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MODERNIZATION OF MILLING MACHINE DCS PRECIMILL M4

Master's Thesis

Author applying for
master's sciences of technical
academic degrees

Tallinn
2015

AUTHOR'S DECLARATION

I hereby declare that this thesis is the result of my independent work.
On the basis of materials not previously applied for an academic degree.
All materials used in the work of other authors are provided with corresponding references.

The work was completed Mart Tamre guidance

“.......”....................2015 a.

The author

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The work meets the requirements for a master's work.

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Supervisor

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Permit to defense

.... curriculum defence superior

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TUT Department of Mechatronics
Chair of Mechatronics Systems

MASTER'S THESIS SHEET OF TASK'S

Year 2015 semester 4

Student: Andrias Niklus, 082794
Curricula: Mechanics
Speciality: Mechatronics
Supervisor: Professor, Mart Tamre
Advisers: Rauno Luiv, CTO in Dental Export, 55603982

MASTER'S THESIS TOPIC:
(in English) Modernization of milling machine DCS Precimill M4
(in Estonian) Freesmasina DCS Precimill moderniseerimine

Thesis tasks to be completed and the timetable:

Nr	Description of tasks	Timetable
1.	Milling machine DCS Precimill M4 dismounting, maintenance and assembly	3. April
2.	Choosing new motor controllers and installing them. Connecting new motor controllers with motors.	30. April
3.	Choosing new motors and installing them if necessary. Changing gears if necessary.	30. April
4.	Choosing new CNC controlling software and installing it.	9. May
5.	Ensuring the work of the whole machine in order to use in manufacturing process.	15. May

Solved engineering and economic problems:

Perform modernization of the milling machine DCS Precimill M4 as cheap as possible. Find suitable hard- and software solutions and using these solution in practical work. Inspecting the gears of the machine and improving them if necessary.

Additional comments and requirements:

Language: English

Application is filed not later than 04. May

Deadline for submitting the theses 22.05.2015

Student Andrias Niklus
Supervisor Mart Tamre
Confidentiality requirements and other conditions of the company are formulated as a company official signed letter

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FOREWORD

The master's thesis topic was chosen in collaboration with Rauno Luiv who is the CTO in a company called "Dental Export". He wanted to add old milling machine DCS Precimill M4 back to production. During the modernization of the machine, people involved considered many various modernization levels. Taking in consideration that the assignment was practical the author ran in to many various problems that would not occur during theoretical work. The main setback was the time needed for completion of the work.

Hereby the author would like to thank master's thesis supervisor Mart Tamre for his support and enterprise Dental Export worker Rauno Luiv for many discussions and for the trust.

EESSÕNA

Magistritöö teema valiti koostöös ettevõtte „Dental Export“ töötaja Rauno Luiviga, kes avaldas soovi freesmasin DCS Precimill M4 uuesti tootmisse rakendada. Töö teostamise ajal kaaluti jooksvalt moderniseerimisega seoses erinevaid uuenduse astmeid. Arvestades asjaolu, et tegemist on praktilise ülesandega tekkis töös ka hulgaliselt tõrkeid ning teostamise ajakulu kujunes algselt planeeritust palju suuremaks.

Siinkohal soovib auto tänada magistritöö juhendajat Mart Tamret tema toetuse eest ja ettevõtte Dental Export tehnilist juhti Rauno Luivi usalduse ja nõuannete eest.

1. INTRODUCTION

The master's degree thesis was collaborated with the company called Dental Design that was founded in 2010 and is specialised to producing good quality artificial teeth. The task was to involve old milling machine DCS Precimill M4 to production. (Extra 1) The milling machine is specially built for producing artificial teeth. DCS Precimill M4 was removed from production when company bought new milling machine Wieland iMes-750. (Extra 2) Taking into consideration that the technology of producing teeth had involved a lot during that time the old machine was just left to collect dust. The demand for artificial teeth has increased lately and one milling machine could not satisfy the need for production output, so the old machine will be re-established to production.

The difference between those two machines is immense. The iMes milling machine uses round milling blocks and is capable of milling following materials: BruxZir (not sintered), zirconia (not sintered), wax, PMMA, cobalt-chrome, titan and e-max. The older machine used rectangular milling blocks and was used to mill sintered zirconia and titanium. Milling sintered zirconia is inefficient and therefore it is not milled anymore. According to recent plans the DCS Precimill M4 will be used to mill titanium, cobalt-chrome and e-max as all of these materials need usage of cooling liquid. Thanks to that solution the newer milling machine form iMes will stay cleaner and will need less service.

The aim of this work is to modernize the old milling machine DCS Precimill M4 and take it into use. This machine was in use during the company's early years and was replaced with the new one because it's amortisation. Now, when demand for artificial teeth has grown significantly the company had to find a way how to increase production. And the best way to do this is to take into use the existing machine that requires modernization. During the master's degree thesis the author will introduce several problems that occurred during modernization process and introduces solutions how these complications can be solved.

The master's thesis is divided into six sections. First paragraph introduces milling machines dismounting, maintenance and assembly. In this part the author will describe the performing of the aforementioned activities and the problems that turned out during that process. The toughest set-back from this chapter was bearings greasing process that finally got quite simple solution.

Second paragraph is focused on the machine's block holder exchange process. The positive and negative sides of this process have been brought out and finally the decision whether it is even reasonable to change the squared block holder for the round one or not.

In the third paragraph the author explains how the new axis amplifiers were chosen. All the additional devices that were needed for the installation of the axis amplifiers are brought out as well. In this paragraph the author also brings out fact if the gears were changed and how was this process carried out.

The fourth chapter is concentrated on choosing the new CNC control software. In this chapter the author compares different software providers and finally makes a well-considered decision on what kind of software to use.

The fifth paragraph turned out to be hardest one as the author finds out that the plans on how to make the machine work are going to fail as the machine parts are too integrated. In this chapter a new control system is designed with all the necessary features. In the beginning of this paragraph the author explains how to connect all the devices that were chosen in the previous chapter. Then the all new tool changing process is worked out that as it turns out needs an extra controller. After that some of the electrical solutions are explained as some of the old parts can be used. Later on the changes with block holding system come up again as the grinding process for glass-ceramics needs special solution. In the end of that chapter the author explains what kind of changes have to be done in G-code in order to use the code calculated for the new machine.

The sixth and final chapter is for cost calculations where the author brings out all the purchases that were made and also the ones that still have to be made.

All of the development is carried out keeping in mind the requests from the company. Different levels of renewals were discussed and the choice was made mainly considering the project cost. During the work some initial ideas were changed due to various reasons. All of the changes made during the process are described in the work.

2. MILLING MACHINES DISMOUNTING, MAINTENANCE AND ASSEMBLY

2.1. Milling machines dismounting

Milling machines dismounting was carried out due to necessity of machines maintenance. Considering the fact that no drawings nor paperwork about the machines mechanical construction were owned a lot of pictures were taken during the dismounting process. Drawings for some of the electrical connections were sent from the manufacturer but as they were incomplete, photos of electrical connections were also taken for precaution. For electrical connections simplified schemes were made using Google Sketch Up software. (Extra 3) The dismounting process was performed using the logic to dismount as little as possible but as much as necessary to carry out maintenance. In the early stages of the dismounting were noticed that the required grease level on some parts was sufficient as other parts clearly needed lubrication. The dismounting took two days to complete not considering electrical connections inside the machine. There was no point of disconnecting anything as long as the new motor controllers had not been chosen. The main obstacle during the dismounting process was lifting the milling part from the body, as the weight of the milling part is about hundred kilograms.

The dismounting was carried out as follows:

1) Dismounting the exterior body from the machine which was necessary to even get close to the rest of the machine.
2) Unlinking the pneumatic hoses from the milling part of the machine. Otherwise it would not have been possible to separate the milling part of the machine from machines body.
3) Unlinking electrical cables that were outside of the machine. Most of the cables had connection plugs outside of the body so it was only necessary to mark the plugs and disconnect them. Some of the components like end-switches and controller next to the machine did not have plugs so the disconnections had to be made directly from the device where there were many wires. Simplified schemes of the connections are shown in Extra 3.

4) Removing the milling part of the machine from the body. The milling part is connected to the body with only three bolts but as the part weighs about hundred it was difficult to remove it as no necessary tools were to be found. Finally the part was removed using manpower of two men, where one of them really hurt his back. Therefore a better plan had to be created in order to mount it back later.
5) Removal of the hinge covers was the last necessary part of dismounting in order to start maintenance.

2.2. Milling machines maintenance

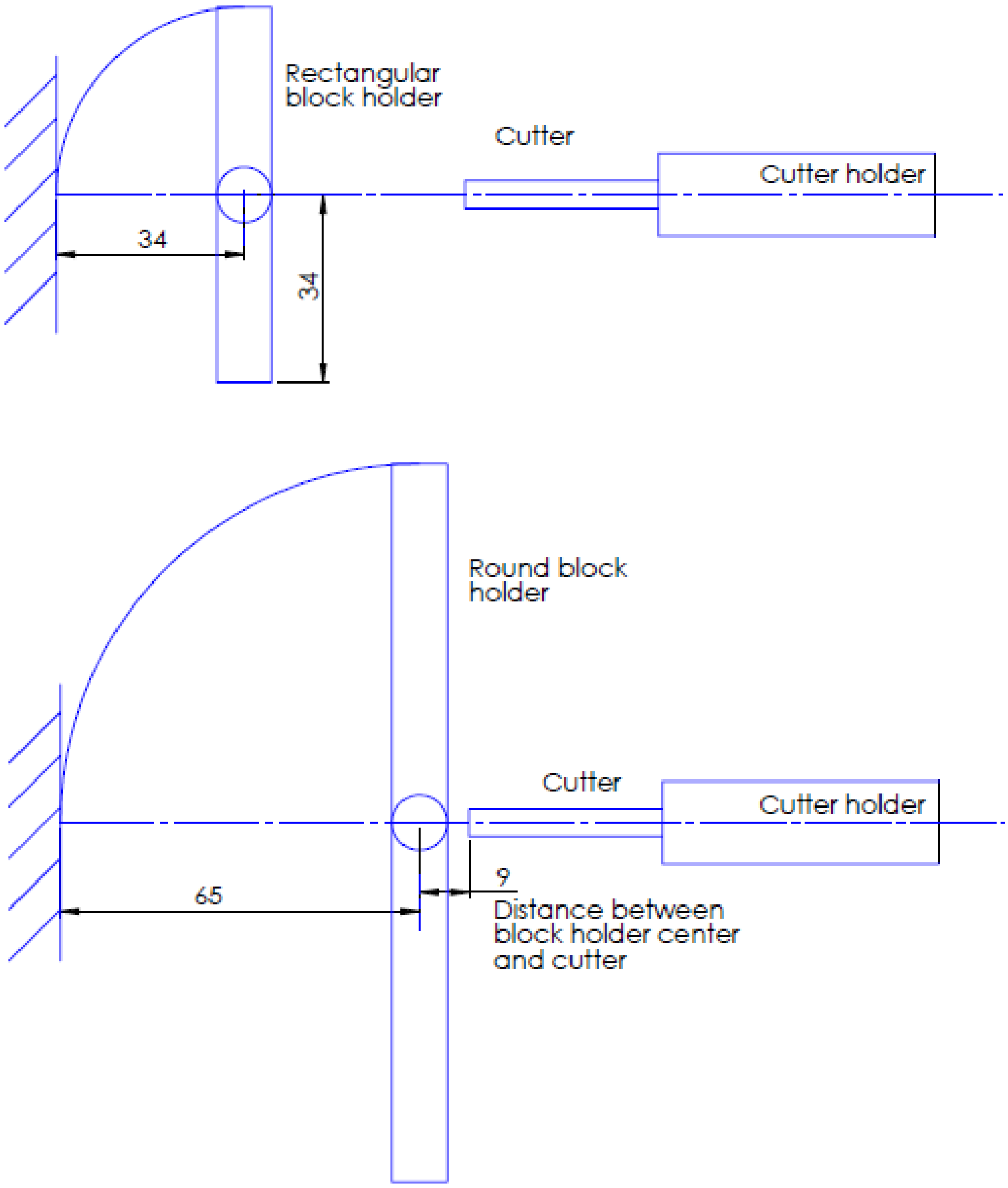
The main purposes of the maintenance were cleaning the machine and greasing the moving parts. Maintenance was carried out during the dismounting and immediately after. Removed body covers were cleaned using Loctite 7010 which is specially designed to clean manufacture machines. While trying to grease the bearings of the machine first big problem was discovered. Special kind of oiling nipples were used in the machine. After long research on the web and many calls to different greasing equipment sellers in Estonia it was realised that no special greasing nozzle was to be found. Changing the grease did not require high pressure so as a last resort using syringe was tried but no success was achieved. Therefore it was decided to produce a special part in order to use standard oiling nozzles. Original nozzles were attached to the machine with M4 thread and the smallest nozzles available in stores used M6 thread. In order to change the greasing a transition from M4 external to M6 internal thread was needed. First a drawing of the part was made (Extra 4). Producing that kind of detail is not difficult but companies are not interested in producing one little detail and therefore the price is really high for just one piece. First it was tried to mill the detail with iMes milling machine but CAM software had trouble calculating it with through hole. So the hole was closed on one side as you can see in the drawing. Only two metal materials were to be chosen: cobalt-chrome and titanium. The detail was milled from cobalt-chrome as it is easier to process it in following phases. Unfortunately the milling machine was not able to mill eight millimetres of the hole. Post-processing was done by using diamond grinding blades for hand milling machine. After breaking two blades it was realised that the material was too tough to get hole through it. The final solution was made from copper by one of the workers from the company who had a lathe at home. Lastly a rubber seal was added to the detail to ensure a hermetic connection. Using this detail it was possible to grease the bearings of the axis.

2.3. Milling machines assembly

Milling machines assembly was made in a way that it was assembled before. Author's drawings and simplified schemes (Extra 3) were used to do that. It was told that some of the end-switches are not working correctly and as for primary inspection their connections were checked. It turned out that one of the end-switches was connected differently from the other. More thorough inspection was carried out in subsequent phases where it also turned out that one of the end-switches had a mechanical defect. The connection between contacts did not change whether the button of the switch was pushed down or not. It was decided to order a new end-switch after the tests of the machine are finished.

3. CHANGING DCS PRECIMILL M4 BLOCK HOLDERS

Companies newer milling machine iMes 750i uses round milling blocks but DCS Precimill M4 uses rectangular blocks. It was considered to start using round blocks on DCS machine to make managing the storage a lot easier. Firstly it was necessary to know how hard it would be to make that kind of change in the machine. The change will be performed if it does not cost too much and is easy to make. Block holder is attached to the machine in a way that its distance can be changed using spacers but we have to make sure that there is enough space for cutter. The machines dimensions were measured and it turned out that there will not be enough space for cutter. The result is easier to understand from the Drawing 1.



