Tapio Niemi

# Modernization of a Cam Press (Amada TP-110)

SeAMK

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# Thesis abstract

Faculty: School of Technology

Degree Programme: Automation Engineering

Specialisation: Electric Automation

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Title of thesis: Modernization of a Cam Press (Amada TP-110)

Supervisor: Ismo Tupamäki

Year: 2019                    Number of pages: 41     Number of appendices: 3

In the thesis, the contactor circuit control of an old cam press machine was changed to a PLC-control. This provided a solution that is more precise, safer and more energy efficient. Logic control also allows better fault management. The cam press will be re-integrated into a larger centralized control within the production line it is located at.

The theory part of the thesis concentrated on the machine components and functions which are limited by international standards. These standards handle machinery and machine safety. The part covered also the Eddy Current-system, the adjustment of which controls the output power of the machine.

In the practical section attention was paid to the changes required by the modernization of the machine. The section also addresses the new physical components, their wiring diagrams and some parts of the logic program.

The solution showcased in this thesis will be evaluated at a later date by the client. The goals set by the client for the project have been met partially by the solution, with only the energy conservation of the chosen drive type being an arguable point.

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## Opinnäytetyön tiivistelmä

Koulutusyksikkö: Tekniikan yksikkö

Tutkinto-ohjelma: Automaatiotekniikka

Suuntautumisvaihtoehto: Sähköautomaatio

Tekijä: Tapio Niemi

Työn nimi: Epäkeskoprässin modernisointi (Amada TP-110)

Ohjaaja: Ismo Tupamäki

Vuosi: 2019          Sivumäärä: 41          Liitteiden lukumäärä: 3

Tässä opinnäytetyössä vanhan epäkeskoprässin kontaktoripiiriohjaus muutetaan PLC-ohjaukseksi. Näin saadaan ratkaisu, joka on tarkempi, turvallisempi ja energiatehokkaampi. Logiikkaohjaus mahdollistaa myös paremman vikatilojen hallinnan. Epäkesköprässi tullaan liittämään uudelleen osaksi suurempaa keskitettyä ohjausta tuotantolinjalla, jossa se sijaitsee.

Opinnäytetyön teoriaosuus keskittyy laitteen osiin ja toimintoihin, joille on annettu rajoituksia kansainvälisillä standardeilla. Nämä standardit käsittelevät laitteita ja koneturvallisuutta. Osuus kattaa myös Eddy Current -järjestelmän, jota säätämällä kontrolloidaan laitteen ulos antamaa tehoa.

Käytännön osuudessa huomiota kiinnitettiin laitteen modernisoinnin vaatimiin muutoksiin. Osuus käsittelee myös uusia fyysisiä komponentteja, niiden kytkentäkaavioita sekä osia logiikkaohjelmasta.

Tässä opinnäytetyössä esitelty ratkaisuehdotus tarkastetaan myöhemmällä ajankohdalla toimeksiantajan toimesta. Tavoitteet toimeksiantajan puolesta saavutettiin ratkaisuehdotuksella osittain, vain valitun voimanlähdetyypin energiantehokkuus on jäänyt kysymykseksi.

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## Terms and Abbreviations

**PSHE**     Plate and Shell Heat Exchanger

**BDC**      Bottom Dead Center

**SPM**      Strokes Per Minute

**T.D.C.**      Top Dead Center

**LS**       Lever Switch, which is the indicative component in cam and follower system.

**AC**       Alternating Current

**Rotor Slip**    Rotor slip is electrical motor's internal concept where the rotor's turning speed is compared in relation to the magnetic fields. If synchronous speed were to be achieved, no torque would be applied into the rotor. (Chapman 2005, 380–401.)

**DC**       Direct Current

**EDC**      Term used in this work for the Miki Pulley manufactured EDC-2 control power unit**.**

**Slip speed**    Slip speed is technically the same as Rotor slip but is defined as the difference between synchronous speed ($n_{sync}$) and rotor speed ($n_m$).  $n_{slip} = n_{sync} - n_m$ (Chapman 2005, 380–401.)

**PLC**      Programmable Logic Controller

**Slave**      Call name for PLCs under the supervision of Master-PLC. Usually a slave performs smaller control functions or data acquisition within the system to keep the master's cycle time as optimal as possible.

| | |
|---|---|
| **Master** | Call name for the PLC with the highest authority in the system. Note that there can only be one master, even if subsystems might be decentralized across large areas. |
| **I/O** | Input and Output, gives an overall idea of the required connections within the system without specifying the apportionment or type. |
| **HMI** | Human Machine Interface, usually a capacitive display that can be interacted with, sizes ranging from 4 to 22 inches. |
| **VAC** | Voltage Alternating Current |
| **VDC** | Voltage Direct Current |
| **ADC** | Analog to Digital Conversion. Arduino has an automatic ADC system, which takes the analog value of 0…5 VDC and converts it to a digital value of 0…1023. |
| **VFD** | Variable-Frequency Drive |

## Pictures

# 1 START OF THE PROJECT

This part will introduce the client and what they do. It is also explained why they wanted this project to be done and what is expected as a result.

## 1.1 To whom

This work has been done for Vahterus Oy, a company focusing on manufacturing plate and shell heat exchangers, PSHE for short, on one of their new automated lines in the early production area that makes the innards for the heat exchangers.

Vahterus Oy is considered by Finnish standards to be a large size company, employing slightly more than 250 people worldwide and exceeding the requirement for an annual revenue of over 40 million euros. (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission), 2016; Official Statistics of Finland (OSF), [Ref. 4 April 2019]) Even with their relatively small size they have held 0.2 % of the worldwide heat exchanger market during the year 2015 and have set the goal to supply 7 % of the PSHE market during the year 2021, with their export taking roughly 90 % of their production. The main market of PSHE is within oil and other chemical process, energy and refrigeration industries. (Vahterus Oy, [Ref. 4 April 2019].)

