From the graph below, the power, nominal current, efficiency of the centrifugal pump can be deduced as follows; Power 0.05kW, nominal current 0.21A and the weight 9.5kg

Figure 11 Pump Selection graph (Kolmeks.fi)



4.3.3 Valves

There are many ways of classifying valves, it can be classified by category, specific type, purpose, or by flow characteristics (e.g. Straight-through or throttled-flow). Descriptions can also differ slightly in different countries. So it is important to read country's standard on automation systems

Industrial valves operate under many different situations and temperatures, which range from the cryogenic to high temperature applications and with different materials that includes grit, liquids, gases, and corrosive chemicals. Control valves give precision control of the flow and on/off valves, which may be further, subdivided into linear and rotary. However, actuators control the movement of a valve manually or automatically.

When selecting a valve(s) for a typical function, the following parameter needs to be considered:

- Fluid to be handled
- Functional requirements
- Operating conditions
- Flow characteristics and frictional loss
- Size of the valve. (Dickenson, 1999.)

A solenoid valve was preferred by the client because is an electromagnetically operated valve. Solenoids offer fast and safe switching, high reliability, long service life, low control power and compact design.

4.3.4 Pipe selection

For a mass flow rate of 6 l/m or 0.1 l/s, the pipe selection can made via pipe size table and to make the right selection, the pipe pressure drop needs to be considered. Pipe pressure drop occurs as a result of resistance to flow. There may be a pressure gain/loss due to a change in elevation between the start and end of the pipe. The diameter of the pipe selected for this work was 1.3mm

4.4 Input and output connection

According to the client, 'e-plan' was preferred to 'metso-DNA' normally used for HAMK University projects. This is the important aspect of the thesis, because of the allocation of channels in the I/O table has to be according to the standard and specifications.

Table 2 I/O Table (Dayo, 2012)

CHANNELS	I/O UNITS IN THE FRAME			
	BIU8	BOU8	AIU8	AOU4
1		MV 220	FT 210	P220 (SPEED)
2		MV 230		
3		P220 (ON/OFF)	TT1-240	
4		MV240	TT2- 240	
5			TT 250	
6				
7				
8				
CARD PLACE	5	6	7	8
AXC4	11	12	13	14

Figure 12 Motor relay connection to digital Output (Dayo 2012)

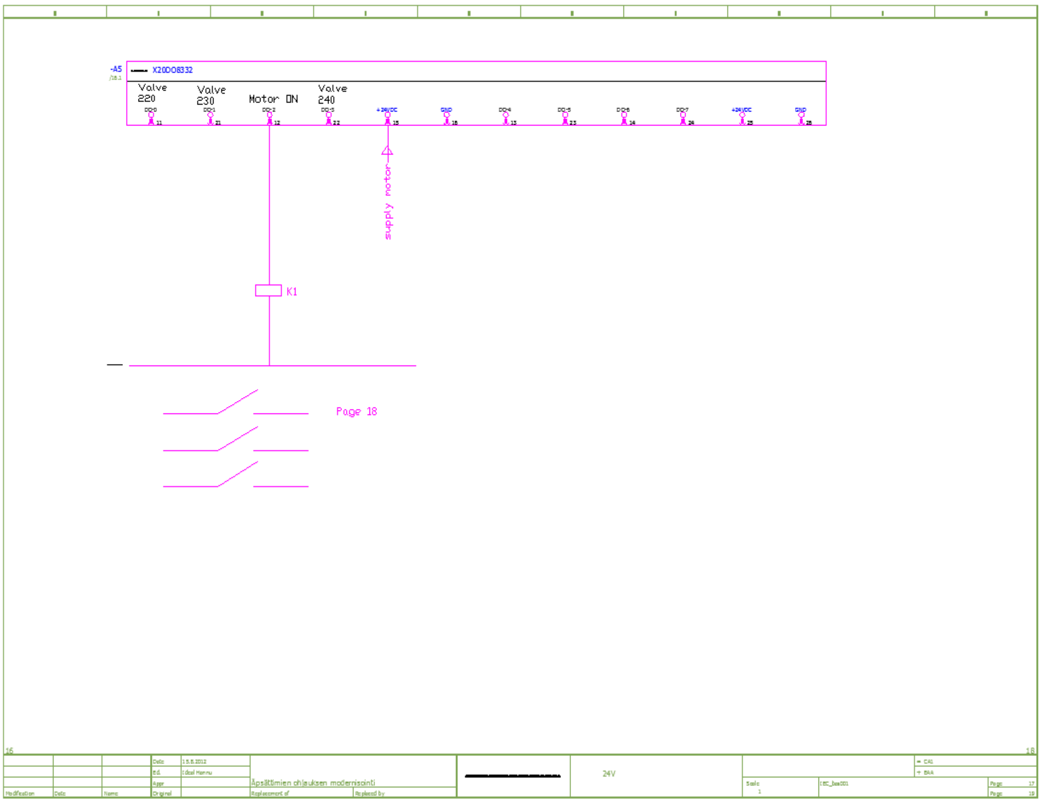


Figure 13 Digital output diagram (Dayo,2012)