Drawing 1. Explanatory drawing about changing the block holder

On the drawing the round block holder is shown on maximum distance. The blocks have to be able to make 180 degree turn and that is how the measuring has been made. If the block holder is able to make 180 degree turn we cannot mill material with thickness of 25 millimetres which is necessary requirement. It is shown on the drawing that the distance between block holder centre and cutter is 9 millimetres, but in order to mill 25 millimetres thick block it has to be at least 15 millimetres. Considering the fact that it is necessary to change the position of the cutter to use round blocks the idea for doing that was dismissed as it would have been costly and complicated. This idea will be considered in the future.

4. CHOOSING NEW MOTOR CONTROLLERS AND INSTALLING THEM. CHANGING GEARS IF NECESSARY.

4.1. Choosing new motor controllers

The choice of new motor controllers was mostly based on motors current and voltage indicators. Furthermore it was considered important that the controller would connect easily with other devices and the connection between computer and controller would be described understandably. Two controllers were selected out as main options: DG4S-08020 from CNC Drive production [1] and Gecko G320X. [2] Main indicators of the two chosen controllers are quite similar. DG4S-08020 controller does have twice as big input signal frequency, in addition it does support motors with lower voltage. The price is also a little bit lower for DG4S-08020. Gecko G320X has better working temperature range though. Considering the fact that the working temperature should not rise over 30 degrees Celsius.

Table 1. Table to compare motor controllers

	DG4S-08020		Gecko G320X	
Motor voltage [VDC]	Minimum	Maximum	Minimum	Maximum
	12	80	18	80
Motor current [A]	0	20	0	20
Working temperature [°C]	0	65	0	70
Input signal frequency [kHz]	0	400	0	200
Price [€]	80		112	

According to table 1 DG4S-08020 controllers were chosen. The key feature why it was chosen was the fact that the additional devices to these controllers were easy to find on the same webpage. The support of CNC Drive was also spectacular.

4.2. Choosing additional devices

Additional devices were chosen as some of them were suggested by the support and some of them were just necessary to complete the task.

First additional device that was ordered was UC-100 [3] that does some of the calculations instead of computer. That device takes load off of computer so the program is more likely to run smoothly. When computer does not make calculations fast enough an error is easy to appear.

Second additional device bought was HDBB2 Break-out board. [4] This device divides signal between different controllers and is capable of controlling other auxiliary signals. When using HDBB2 breakout board it is possible to make connection professionally and easily observable as the connections are made using RJ45 cable.

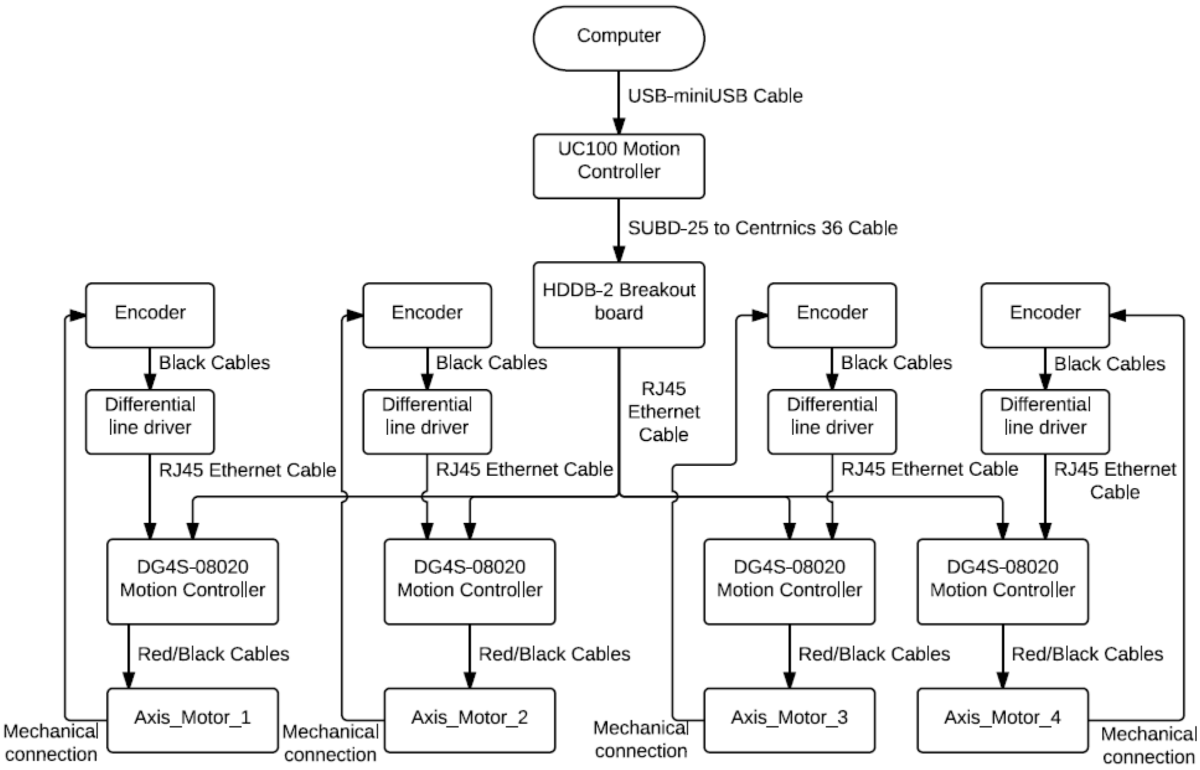
Third devices that were ordered were differential line controllers. [5] Differential line controllers differentiate the signal that comes from encoders. When disconnecting the old motor controllers it was discovered that from encoders only A and B signals from encoders were used but new controllers need A+, A-, B+ and B- signal. After more thorough inspection it was found that the encoders actually sent out the necessary signal but this signal was processed to A and B signal. Still as for precaution and thanks to the low price of the differential line controller they were still purchased.

For fourth additional device a 12 VDC power supply was purchased. [6] It was mostly necessary for testing as it powered the new motor controllers during testing process. It was decided to use it also after testing to make schemes easier to track.

Fifth additional device that was purchased was step-down transformer from 12 VDC to 5 VDC. Author used it to power encoders during testing.

Sixth and final additional device was programming stick for DG4S-08020 motor controller. [7] This stick was necessary to make connection between controller and computer. With programming stick it was possible to connect the controller with computer via USB port. Additional software was downloadable from CNC Drive's homepage.

In order to connect all these devices different type of cables are required. In drawing 3 the main connection scheme with required wire types is brought out.



Drawing 2. Connections between devices on block scheme

4.3. Installing motor controllers

The installation of the motor controllers turned out to be a lot harder than it was expected. Firstly to start programming the controller it was tested to provide digital power to controller but computer could not connect to device with only digital powered applied to it. After that digital power and five volts to encoder input was provided but computer was still not able to connect to the controller. It turned out that in order to start programming the motor controller had to be already correctly connected to the machine. When connecting the encoder with differential line controller another problem appeared. The encoder signal game from terminals and it was processed by special processor that was integrated with the old computer. As the old computer did not work anymore it became apparent that the encoder A and B signals could not be taken from the same terminals they were taken before. Therefore the author decided to connect encoders taking signal straight from encoders. The encoders give out signals with six wires plus they have two wires to power the encoder. In the drawings that were given from support about the encoder signals the wire colours did not match. The author presumed that the connection numbers to the terminals were correct but once the author connected the encoder, error about encoder signals appeared on the controllers LED indicators. After that voltages between encoder wires were measured and voltages between two different pairs of wires were established. The encoders used with the machine do not have any recognition signs on them so the author had to anticipate that the signals with voltage between them were the correct ones. When connecting the controllers with encoder signals that the author chose no error was discovered by the controller. The computer unfortunately was still unable to connect to the controller. It managed to update the software in the controller though. In order to move forward the author had make test the encoders to be sure about its outputs that should be as follows:

1) A channel -
2) A channel +
3) B channel -
4) B channel +
5) Index –
6) Index +
7) 5 VDC
8) GND

After this problem occurred the hole controlling system was examined and it turned out that all the procedures are controlled by computer not by controllers and electrical schemes as it was assumed. With this new information and considering the fact that the old computer does not work it was decided that it would be easier to design new controlling system from the scratch than to try to restore the old one. Therefore the plans took a huge turn and the author decided to design a new controlling system to machine as a master's thesis and to build the machine after the controlling system's design is complete.

4.4. Changing gear where necessary

The motors control the axis by spinning the threaded rods. The force from the motors shaft is transferred to threaded rod by rubber belt. The machine worked with spectacular accuracy with these gears and therefore it was decided not to do any radical changes to them. All the rubber belts were inspected and it was decided that all of them are in good condition. Therefore all of the rubber belts were tightened and the bearings were already greased in the maintenance phase. No other changes were necessary.

5. CHOOSING NEW CNC CONTROL SOFTWARE

When choosing new CNC control software the author based on the fact that it had to be cheap, reliable, easy to understand and easy to connect to other devices. All the parts were ordered from CNCdrive Motion Control and therefore the first choice of the software game from the same site. The site offered software called UCCNC that should be able to control up to 6-axis. [8] It is able to execute G-code that is also necessary and is it originates from the same place as the ordered parts it is definitely compatible with other devices.

Another software that was brought out on the same webpage is Mach3. [9] Mach3 is also compatible with ordered devices and especially with UC100. When comparing Mach3 and UCCNC it was soon noticed that Mach3 is much more opened system that supports a lot of plugins and is more configurable. After researching feedback from other users it became clear that Mach3 is a better choice because of its configurability.

When the author had decided to use Mach software another choice had to be made because a new version Mach4 had been released. The newer version should probably be better but it does not have all the extra plugins yet as the Mach3 has. Fortunately both of these programs had free demo version downloads. The author downloaded both of these programs for testing.

While comparing these programs it seemed that Mach4 is better. It was easier to find all the necessary input and output visualisations, it had much better graphics and all the extra functions were simpler to find. Mach3 on the other hand seemed a bit out-dated. It had quite bad graphic and most of the extra functions were more clicks away. The older version did have its perks as well. First of all it was trustworthy as it has a lot of satisfied users. Secondly there is a lot more information available online for debugging any errors that might occur. Finally it was a little bit cheaper than the newer version.

After almost choosing the new Mach4 version a sad fact turned out as the author suspected. The UC100 motion controller plugin was only available for the old Mach3 version. Therefore it became clear that Mach3 software will be used for the project.

During the process a comparative table was made to make decision-making easier.

Table 2. Comparative table for choosing the new CNC control software

Program	UCCNC	Mach3	Mach4
Control at least 4 axis	Yes	Yes	Yes
Able to execute G-code	Yes	Yes	Yes
Compatible with UC-100	Yes	Yes	No
Widely used/lot of information available online	No	Yes	Not yet
Supports many add-ons	No	Yes	Not yet
Price [€]	45	215	200

According to the table 2 and explanations give before the Mach3 seems rational choice to be made. It is the most expensive program according to the table but the price in the table is calculated with the UC-100 Add-on. UCCNC has it integrated and Mach4 does not support it yet.

The program will be purchased only after the testing is done and machine is ready to be put into manufacturing process.

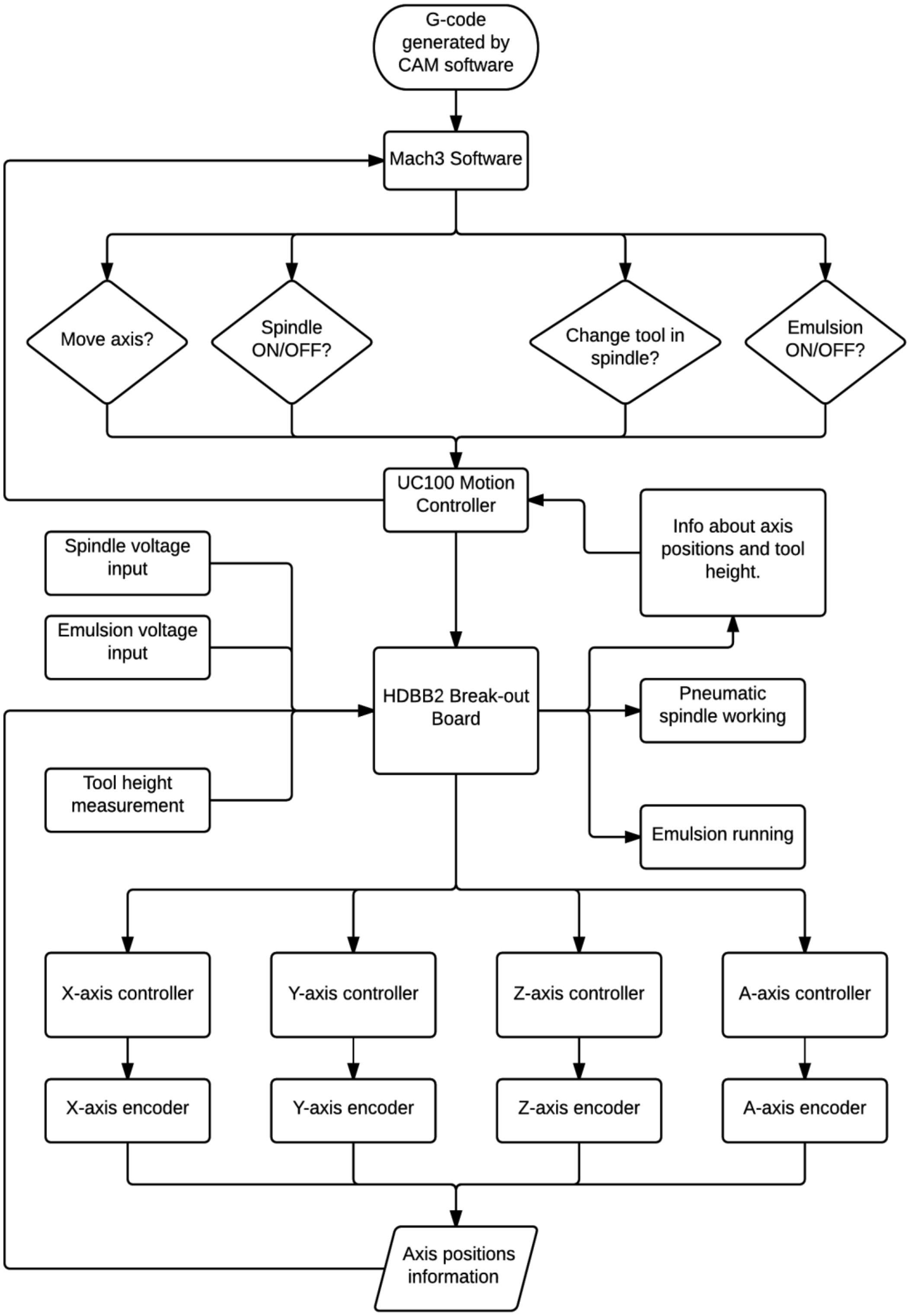
6. DESIGNING THE NEW CONTROL SYSTEM

It was explained that the old control system was very integrated to its host computer. Almost all the calculations were done through its computer and the computer had special controllers attached to it. The controllers were connected to the motherboard via ribbon cable and no information about these connections were to be found. As a result it was decided to design a new control system from the scratch. It will be a very long process to get the machine working but it was evaluated as the easier way of getting it done.

6.1. The main working order

It was very important to start with building up the main idea of how the machine is going to work. In order to do that an explanatory block scheme was drawn. The whole system became big as all the features had to be considered. On the block scheme (Drawing 3, page 18) is shown the main idea of the controlling process. The main application that the system does is to move axis. In order to move axis the system needs feedback from axis position. Therefore the signal has to go to the axis and the feedback is taken from encoders. Other features also have to be controlled, such as: emulsion pump work, spindle work and tool height has to be measured and considered during manufacturing process. Fortunately the Mach3 software already has built in such features as measuring tool height and controlling if the spindle is rotating.

When drawing a block scheme it became obvious that the whole system will not fit on one scheme to explain it thoroughly. For example a tool check was entirely left out from the main process drawing. Therefore other schemes were drawn in order to explain different steps of the process.



Drawing 3. Explanatory drawing of the main controlling system

6.2. Controlling axis movement

The main task of the machine controlling is obviously controlling the axis movement. The machine will be working with four moveable axis. X-, Y- and Z-axis have linear movement and the A-axis has rotary movement. The newer machine iMes 750i that is used in the manufacturing process does have similar axis movement. The iMes does have a fifth C-axis rotary movement that DCS Precimill M4 does not have. The C-axis movement can be disabled on the CAM software and as the company wants to use the same CAM software on both machines it is an important feature.

All of the axis (four of them) are controlled by DG4S-08020 axis amplifiers. (Extra 5) DG4S-08020 has five different connectors:

1) Power in connector
2) Motor connector
3) USB connector
4) Main connector
5) Encoder connector

In working order four of those connectors must be connected. The USB connector is used only in programming phase.

6.2.1. DG4S-08020 axis amplifier connections

It was mentioned in the previous chapter that DG4S-08020 has five connectors: Power in, Motor, USB, Main and Encoder. The axis amplifier's connections are connected as follows (also see extra 6):

X-, Y- and Z-axis amplifiers Power in connections are connected to the 56 VDC power supply for the motors. 56 VDC power supply voltage comes from the 230 VAC to 40 VDC power transformer that has existing electrical scheme after it. Motor connectors are connected directly to motor. Arm 1 is connected to motor plus terminal and Arm 2 is connected to motor minus terminal. USB connector is used only for programming the device. It connects with programming stick through four pin connector. Main connector connections are made with RJ45 plug that has eight wires.

The wires inside RJ45 have to be connected as follows:

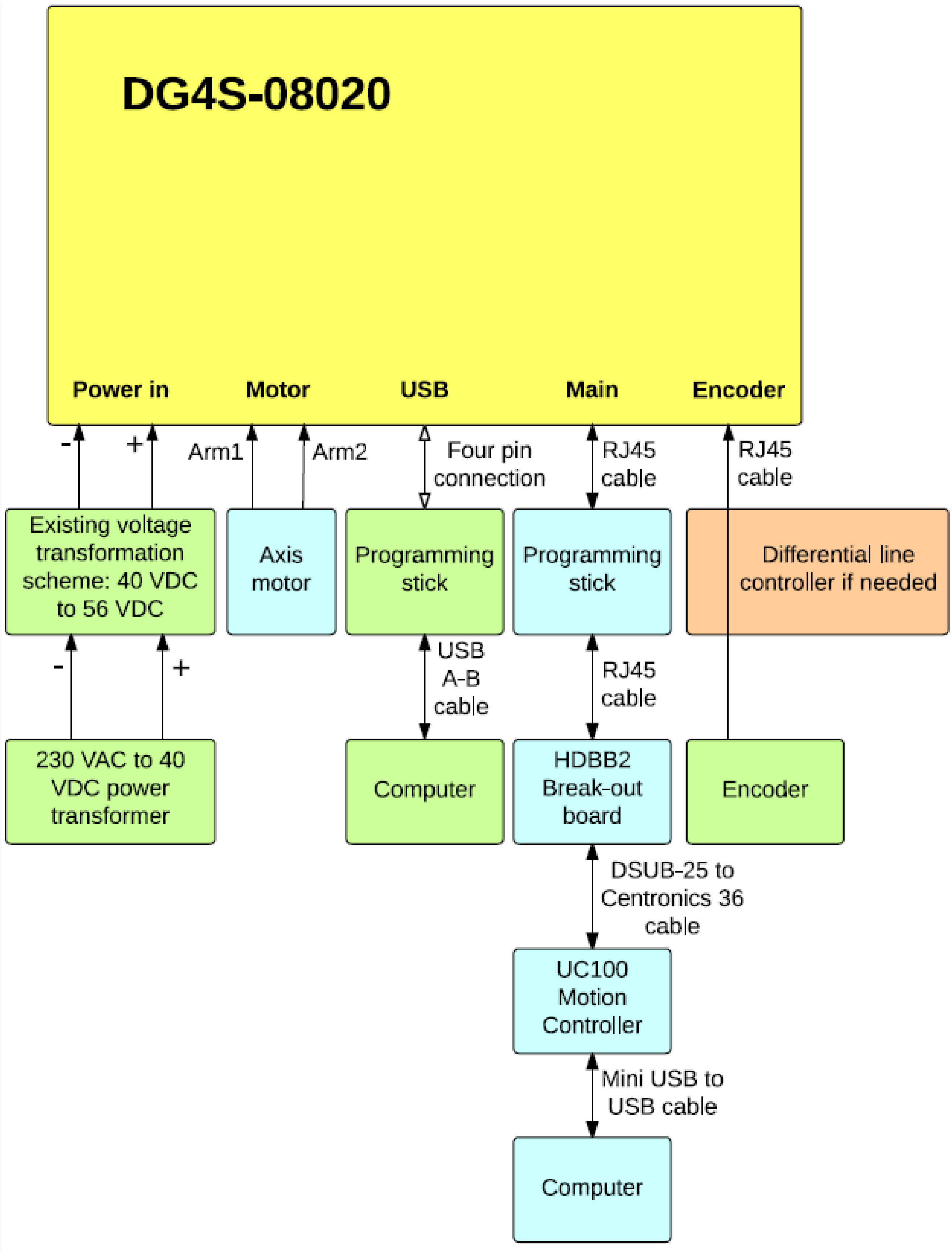
1) Step signal input
2) Direction signal input
3) Ground for Step and Direction signals
4) 5 VDC power input (only used when 12 VDC is not applied)
5) Reset (input) and Stop (input)
6) Error (output) and Stop input
7) DC power + (12 VDC input for digital power)
8) DC power – (ground for the 12 VDC power supply)

This kind of connections are gotten from HDBB2 break-out board. The board does not give out any signal on pin four as required from the DG4S-08020 manual. The signal to the board comes from UC100 motion controller that gets its signal from the computer.
Encoder signal is also gotten using RJ45 plug. The pinout for the Encoder signal is as follows:

1) GND
2) 5 VDC
3) Index +
4) Index –
5) A channel +
6) A channel –
7) B channel +
8) B channel –

CNCdrive. As there is no information about the encoders that are installed on the machine these signals will be first connected during testing period.

The connections to the X-, Y- and Z-axis amplifiers are shown on the drawing 4. For the A-axis amplifier the only difference is power in voltage. A-axis amplifier gets 24 VDC to its Power in connector straight from the 230 VAC to 24 VDC power transformer.



Drawing 4. The connections to the X-, Y- and Z-axis amplifiers

6.2.2. HDBB2 Break-out board and its connections

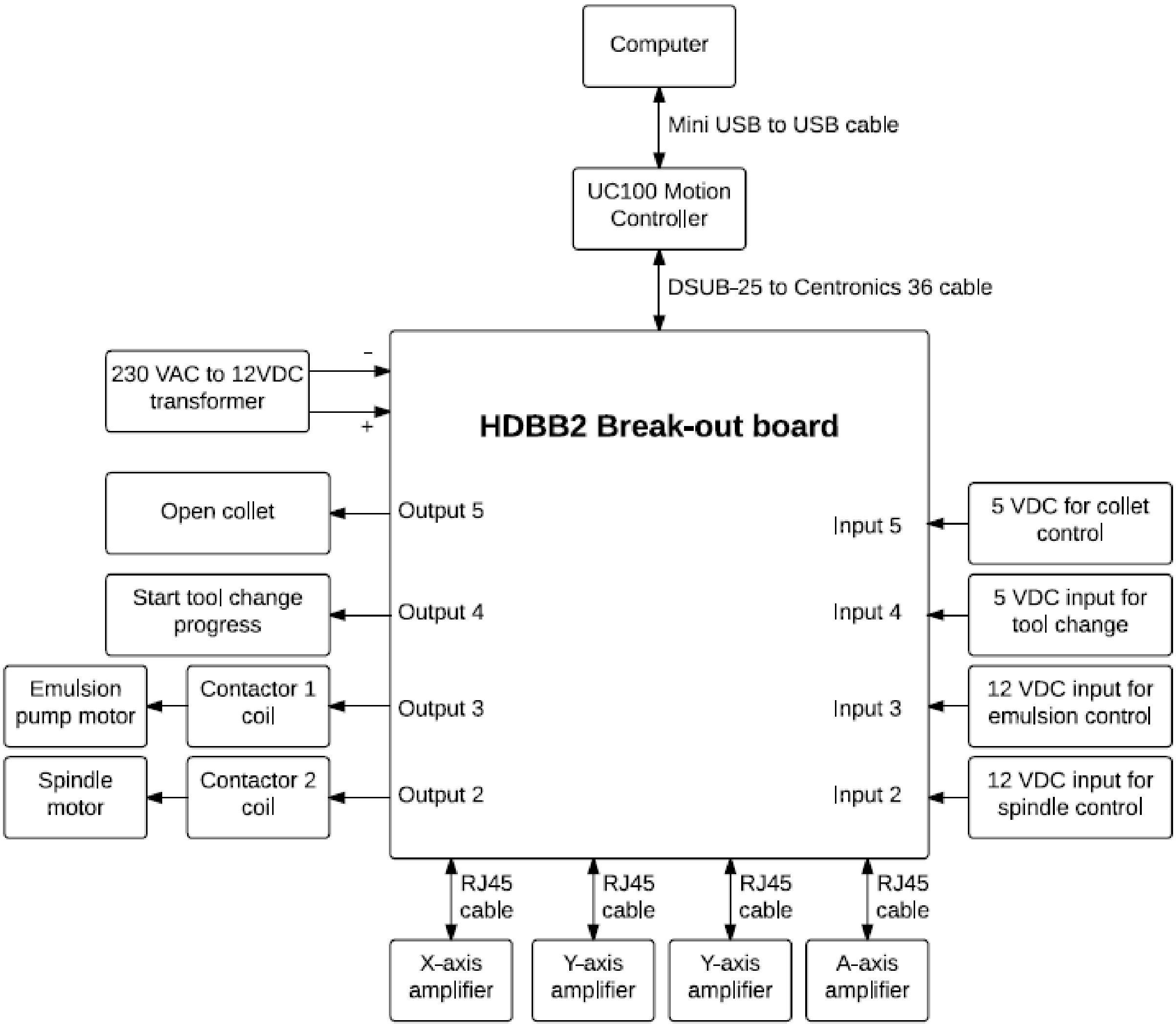
The break-out board’s (Picture shown in Extra 6) main task is to divide signal between different axis amplifiers. It has main input that is connected with Centronics 36 cable and four main RJ45 outputs for axis amplifiers. It has five extra inputs and outputs, power input for 12 VDC supply, Reset input and Error input and output. All-in-all it has 38 extra screw terminals in addition to plug connections. The Centronics cable gets signal from UC100 that has DSUB-25(LPT) plug, so standard transformation cable is used in order to transfer these signals. The plugs pinouts are shown in Extra 7. The RJ45 pinout signals are as follows:

1) Step signal
2) Direction signal
3) LPT port ground
4) N/C (no internal connection)
5) Reset signal
6) Common Error line
7) 12 VDC power output +
8) 12 VDC power output –

This kind of output is compatible with DG4S-08020 Main input and makes it easier to connect these two devices.

The pinout for screw terminals are shown in Extra 8.

The HDBB2 Break-out board is used as the main unit for controlling the work of the whole machine because it is easily connectable to the computer and its signals can be controlled and programmed in the Mach3 software. Only tool change progress needs its own controller, all other devices will work through the Break-out board. The tool changer controller will still get its start signal from the board and will notify the board when it is done. The main connections of the Break-out board are shown in the drawing 5.



Drawing 5. Simplified scheme for connecting HDBB2 Break-out board

6.2.3. UC-100 and its connections

The UC-100 Motion Controller (Picture is shown in Extra 9) is used to decrease the amount of calculations that the controlling computer has to do. Some of the calculations are made in UC-100 instead of the computer. The use of UC-100 is important because if there are any delay of signal coming from the computer it will corrupt the controlling system. Using UC-100 evidently decreases that risk. UC-100 is connected to the computer via mini-USB to USB cable. The other plug is connected to the HDBB2 Break-out board via DSUB-25 to Centroncs 36 cable. Mach3 CNC control software that is used has a plugin for UC-100 Motion Controller and that makes it easy to use.

6.2.4. Differential line driver, its usage and connections

Differential line driver was used to differentiate the signal that comes from the encoders (Picture of the driver is shown in Extra 10). This device is only necessary when encoders with signals outputs A and B are used. If encoders send out A+, A-, B+, B- signals then differential line drivers are not needed. Differential line drivers have screw terminals for input wires and RJ45 plug to send signal out. Differential line driver input signals are the following:

1) GND
2) A channel
3) 5 VDC
4) B channel

Differential line driver's output signals are the following:

1) GND
2) 5 VDC
3) Index –
4) Index +
5) A channel –
6) A channel +
7) B channel –
8) B channel +

While at first the author was not sure about using differential line drivers as the encoders sent out seemingly correct signals then over the time it was decided that new encoders will be ordered to avoid losing time while trying to put the machine back into production. The old encoders have no marking as said before and therefore it is quite difficult to verify what kind of signal they actually send out. This can only be tested by using oscilloscope not with simple tester. Setting up oscilloscope and getting the right signals is very time consuming especially considering the fact that the company does not have its own oscilloscope. Therefore it seemed reasonable to order new encoders instead.

6.3. Tool changing process

In order to mill precisely the milling machine must be able to use different tools automatically. The machine has a tools holder (tools rollercoaster) for twelve different tools. The products are milled out using maximum of three different tools depending on the material and chosen accuracy. The DCS Precimill M4 machine has to be able to mill three different material types:

1) Cobalt-chrome
2) Titanium
3) E-max (Glass-ceramics)

Titanium and cobalt-chrome are milled using the same three tools:

1) 3 mm ball-ended milling tool
2) 2 mm ball-ended milling tool
3) 1 mm ball-ended milling tool

The main difference is that cobalt-chrome does not have to be milled using emulsion for cooling. The newer machine anyhow does not use it. For the DCS machine it is planned to use emulsion for cobalt-chrome as well to enable longer life-time for the tools.

The E-max or Glass-ceramics are actually grinded using the following tools:

1) 2,5 mm ball-ended grinder
2) 1 mm ball-ended grinder
3) 0,6 mm ball-ended grinder.