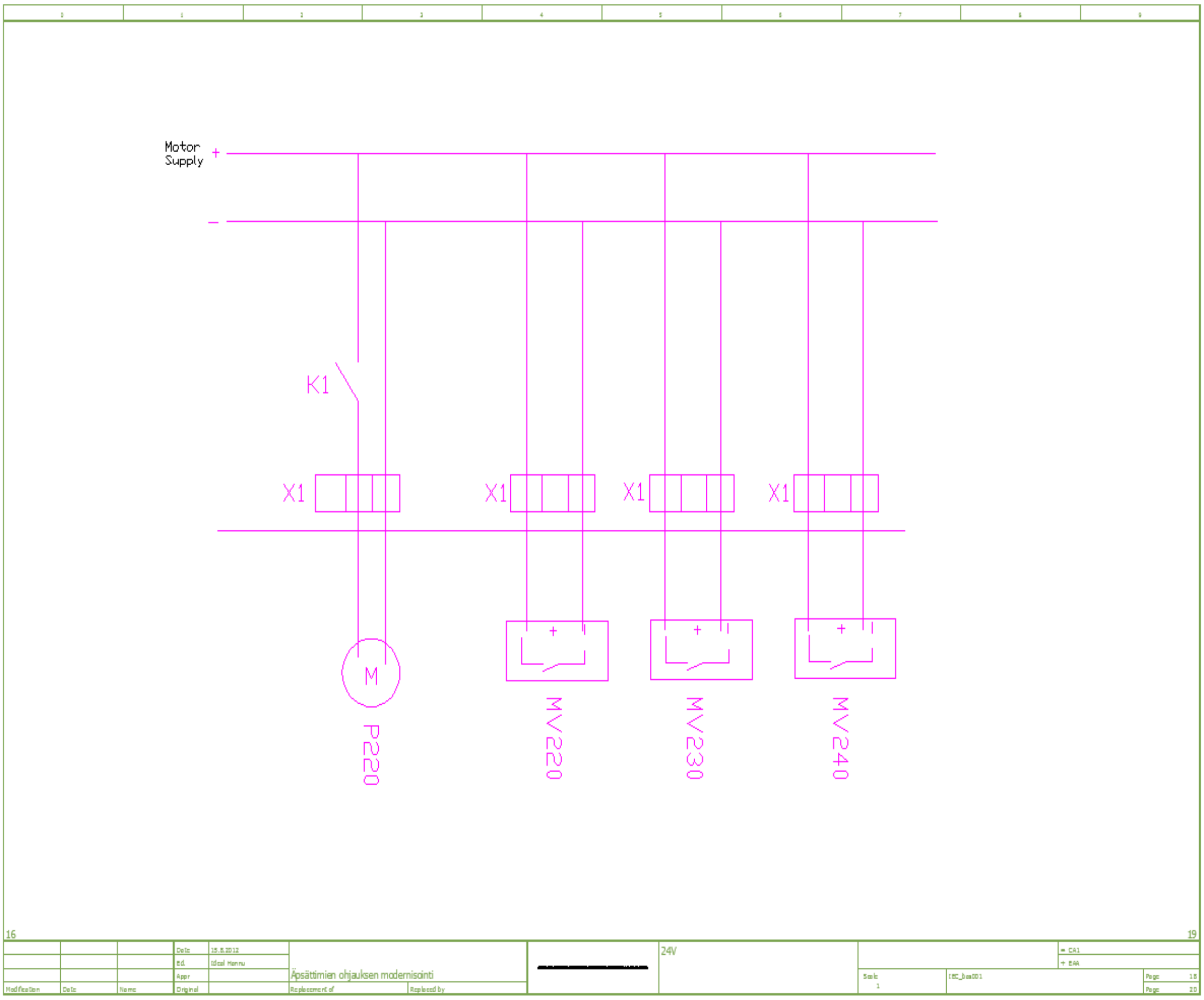


Figure 14 Analog input diagram (Dayo, 2012)