All the necessary calculations for grinding are done in CAM software and therefore only one other mechanical modification has to be done. The grinding process uses different kind of material blocks. These blocks are small and are used to grind out only one tooth. The newer machine has a special block holder where it is possible to attach three small grinding process blocks. For the DCS Precimill M4 a similar kind of solution has to be worked out or it is preferable to start using round block holder from the scratch. The solution to this problem is brought out in paragraph 7.5.

Considering the fact that six different tools are needed for the manufacturing the tool changing process will be designed for six tools.

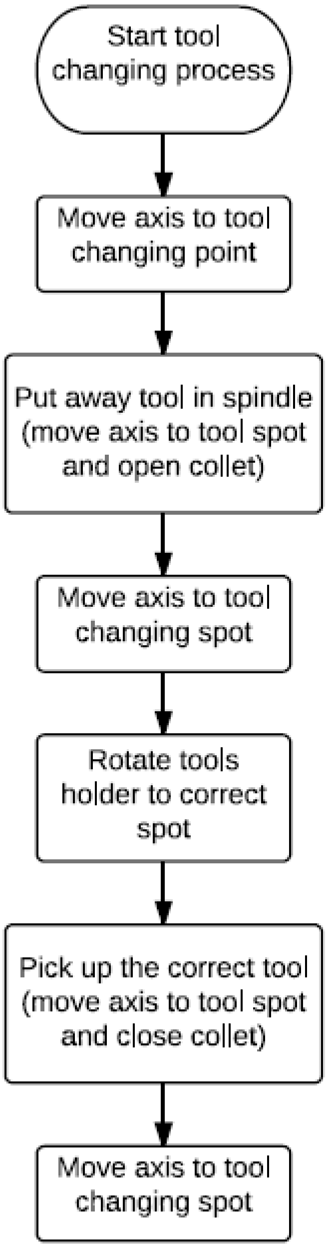
6.3.1. The main idea of tool changing process

The tool changing process has to be carried out by another controller. The chosen board is Arduino UNO (Picture is shown in extra 11) as the author has been working with it before. [10] It is easy to connect Arduino to computer and the programming has been made easy as well. Although it is not really meant to be used in manufacturing processes it is easily able to control the tool changing process. The board can be placed in the electric shield where it is protected from the dust and moisture. The price of this product is quite low, only about 20 euros. The board still has to be able to communicate with Mach3 CNC Controlling software. Therefore it sends and receives signals from HDBB2 Breakout Board. The main communication between those boards is when to start the tool changing process and when it is done.

Arduino board itself has only digital outputs, therefore an 8-channel 12 V Relay Shield Module for Arduino UNO [11] is ordered (Picture is shown in Extra 12). The board itself connects to Arduino UNO easily (Connections scheme shown in Extra 13) and it can be controlled by Arduino easily as well. The connections are simply made and after connecting power supply and GND to the Relay Shield Arduino's digital outputs from 1 to 8 are connected to the Relay Shield's inputs from 1 to 8.

The main idea how the process should work is brought out in the drawing 6. When the program starts the user himself has to make sure that the correct tool is in the collet. When the tool changing process is brought up in the G-code the machine will move to tool changing spot. After that it moves to put away the tool, then the HDBB2 Breakout Board will send out signal to open the collet. The tool then stays in the holder and the machine moves back to the tool changing spot. Then the signal for tool changing process is sent out and control board will move the tool rollercoaster to its correct position. The machine has time delay programmed in G-code while this process takes place. After the delay the machine moves to pick up the tool, when the destination is reached the collet is closed. The machine has picked up a new tool and now it moves back to tool changing spot. After reaching the tool changing spot the machine starts spindle and emulsion again and starts milling/grinding again.

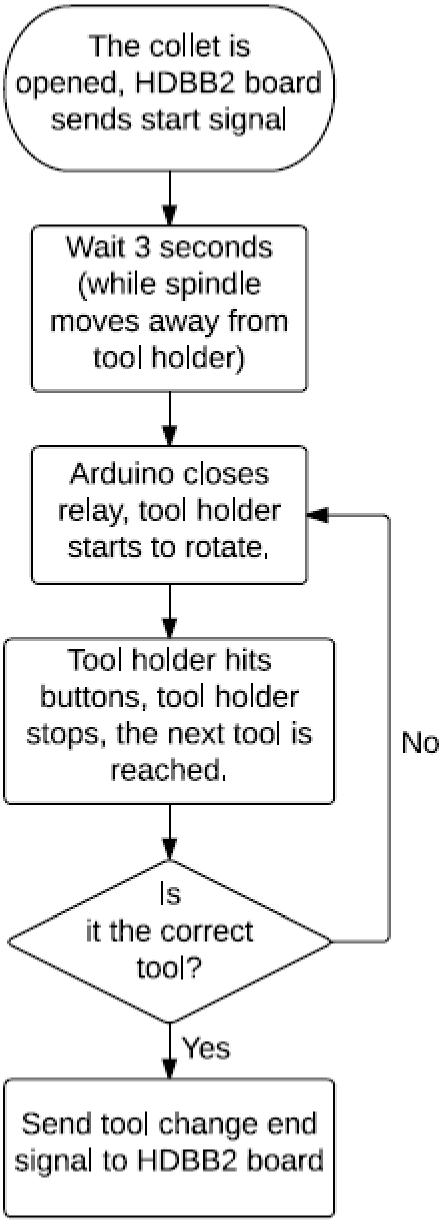
The Mach3 itself does not support tool changing process although a plugin TLO Setter can be purchased to measure tools that is also necessary for accuracy. During this design we leave out tool measuring as the length of the tools are known for us. After the machine is in working order again the tool measuring process is considered again to increase accuracy. The tool changing process should be integrated too, but unfortunately it would be too expensive to accomplish therefore we have to come to terms with the fact that the Mach3 does not know what tool is in the spindle. The machine also does not verify whether the tool is broken. This feature will be considered along with tool measuring process.



Drawing 6. Tool changing process main algorithm

6.3.2. Devices used for tool changing process

The main device that controls the tool changing process is Arduino UNO programming board. For stopping the tool rollercoaster on the right spot two buttons are used, when both of them are pushed down the rollercoaster stops. Two switches are used in order to make placement more accurate. In Drawing 7 the scheme illustrates how the tool change is processed by Arduino controller.



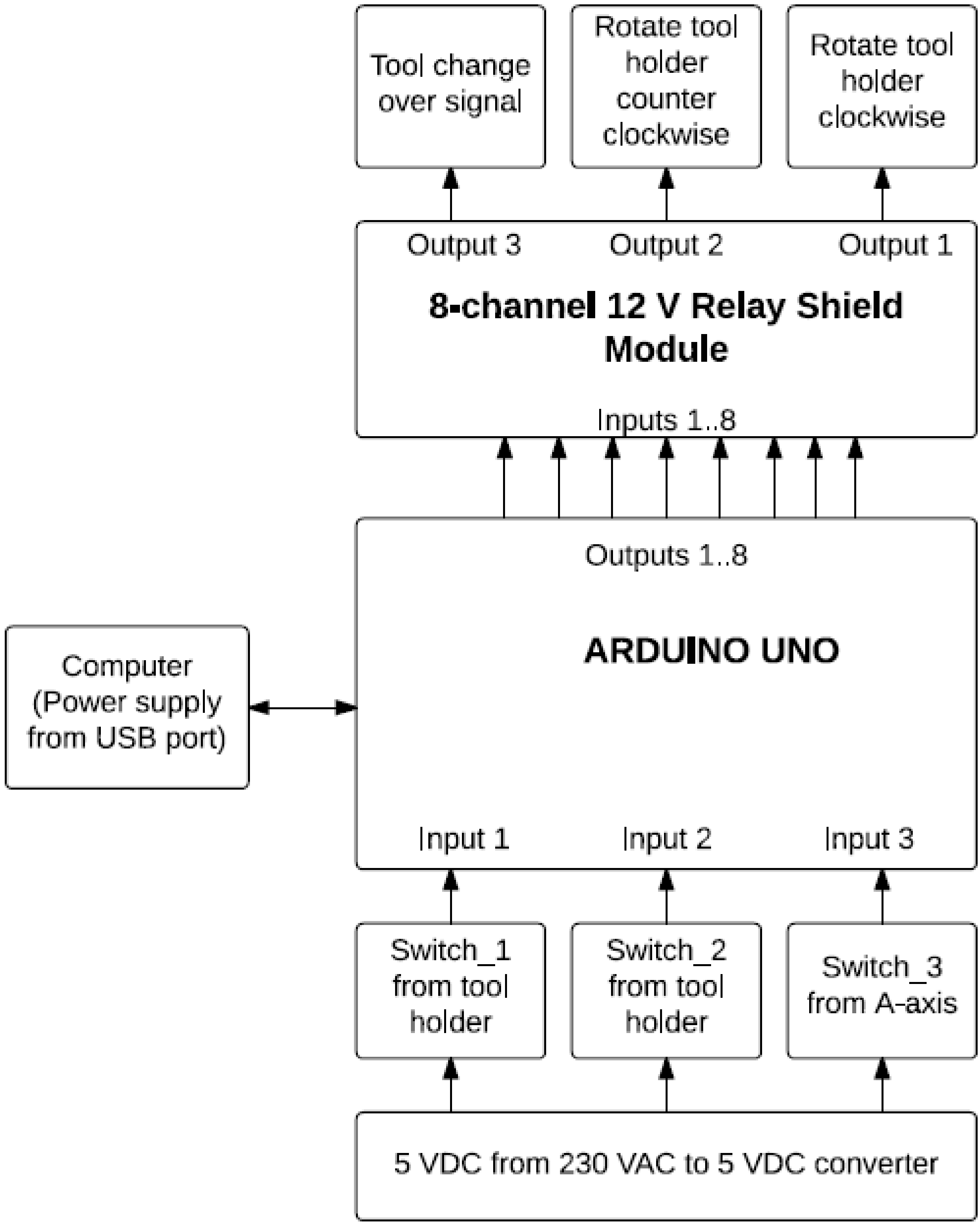
Drawing 7. Scheme about tool changing process for Arduino

The waiting period is necessary to avoid collision of the machine parts. The rollercoaster starts to move after the spindle has surely moved away from it. This will make the process a little bit longer, but for safety reasons it more reasonable to lose some time than risk with equipment. The choice whether the right tool is in the tool changing spot is made by Arduino logic. The logic is written in a way that the author knows the correct sequence of the tools that are being used. All the information that Arduino needs to know for that process is whether the A-axis is in zero degree or hundred and eighty degree angle. In order to get that information a switch is placed next to the A-axis and the signal from that switch is sent to Arduino input.

6.3.3. Arduino UNO connections

Arduino UNO gets signal from three switches, two them are in order to control the tool rollercoaster and one is used to verify the angle of the A-axis. One input signal is used to get signal for starting the tool change process. Two output signals are used to move the tool holder in one direction or another. Third output signal is used to send tool change finish signal. The simplifying scheme is brought out in Drawing 8.

Arduino UNO itself gets its power supply from USB port (5 VDC) and it is connected to the computer via USB all the time when the machine is working.



Drawing 8. Simplifying scheme of Arduino UNO's connections

6.3.4. The logic of choosing the right tool

Choosing the right tool for the Glass-ceramics or Titan/Cobalt-Chrome is processed the same way and is similar in any way. Therefore only metal tools changing is being explained in this paragraph, but it has to be reminded that the same process applies to Glass-ceramics as well.

The first tool has to be manually selected and it is always the 3 mm tool. The tools will be placed to the rollercoaster in the following order:

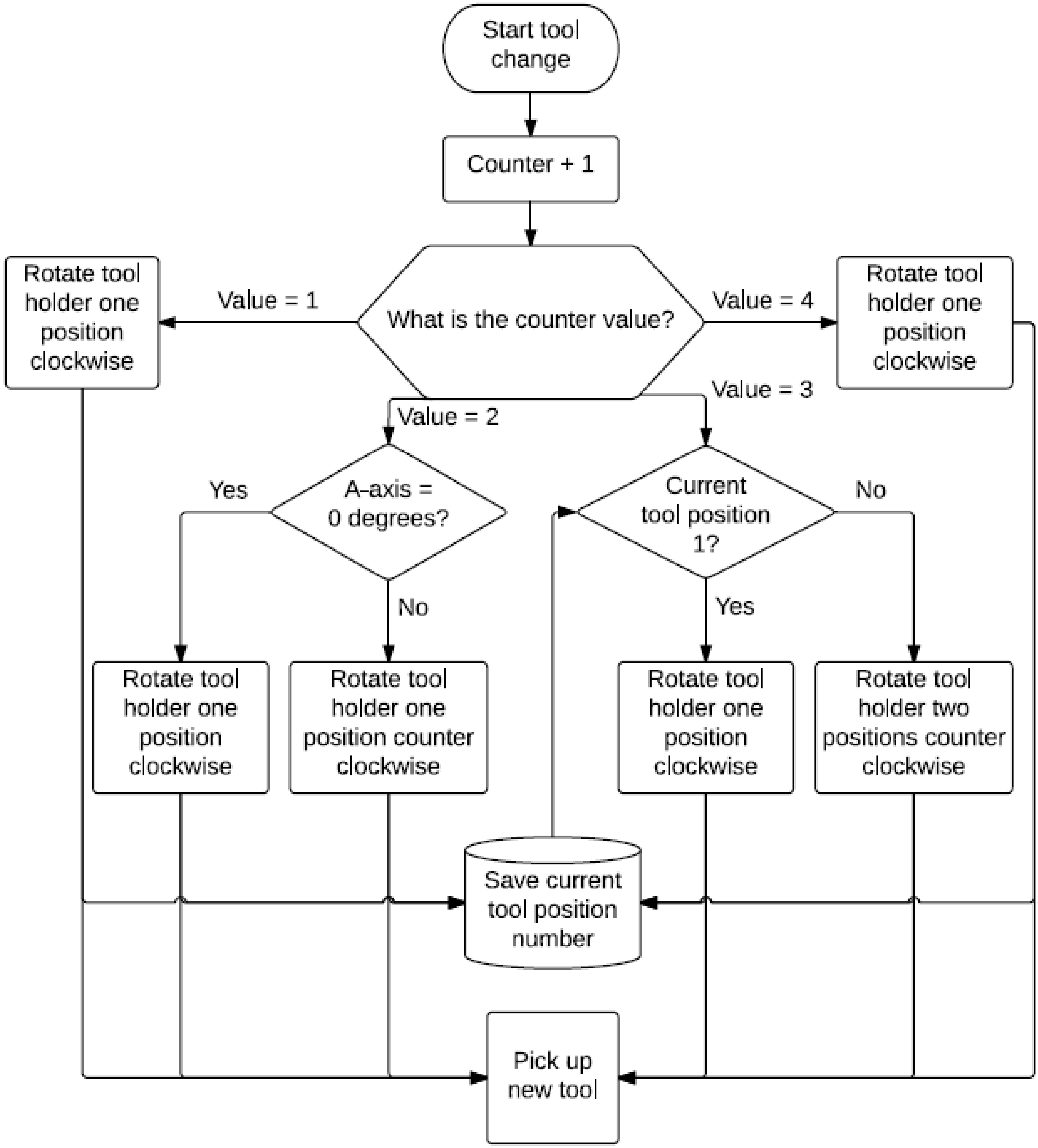
1) Position number 1 – 3 mm tool
2) Position number 2 – 2 mm tool
3) Position number 3 – 1 mm tool

When the first tool change appears the machine has to put away the 3 mm tool and change it to 2 mm tool. In order to do that the machine first puts away position 1 tool. Then the rollercoaster moves clockwise until the tool changing position is reached and the machine picks up position number 2 tool. As some of the milled products need more smooth surface treatment than the others this is the place where the controller has to know what is the angle for the A-axis. The CAM software calculates the G-code in a way that first one side of the block is milled and then the other side of the block is milled, so when the second tool change appears the machine puts away tool and then depending on whether the A-axis is on zero or hundred and eighty degree angle the next tool is chosen. When the A-axis angle is zero degrees the rollercoaster will move clockwise and the machine will pick up tool in position 3. When the A-axis is hundred and eighty degrees the machine will move counter clockwise and pick up tool in position 1.

The next tool change depends on what kind of tool was used in previous phase. When tool in position 3 was used then the machine will have to move counter clockwise two spots and pick up tool in position 1. When the tool from position 1 was in the spindle the tool holder has to move clockwise for one spot and pick up tool in position 2.

After the use of tool in position 2 again there will be no more tool changes as the machine uses the slimmest tool only on one side. If the tool from position 1 was in the spindle the machine has to change for the tool in the position number 2.

Control algorithm for this process is brought out in Drawing 9.



Drawing 9. Control algorithm for tool changing process

6.4. Electrical changes and solutions

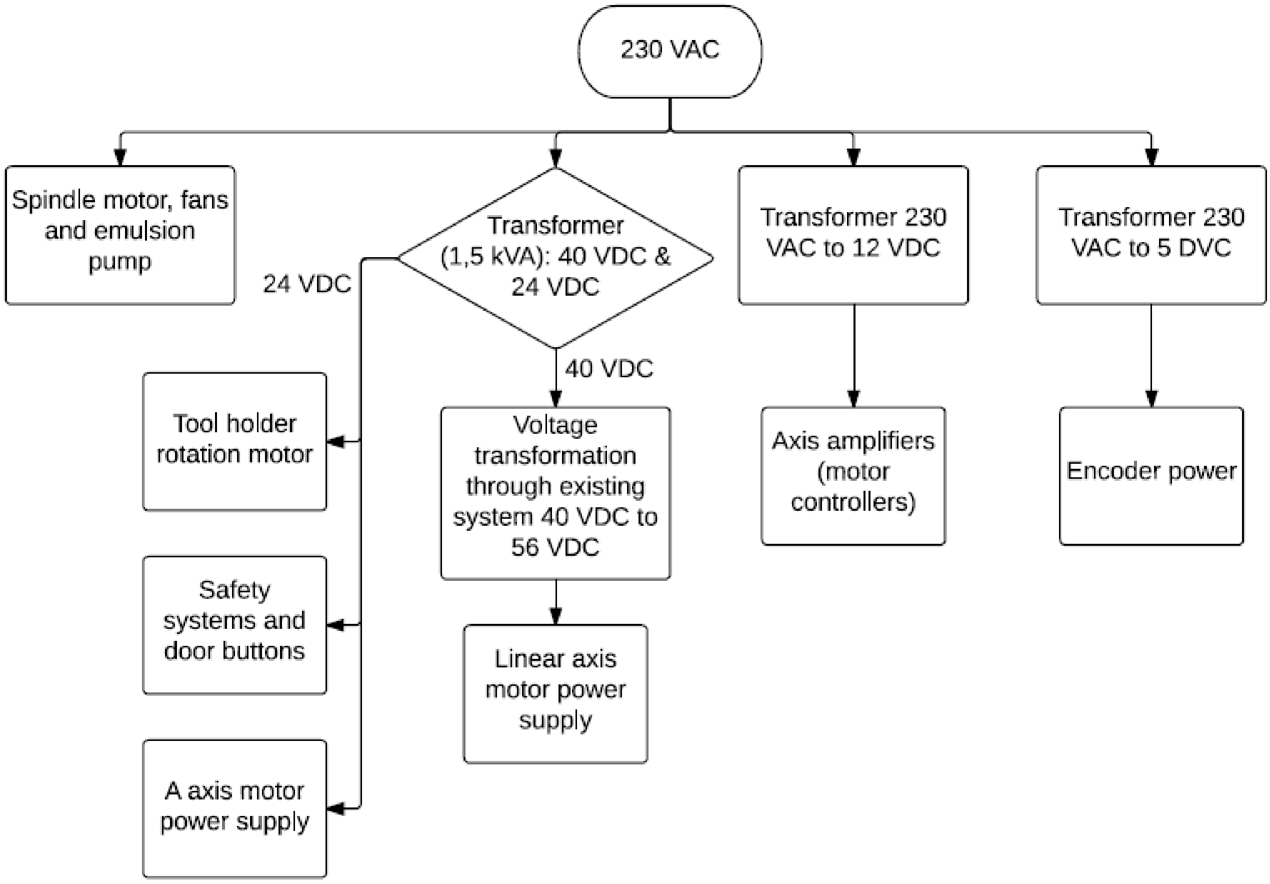
The new system for the machine needs some changes in electrical area as some of the old systems used are now left aside and some of the new solutions need different kind of electrical connections. The basic solution of the new electrical scheme is brought in drawing 10. The main power supply comes from usual wall socket and delivers 230 VAC to the system. From there the power is divided mostly into four groups.

The first group uses directly 230 VAC for their work. Main devices that use this power supply are spindle motor, cooling fans and emulsion pump. Their work is controlled by relays, contactors and switches though.

The second group uses 1,5 kVA transformer that supplies 40 VDC and 24 VDC voltages. 40 VDC power supply is used only by linear movement axis motors, but before it reaches the motors the voltage is being raised up to 56 VDC by existing electrical scheme (Scheme shown in Extra 12). From the 24 VDC transformer output the power supply is gotten for tool holder motor, existing safety systems and door buttons, A-axis motor power supply.

The third group from the main supply is 230VAC to 12 VDC power transformer that the author added. It is used to supply digital power for axis amplifiers.

The fourth and final group is 230 VAC to 5 VDC power transformer that is used to power encoders.



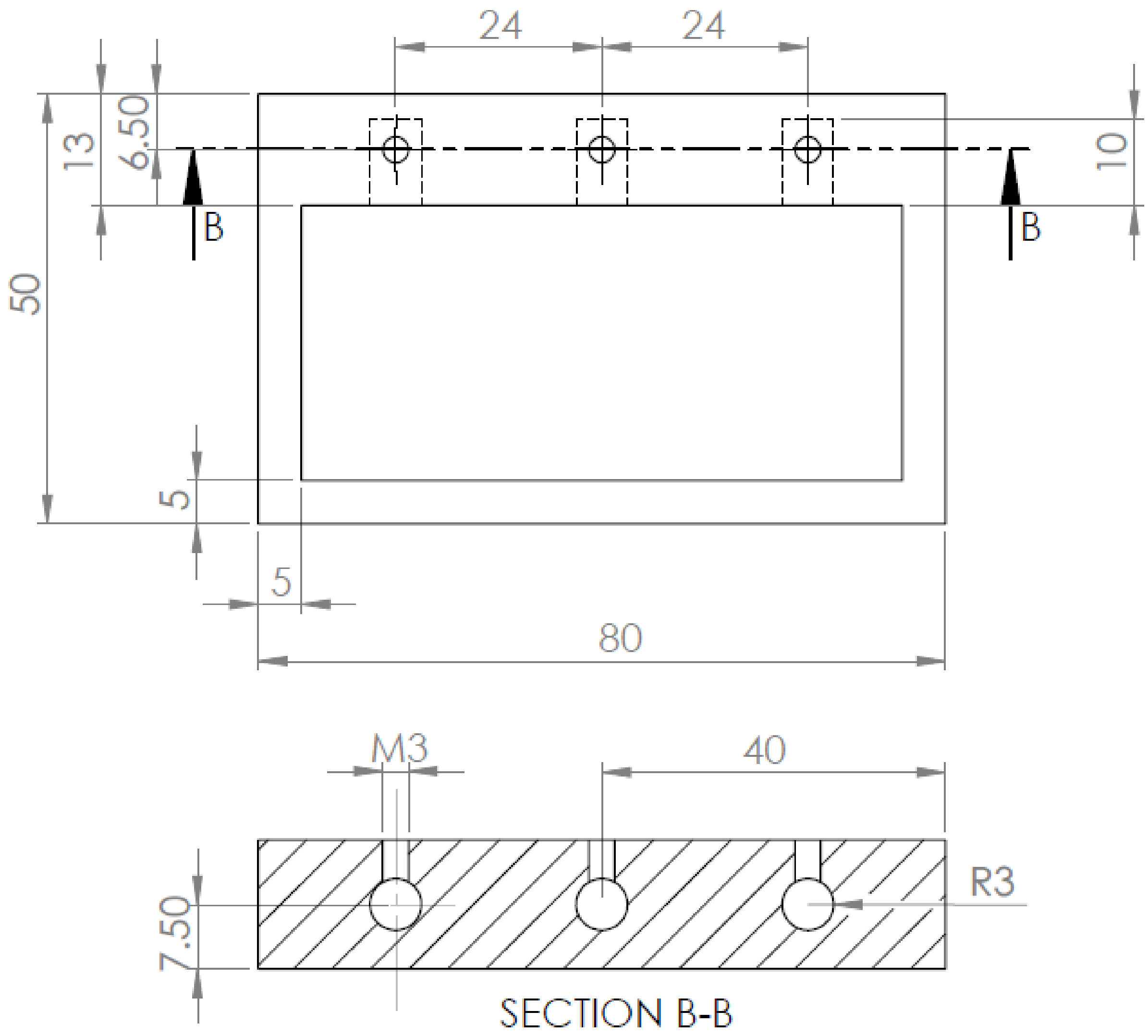
Drawing 10. Simplified main electrical scheme

6.4.1. Devices controlled by relays and contactors

The main devices that are controlled by different types of switches are spindle control motor, emulsion pump and tool holder rotation motor. The spindle control motor is controlled by an existing contactor that has 12 VDC coil for switching the contactor. This 12 VDC control signal is gotten from Arduino UNO controller. The same solution is used for the emulsion pump. Tool holder rotation motor is controlled by two relays that are controlled by Arduino UNO board. Two relays are used because the motor has to be able to work in both directions.

6.5. Block holding system for glass-ceramics

When the need for glass-ceramics block holder game up, it was considered again to rebuild the machine to use round block holder. The round block holder already has a block for the glass-ceramics and either way we would have to order one of the holders: round block holder or squared block holder for the glass-ceramics. After considering both opportunities again it was decided that squared block holders will be used and new holder for the glass-ceramics will be ordered. This decision was made because the mechanical work for rebuilding the machine would be time consuming and might turn out to be quite expensive and the company still has a lot of unused squared material blocks that need to be used. Drawing for the new holder was made in order to produce the part.



Drawing 11. Block holder drawing

While modelling the new block holder it was important to make sure that the blocks would be in the same point from the zero-point than they are in the new machine. This is important because the CAM does the calculations according to the iMes 750i machine and this gives the author a chance to use the same G-code transformer for full blocks and glass-ceramic blocks as well. Therefore measurements form the round block holder centre were taken and the same measurements were transferred to the squared block holder.

For the small blocks to be in the right position some of the measures of the block have to be quite precise. The 13 mm wall is the first thing that has to be very precise. Only 0.05 mm error will be tolerated. The other things that have to be very precise are M3 screw holes as these holes are used to attach small glass-ceramic blocks to the block holder. Only 0.05 mm error will be tolerated there as well. Last precise holes have to be the 6 mm diameter holes where the small blocks holders are attached. For these holes tolerance of 0.05 mm also applies.

Other measurements do not have to be that precise because they are not really used for positioning the small blocks to the correct places. For other measurements tolerance of 0.2 mm is used.

6.6. G-code and changing it

G-code is the main code used in CNC control programs. When it is opened with Notepad program it seen that the G-code is basically a text file where is mostly written different axis positions. It also has information about the specific job, like its name, materials decreasing factor, expected milling time etc. The main rows for process look like following:

```
G1 X-7.03859 Y8.15368
G1 X-7.07858 Y8.14841 Z4.87724
G1 X-7.19856 Y8.13408 Z4.90931
G1 X-7.27854 Y8.12351 Z4.92787
G1 X-7.39852 Y8.10678 Z4.95226
```

On these random but usual rows from the code can be read out the following information. G1 or G0 indicates whether the spindle is working or not. G1 implies that the spindle is working.

Next the X value from the first row of the example (-7.03859) indicates the position where X-axis should go and the same explanation applies to Y-, Z- and A-axis too.

In order to make the same G-code work on DCS Precimill M4 and iMes 750i some changes in the code have to be made. The author has worked with VBA and Excel before and that is why it was decided to modify the code in Excel using Macros. The code can be easily imported to Excel and later on it can be exported as a text file.

First changes that have to be made is recalculating the axis values. The X-, Y-, Z- and A-axis will need coefficient to adapt them with the CAM calculations. As the machine does not work yet those exact coefficients are unknown. The G0 and G1 do not need any changing as the work of the spindle is the same for both machines. Another thing that needs to be re-written totally is tool changing process. The iMes machine uses specially made CNC controlling software and it has integrated tool changing part in it. When the tool needs to be changed a new window is opened that does the tool changing and measuring of the tool. Mach3 does not have an add-in that could to the same job, therefore the tool changing part has to be partially made in G-code and another part has to be done by different controller. According to the plan the tool changing process should be re-written in a way that the machine would first put away the tool and then notify Arduino controller to start its part of the job. Later on the machine should wait for the signal from Arduino and finish the tool changing process. After the tool change process is complete the machine has to return to its milling job and move according to original G-code again.

7. COST CALCULATIONS

Cost calculations are made considering the devices that have been ordered and some of the devices that are yet to be ordered. No transportation costs are added to the list. New block holder price is not exact yet, so in the calculations is used approximate price of the product. In the last meeting it was considered ordering new encoders to speed up the whole process and that is the reason why the price of them was added to the calculations. There is also a row for extra expenses. This is row has been put to the table because all kind of surprising expenses that might come up when the whole design is assembled. For example some devices might be broken or some extra devices still need be bought that were not considered before. At the moment all the necessary cables have been gathered from the company but there might not be enough cables for the whole machine. Considering the fact that a German company offered to modernize the machine for amount of 30 000 € the current price is very good.