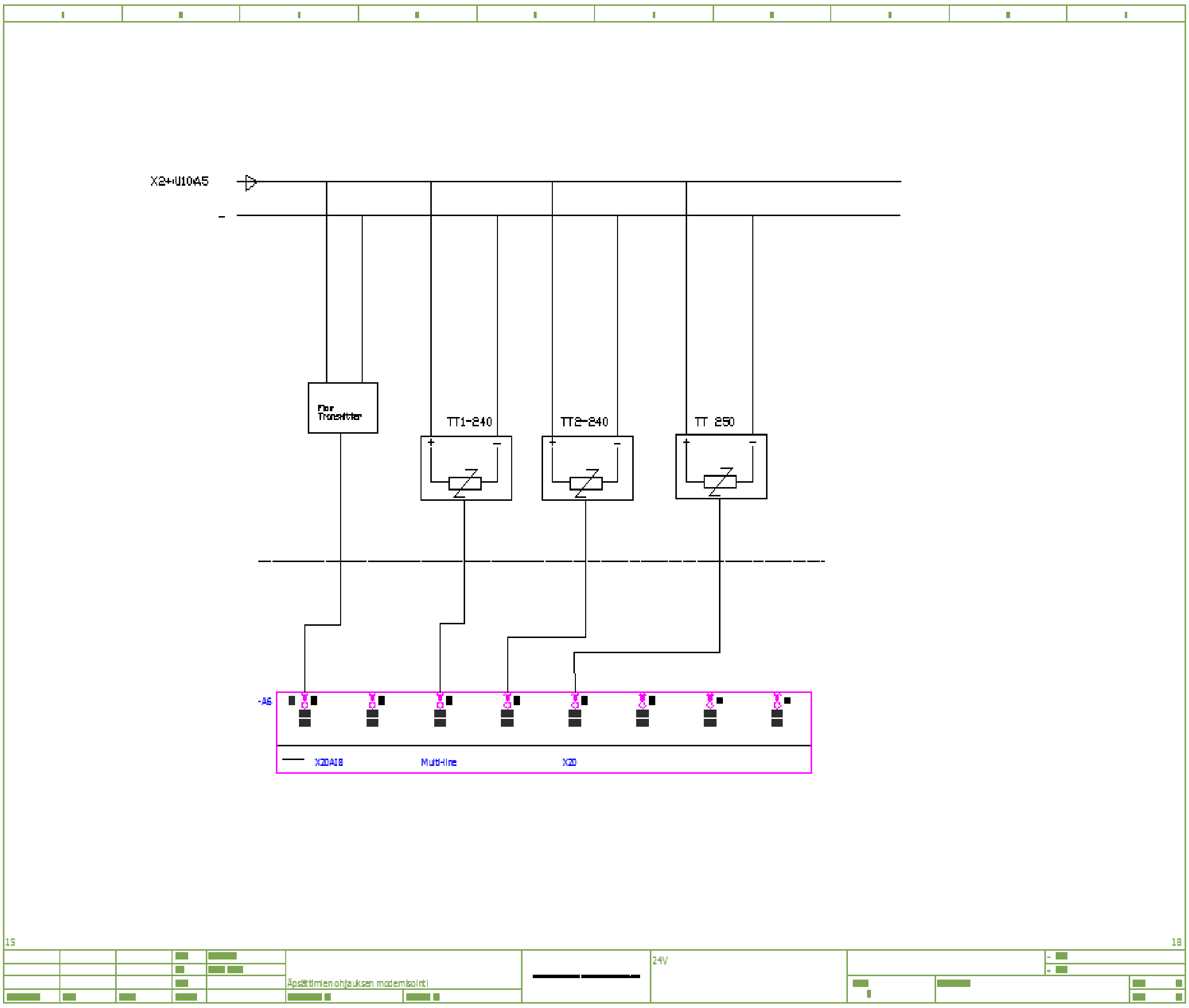
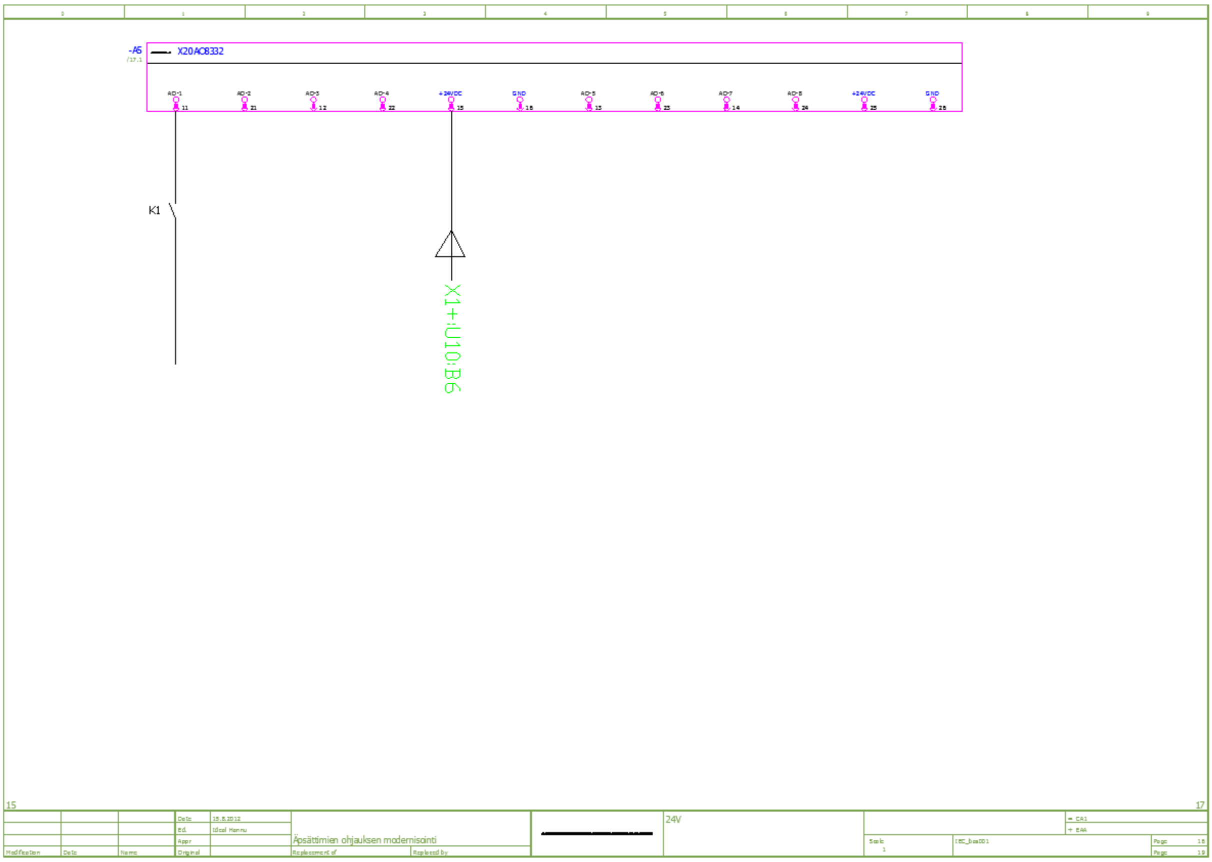