Table 3. Cost calculations table

Device name	**Item price [€]**	**Number of items**	**Total price [€]**
DG4S-08020	80	4	320
HDBB2 Break-out board	50	1	50
Power supply S25-12	14	1	14
Differential Line Driver	4.5	4	18
Programming Stick	12	1	12
Arduino UNO	26	1	26
12 V Relay Shield	8	1	8
12 V to 5 V step-down	4	1	4
Mach3 Software License	215	1	215
Block holder for glass-ceramics	~100	1	100
Extra expenses			300
Incremental Encoder	46	4	184
TOTAL:			**1251**

8. SUMMARY

The project was started with a plan that seemed easily feasible with couple of months but during the execution process the project got more and more complicated. The first parts of the work that mostly included maintenance went well with only few set-backs on the way like finally getting the greasing nozzle's transformation for the maintenance process. The delay of course made the assembly a bit harder as the dismounting was done a month ago and the author could not remember the positions of some of the parts. Fortunately pictures were taken for precaution and all the information was eventually gathered.

The decision about the change of the block holder was done during the meeting with the second advisor. It was decided that the block holder should not be changed as it would need mechanical reconstruction of the machine and there is a lot of unused squared material in the storage.

The processes of finding new devices was the smoothest one as enough information was available online. All the devices that were ordered had very specific manuals available and that made the research a lot easier. The project was still delayed a couple of times as some of the parts that were ordered arrived two months after the order was made. Equipment for the machine was at first ordered device by device because of lack of information about the milling machine. Installing of the devices turned out to be a lot harder though as during the process it became clear that the original plan cannot be carried out. The machine was built a much more integrated than estimated. The main problem was caused by the controlling computer that did not work anymore. In that computer different controlling schemes were added with ribbon cable and no information about those connections were known. Fortunately the gears did not need any drastic changes as they were in good shape. Only the belts need to be strained.

The choice of the new CNC control software was quite easy to make as well. Two programs were recommended on the website where the devices were purchased. Further investigation broadened the choice to three different software options. Two of the choices were the same program's different versions and as one of them is really new the author made up his mind of choosing Mach3 software as it seemed to be the most reasonable solution.

During the process it was decided to design a new controlling system from the scratch as the old system was too integrated for restauration. The designing process started with generating the main algorithm for the whole process. This scheme was produced quite fast as any of the specific solutions did not fit to the scheme. Then the author described the connections for the main devices separately. The connections for the motor controllers and break-out board were explained the most thoroughly as they were the most complicated ones. More brief overviews were given to simpler devices connections as UC-100 motion controller and differential line module. After that the author started solving seemingly the most complicated problem, the tool changing process. It is complicated because the process has to be controlled by another controller that still needs to communicate to the software that is used. The process was started by finding out the basic solution for the process. This is where it was made clear that the controller can communicate with the main program via break-out board that has some extra outputs. Then the devices for conducting the process were chosen. Arduino UNO programmable board was chosen to control the process as the author has experience working with that board. For connecting the board a relay module was purchased. After the devices had been chosen the connections to the other parts were worked out and explained. Moving forward the solution of choosing the right tool was explained by algorithm. Then the author worked out some basic electrical solutions to the machine and explained them. After the electrical part the block holding problem needed to be solved again as the small glass-ceramic blocks need a special solution. Then the change for the round block holder came up again but in the end it was still decided to make a new small blocks holder for the squared block holder. Drawing of the design with important measurements were then brought out. Finally the necessary changes in the G-code are explained and the solution on how to change the code is explained.

The last part of the work is calculating the cost of the whole project. Purchased devices with their prices are listed to calculate the cost of the whole project. There are also some devices that still need to be ordered. The author left some room for unforeseen expenses as some surprises still might come up.

Considering the whole process it was very instructive to the author. Comparing this project to usual more theoretical projects a lot of unexpected time delays occurred that the author can consider in future projects. Also it was a good lesson because the project got a lot harder during the execution. The projects carried out until this one were quite specific and feasible.

The author will consider the project as a success. In the near future the author will try to put his design into operation step-by-step. At first the axis movements have to be correct. For that the axis amplifiers have to be in working order and new encoders have to arrive. Then the G-code has to be modified. When the axis movements are in working order, only then the tool changing process and new block holders for glass ceramics will be considered.

8. KOKKUVÕTE

Projekti alustati plaaniga, et see on paari kuuga kergesti teostatav kuid protsessi käigus muutus projekti aina raskemaks. Esimesed osad tööst mis käsitlesid peamiselt seadme hooldust läksid ladusalt, vaid mõne üksi tagasilöögiga nagu näiteks õlitusnipli vahelüli saamine. Viivitus muutis muidugi seadme kokkupaneku raskemaks, kuna see oli lahti võetud juba kuu aega tagasi. Õnneks oli autor ettevaatusabinõuna teinud seadmest pilte ning seadme detailide paigutused olid fotodel piisavalt hästi näha.

Otsus blokihoidja vahetuse kohta võeti vastu koosolekul koos ettevõtte tehnika juhiga. Lõpuks otsustati, et blokihoidjat ei vahetata ümmarguse vastu kuna see nõuaks mehaanilist rekonstrueerimist ning ettevõttel on laos hulgaliselt kandilisi blokke alles.

Uute seadmete valimise protsess möödus kõige sujuvamalt, kuna veebis oli piisavalt informatsiooni saadaval. Kõikidel seadmetele, mis telliti olid olemas väga spetsiifilised kasutusjuhendid ning see muutis uurimise oluliselt lihtsamaks. Projektis tekkisid siiski mitmed viivitused tänu ettevõtete vahelistele tarneaegadele, näiteks tuli oodata mõnda detaili peaaegu kaks kuud. Algselt telliti seadmeid detaili haaval, kuna freesmasina kohta ei olnud palju informatsiooni ning autor ei olnud kindel kui suures osas seadmed tuleb välja vahetada. Seadmete paigaldamisel tekkis probleem, mille käigus saadi teada, et esialgne moderniseerimise plaan ei ole reaalselt teostatav. Probleem põhines asjaolul, et freesmasin oli ehitatud väga integreeritult ning eraldi seadmete vahetamine on raskendatud. Peamiseks probleemi allikaks oli masina juhtarvuti, mis enam ei töötanud. Juhtarvutile oli pandud lisaks kontrollerid, mis olid ühendatud lintkaabliga ning nende seadmete kohta puudus igasugune informatsioon. See avastuse põhjal võeti vastu otsus kogu juhtimissüsteem algusest peale üles ehitada, kuna see tundus lihtsam kui vana süsteemi restaureerimine. Õnneks ülekanded ei vajanud erilisi muudatusi, kuna peale inspektsiooni otsustati, et need on heas seisukorras. Ainult rihmad vajasid pingutamist.

Uue CNC tarkvara valimine tuli ka suhteliselt kergelt kuna kahte programmi oli soovitatud samal veebilehel kust telliti mootori kontrollerid. Lähemal uurimisel lisandus valikusse ka kolmas programm, mis iseenesest oli ühe eelneva valiku uuem versioon. Autor langetas otsuse kasutada Mach3 tarkvara, mis tundus vägagi mõistlik.

Protsessi käigus otsustati juhtimissüsteem alates nullist uuesti üles ehitada, kuna see tundus lihtsam kui vana süsteemi restaureerimine. Uue süsteemi projekteerimine algas peamise juhtalgoritmi genereerimisega. Skeem suudeti välja töötada küllaltki ladusalt, kuna spetsiifilised osad sellele ei mahtunud. Seejärel kirjeldas autori peamiste seadmete ühendusi eraldi. Käsitleti teljevõimendite ja *„break-out board"* ühendusi. Seejärel anti põgusam ülevaade lihtsamatest ühendustest nagu UC-100 liikumise kontrolleri ja diferentseeriva mooduli ühendused. Seejärel asus autor lahendama kõige keerulisemat probleemi, terade vahetamise protsessi. Kõige keerulisemaks on ta tituleeritud, kuna selle protsessi jaoks on vaja kasutada eraldiseisvat kontrollerit, mis peab siiski olema võimeline suhtlema põhisüsteemiga. Autor tegi suutis leida lahenduse, kus suhtlus toimub läbi *„break-out board"* lisaühenduste. Seejärel valiti protsessi juhtimiseks peamine kontroller, Arduino UNO, kuna autor on selle seadmega varasemalt kokku puutunud. Ühenduste tegemiseks soetati Arduino plaadile lisaseadmena relee moodul. Peale seadmete valimist näidati ära seadmete ühendused ülejäänud masinaga. Seejärel seletati algoritmi abiga tera vahetamise peamine protsess. Järgnevalt projekteeris autor seadmele peamise elektriskeemi ning selgitas oma valikut. Peale elektriosa tuli jällegi kõne alla blokihoidja vahetus, kuna klaas-keraamika jaoks on vaja spetsiaalset väikeste blokkide hoidjat. Töö tulemusena projekteeriti aga väikeste blokkide hoidja kandilisele blokihoidjale. Projekteeritud detaili joonis koos tähtsamate mõõtmetega on töös välja toodud. Lõpuks on seletud ka G-koodi muutmise aluseid ning põhjuseid.

Viimane osa sisaldab endas kuluanalüüsi kus on tabelis välja toodud kõik tehtud kulutused. Lisaks on kirja pandud kulutused, mis on vaja veel projekti käigus teha ning ka varusumma, kuna võib esineda ka veel ettearvamatuid kulusid.

Kogu protsessi arvesse võttes osutus see autorile väga õpetlikuks. Võrreldes seda projekti eelnevalt teostatutega, mis on olnud oluliselt teoreetilisemad, tekitasid projekti läbiviimisel olulisi probleemi ajalised viivitused. Edasiste projektide planeerimisel tuleb selliste ajaviidete arvestamine kindlasti kasuks. Lisaks oli autorile õpetlik ka projekti raskemaks muutumine. Senised projektid on olnud küllaltki spetsiifilised ning sarnaselt plaanile teostatavad.

Autor loeb töö edukaks, kuna projekt muutus oluliselt keerulisemaks ning vajalik teoreetiline töö on nüüdseks tehtud. Järgnevalt proovib autor enda projekteeritud süsteemi töösse rakendada järk-järgult. Esmalt tuleb telgede liikumine saada täpseks ja kontrollituks. Selleks tuleb lõpuni viia teljevõimendite seadistamine ning G-koodi muutmine. Järgnevalt tuleb oodata uute teljevõimendite saabumist. Kui telgede liikumine on kontrolli alla saadud, alles siis võetakse käsile terade vahetamise protsess ning klaas-keraamika jaoks mõeldud blokihoidja valmistamine.

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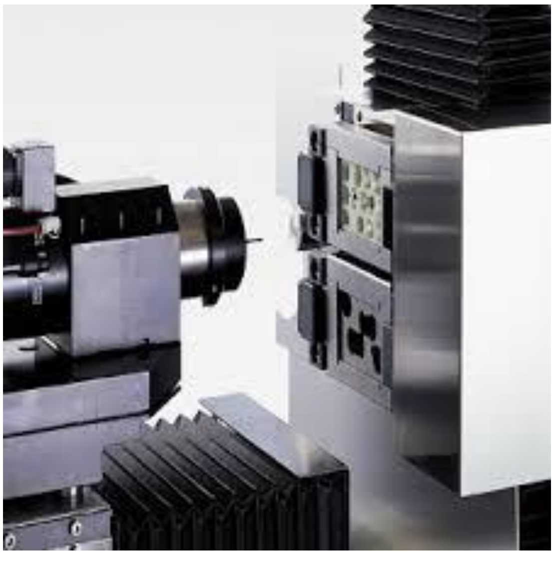
EXTRAS

E1 Milling machine DCS Precimill M4

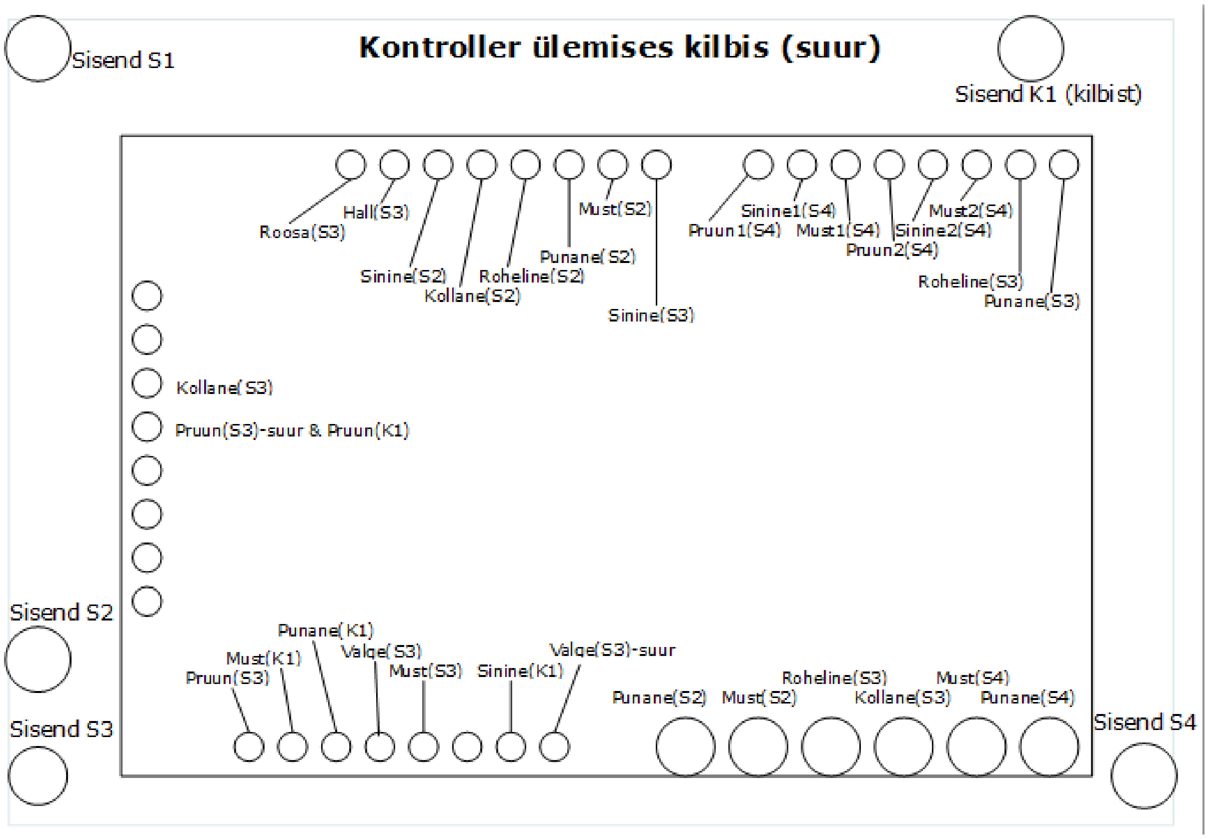


Extra 1. Pictures of the milling machine DCS Precimill M4

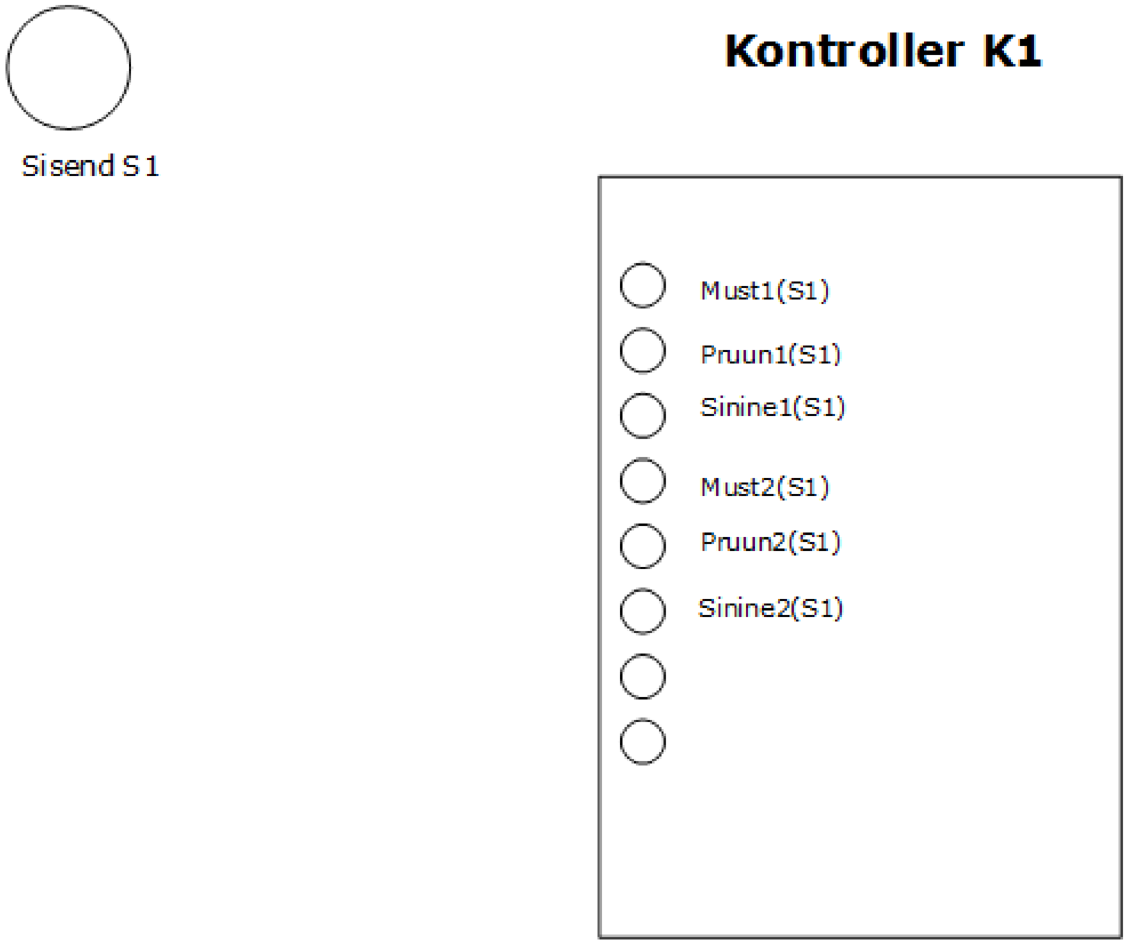
E2 Milling machine Wieland iMes-750i

Extra 2. Picture of milling machine Wieland iMes-750i

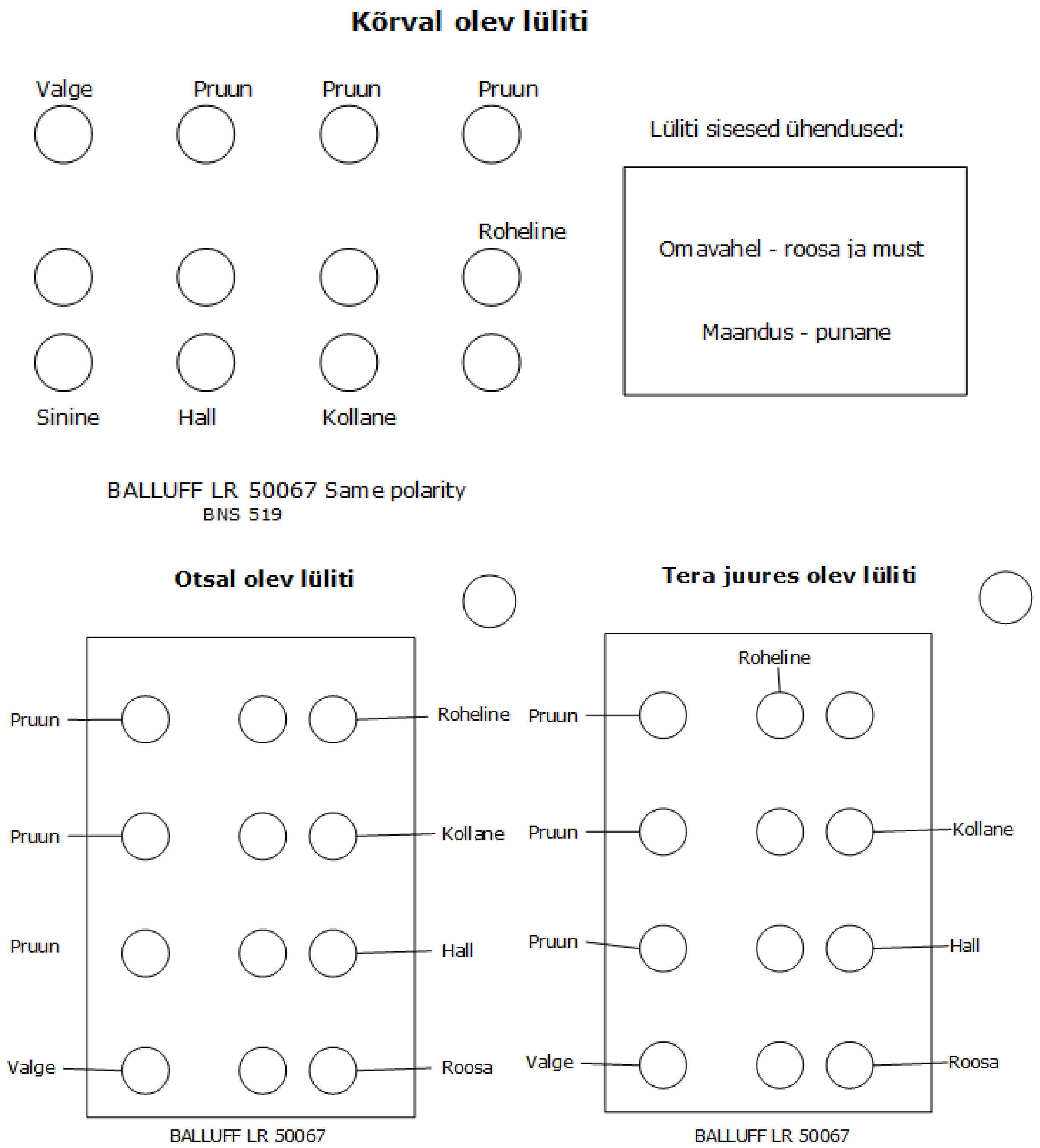
E3 Simplifying schemes about electronic devices of the milling machine



Extra 3.1 Big controller’s simplified connections scheme

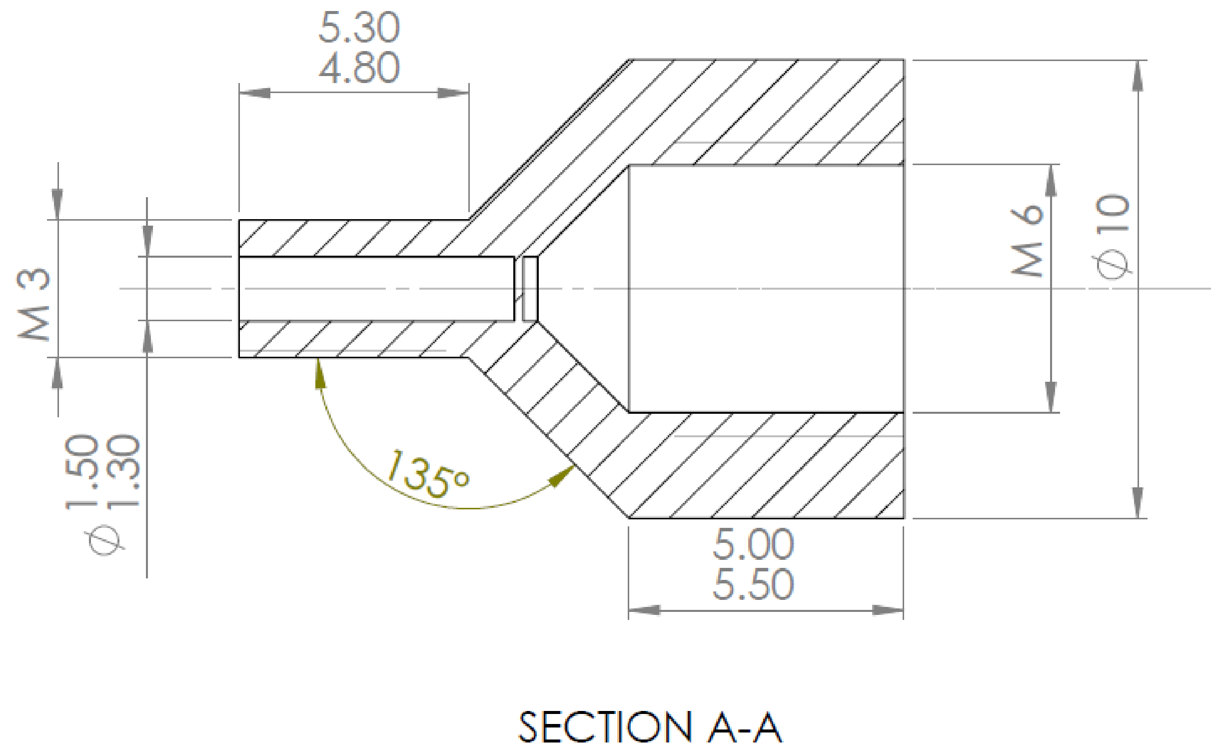


Extra 3.2 Smaller controller’s simplified connections scheme



Extra 3.3 End-switches simplified connections schemes

E4 Greasing nozzle's thread transition drawing

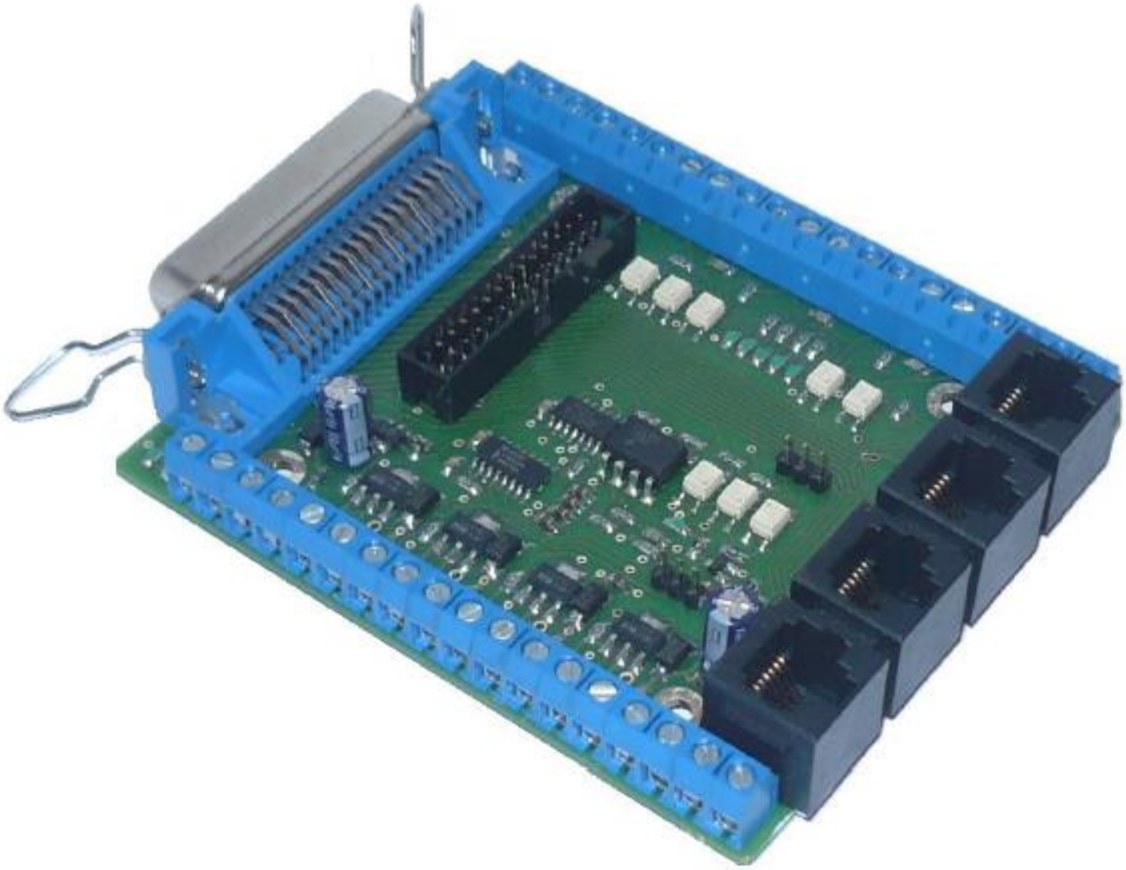


Extra 4. Greasing nozzle's thread transition drawing

E5 DG4S-08020 picture

Extra 5. Picture of DG4S-08020 axis amplifier

E6 HDBB2 Break-out Board



Extra 6. Picture of HDBB2 Break-out board

E7 HDBB2 Centronics 36 cable connections

Function on board	LPT port pin number	Centronix port pin number
X-axis step signal	2	2
X-axis direction signal	3	3
Y-axis step signal	4	4
Y-axis direction signal	5	5
Z-axis step signal	6	6
Y-axis direction signal	7	7
A-axis step signal	8	8
A-axis direction signal	9	9
Input#1 [common error line]	15	32
Input#2	10	10
Input#3	11	11
Input#4	12	12
Input#5	13	13
Output#1	17	36
Output#2	1	1
Output#3 [charge pump]	14	14
Output#4 [analog output]	16	31
Signal ground	18-25	19-30
Shield	Cover	17