Figure 15 Analog output diagram (Dayo, 2012)



5 CHALLENGES

There were numerous challenges I encountered in the course of my thesis work. These challenges are described below.

- Lack of well-defined project scope at the beginning

The contact person of the commissioning organization had a limited understanding of the modus operandi of the water-cooled VSDs. As a result, it was somewhat difficult to set a clear scope and targets for the project. I managed to ensure that, constant communication and brainstorming with the commissioning company's representative. Afterwards, we did outstanding team work to set valuable expectations that will ensure the realization of maximized business result.

- Distance

I covered about 200kms twice a week to and fro the commissioning company. This was a really challenging task for me because I still had classes at the same time with my thesis work. In the end, the sacrifices were worth it.

- Software availability

At the time of my thesis, the school computers were formatted leaving no software available at school for me to use. This made the project complicated and delayed it. I waited until the school was able to reinstall the CAD software for the P&ID design before I could get started with the project.

- Inadequate reference materials

There was no previous related robust research on water-cooled VSDs in my university and it was difficult to access resource materials to learn more about the technology. I consulted various libraries to find out publications relevant to my project. The use of the internet was also adopted as a good source here.

- Lack of funding

I did not have any funding either from the school or the commissioning company for my thesis work.

6 CONCLUSION AND RECOMMENDATIONS

The P&I diagram was successfully designed according to the company's expectations and the allocation of input and output channels to the field devices were accepted by the client. Implementation could not be completed because the simulation software of the commissioning company was not available for the project. Nevertheless, the research work and the diagrams were accepted. Numerous skills were acquired during the thesis work, which prepared me for the future.
Some of the skills acquired during the thesis include but are not limited to the following:

- To use eplan software capability
- Knowledge of field device connections
- Knowledge about VSDs cooling systems
- Deeper knowledge of industrial robots
- Knowledge of the process improvement and optimization

I strongly recommend further research to this project in the future. This would check the implementation and results compare with conventional air-cooled VSDs.

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