Extra 7. Blow diagram for Centronics 36 and LPT pin mapping

E8 HDBB2 Break-out board screw terminal connections

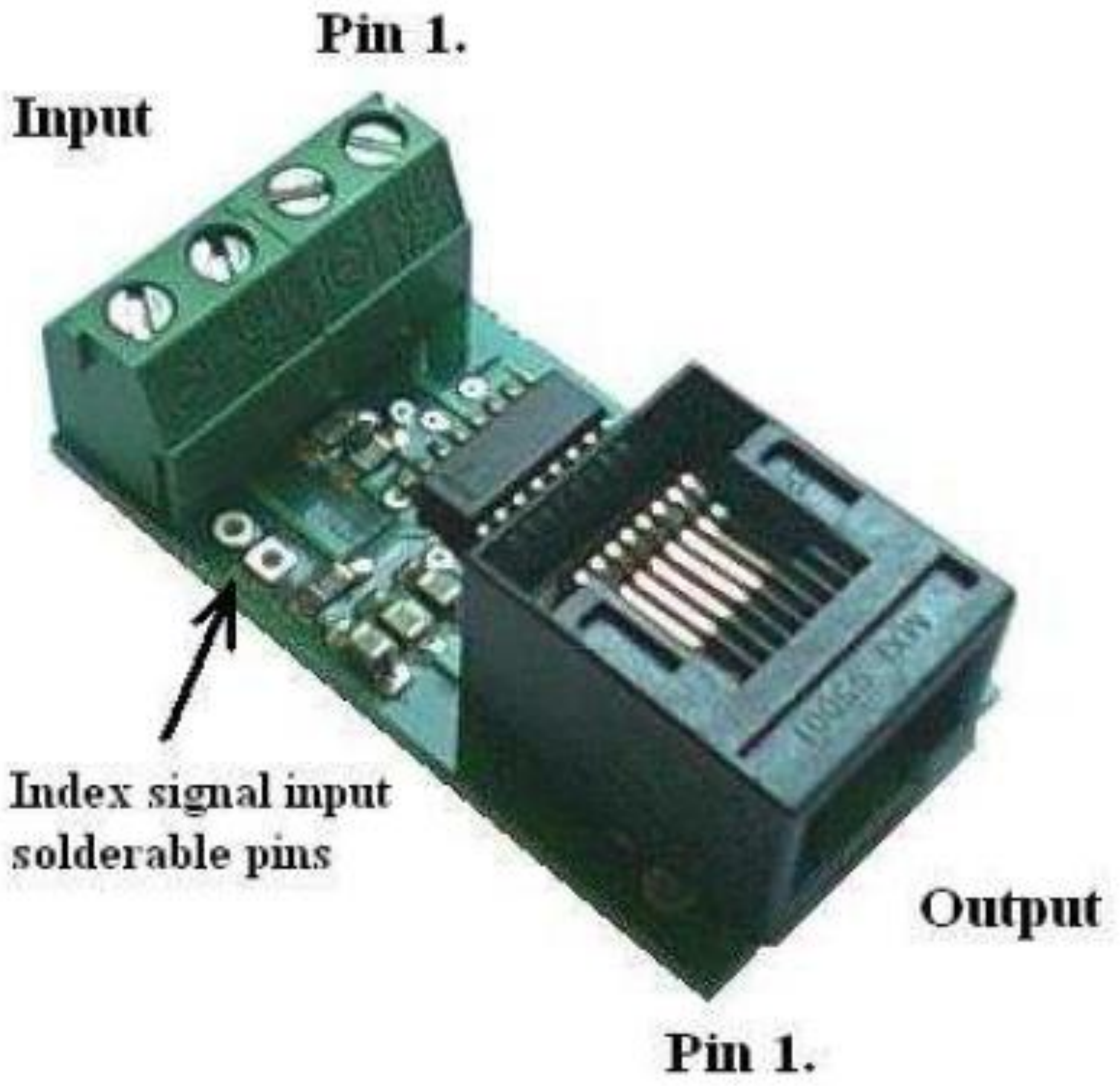
01.) PGND	02.) Input 5.-	03.) Input 5.+	04.) 12Vout
05.) PGND	06.) Input 4.-	07.) Input 4.+	08.) 12Vout
09.) PGND	10.) Input 3.-	11.) Input 3.+	12.) 12Vout
13.) PGND	14.) Input 2.-	15.) Input 2.+	16.) 12Vout
17.) PGND	18.) Input 1.-	19.) Input 1.+	20.) 12Vout
21.) Error I/O	22.) PGND	23.) Reset input	24.) PGND
25.) 12Vout	26.) Output 1.	27.) 12Vout	28.) Output 2.
29.) 12Vout	30.) Output 3.	31.) PGND	32.) Analog output
33.) Output 4.	34.) 12Vout	35.) 12V DC input	36.) PGND
37.) PGND	38.) 12Vout		

Extra 8. HDDB-2 Break-out board screw terminal connections

E9 UC-100 Motion Controller

Extra 9. Picture of UC-100 Motion Controller.

E10 Differential Line Driver

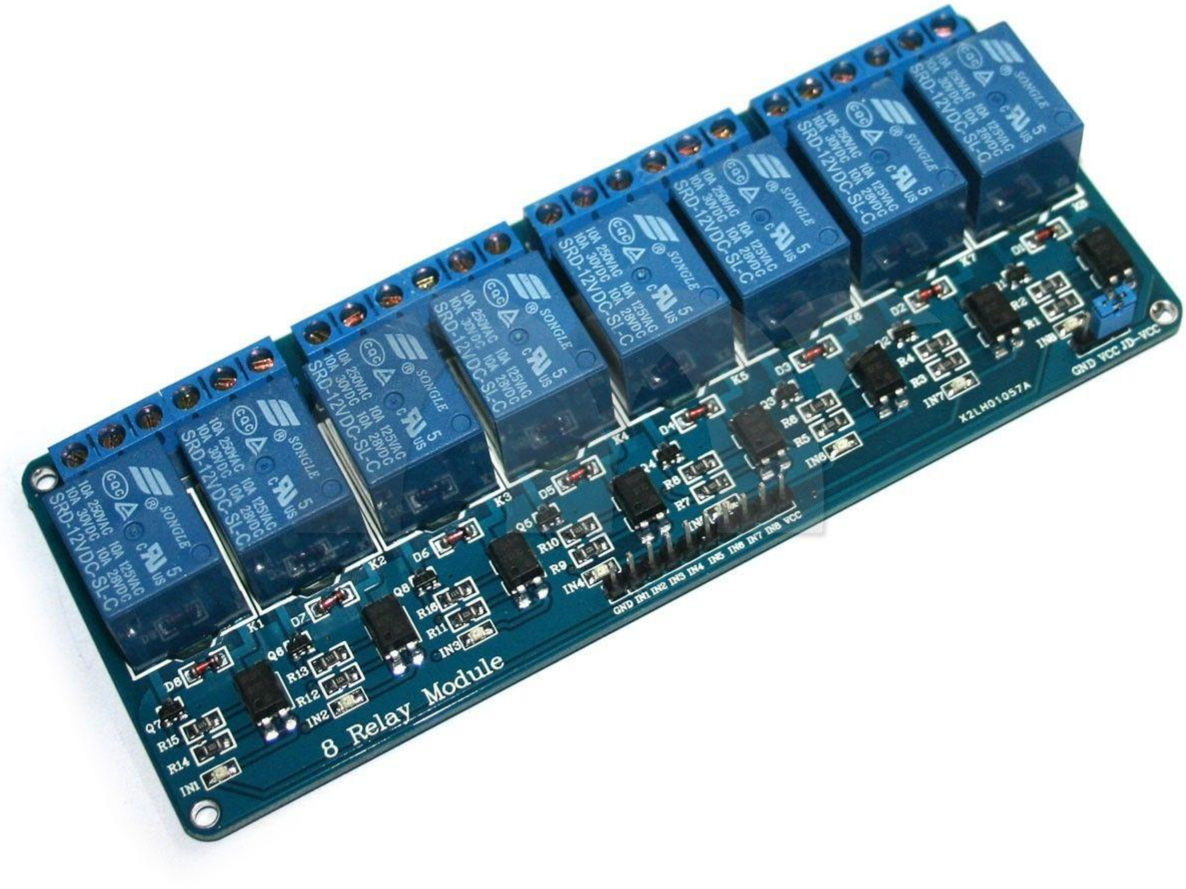


Extra 10. Picture of Differential Line Driver

E11 Arduino UNO

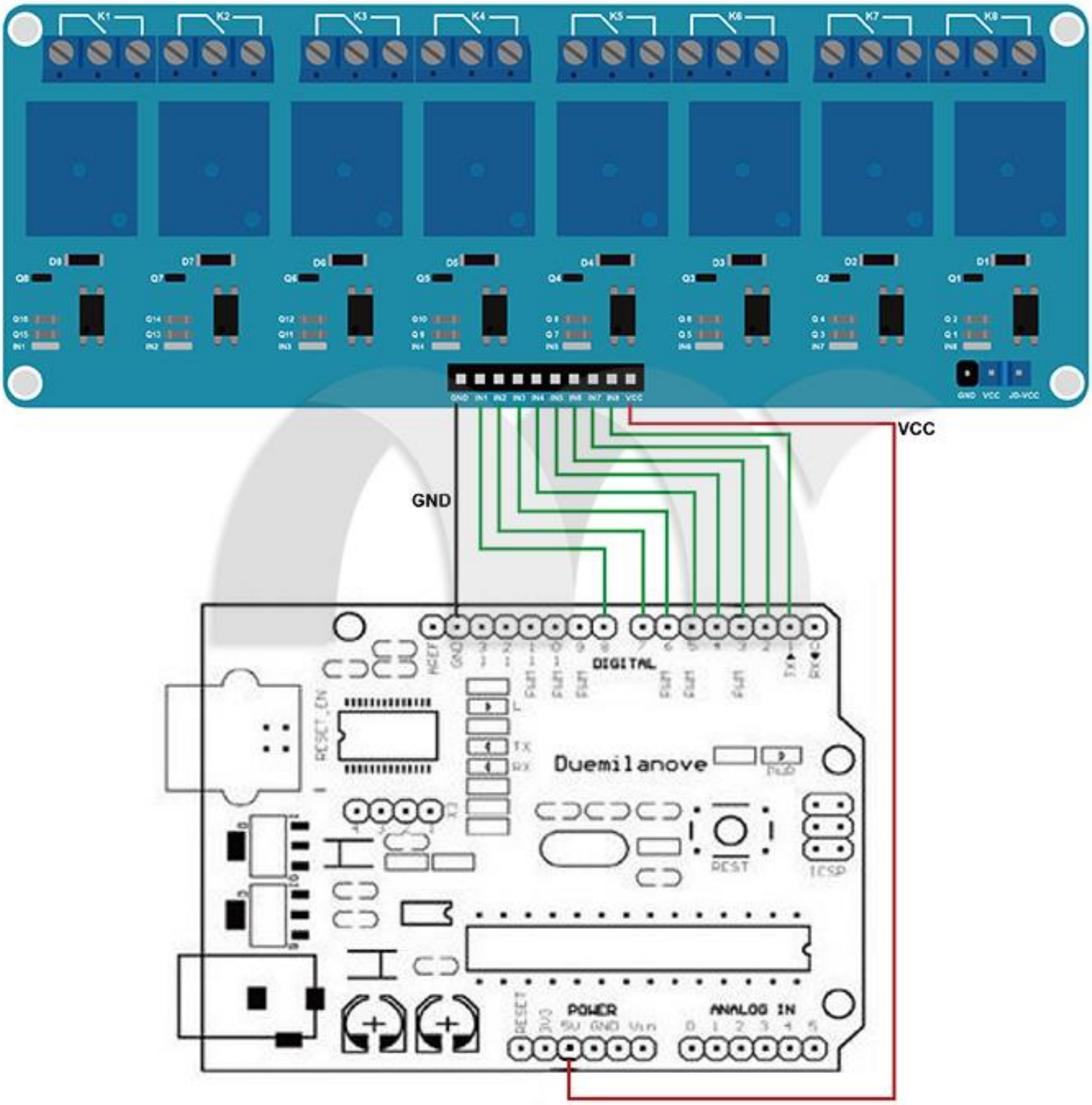
Extra 11. Picture of Arduino UNO

E12 Relay Module



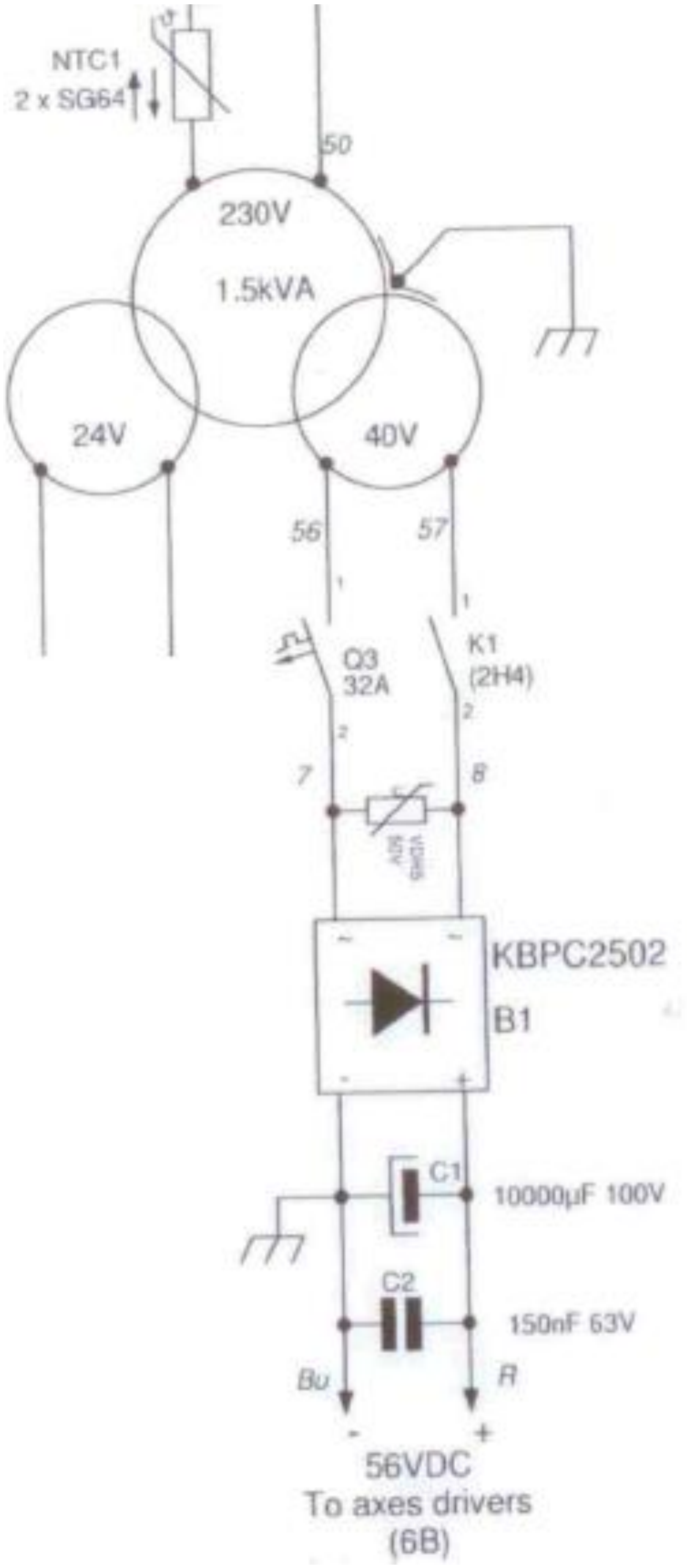
Extra 12. Picture of 8-Channel 12 V Relay Shield Module for Arduino UNO

E13 Arduino UNO and Relay Shield's connections



Extra 13. Drawing how to connect Arduino UNO with Relay Shield

E14 Existing voltage raising scheme



Extra 14. Drawing of existing voltage raising scheme