The manufacturing, assembly and function of Plate & Shell Heat Exchangers can be summarized with the following list:

1. Plate material is chosen individually for every application.
2. Plates are pressed and cut from a sheet metal.
3. Plates are welded together to a pack, with the gaps between the plates functioning as channels for hot and cold circulation.
4. Plate pack is installed in a cylindrical shell, where hot and cold circulations run in opposite directions on each side of the plates and each gap has alternately a 'plate side' circulation and a 'shell side' circulation.
5. Circulation is directed into the pack of plates and out through combination pipes. (Vahterus Oy, [Ref. 15 May 2019].)

Picture 1. Plate pack before final assembly. (Vahterus Oy, 2019)



Picture 2. One of the models in finalized state. (Vahterus Oy, 2019)

As seen in Picture 1, the edges of the cutout holes have been TIG-welded with their adjacent partner as will be every other outer edge of the plates. From this inner-outer-inner style weld, a plate pack is produced which best resembles an accordion. This pack is later installed into the shell and connected by welding the pipe connectors that can be seen in Picture 2. The pipes at the ends of the shell are connected to the inner 'plate side' circulation (the small hole seen in picture 1) and the pipes on the mid-section (seen above and below) are connected to the 'shell side' circulation which correlates to all the space between the outer shell and the plate pack.

## 1.2 Reasons

Reasoning behind the modernization decision has been long term economical gain. The renewed line in the production, is hoped to increase energy conservation and production efficiency. It is also expected to increase safety, simplify fault management and shave off outdated technology.

## 1.3 Goals

The goal is to provide a safe, modern and efficient solution to replace the outdated control system of the cam press. This way there would be reduced need to do maintenance work for the press dies, which in turn should increase the quality and quantity of manufacturing.

# 2  PRODUCTION LINE AND THE CAM PRESS

This part will be going over what the production line does and what it looks like, before transitioning to explain the inner workings and operating principles of the target of our modernization. (The press can be observed as the middle piece in picture 3. and on its own in picture 6.) There is also a heavy focus on component and function requirements within this section.

## 2.1  Production line

The sub sections here will be giving a rough idea about what the production line machinery and their functions are in the manufacturing process. The safety design is also being addressed briefly from the whole production lines perspective.

### 2.1.1  Basic rundown

The production line produces plates for the smaller end of the product family, and as a line doing only relatively simple process, it has an allotted area of roughly 7 times 30 meters.

The cam press in this line is being spool fed with the chosen sheet of metal, which it then simultaneously presses into the desired form (can be observed in Picture 1) and cuts off the plate from the sheet, and also makes the cuts for the inner holes. The plates are then collected and stacked by a 5-joint arm robot, before the cycle repeats itself.
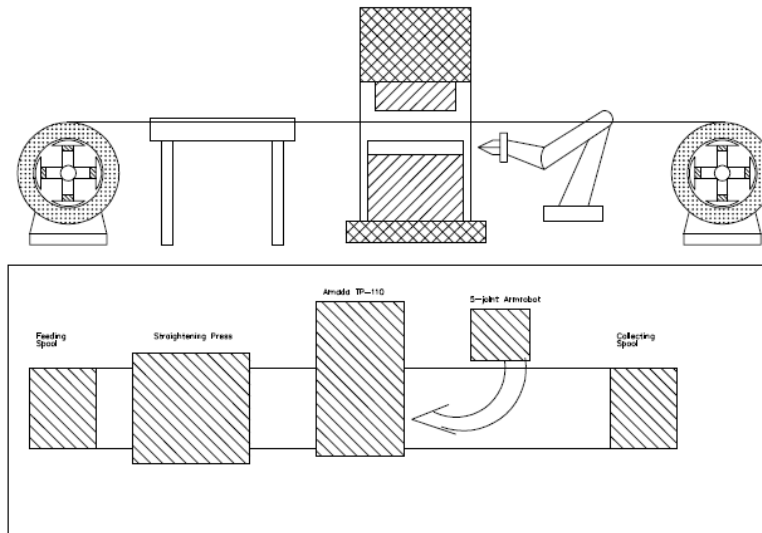
Picture 3. Rough depiction of the line layout and machinery.

### 2.1.2   Other machinery

On the line there is a spool system that consists of two parts. The first is the spool which has the unprocessed end of the sheet metal roll and has a constant mechanical brake on. The second part is the spool that uses an electrical motor to pull from the residual processed end of the sheet metal from the first spool through a press that straightens the sheet metal, through the gap of tool dies in the cam press and finally onto a roll on itself. The best way to describe this would be to compare it to an old tape recorder system that just happens to have the tape getting punchouts at set intervals while being transferred onto the other spool.

Located between the cam press and the pulling spool there is an old ABB manufactured 5-joint arm robot that serves the purpose of removing the cut out and pressed plate from between the dies. The cam press has an in built pneumatic cylinder that lifts the plate so it can be easily taken by the robot. Once the arm has taken a hold of the plate, the robot will show it to an inductive sensor on the side of the cam press. This gives permission for the rest of the line system to start a new cycle. After giving the permission, the robot will then proceed to take the plate to the edge of production line and stack the plate into a trolley. The trolleys will be taken to later stages of production once filled.

On the edge of the line there is fitted one welding station, within the bordering Safety fence, that is used to make the connections of the smaller holes simultaneously with two rotating TIG-weld pistols. This welding station can be accessed from both sides but operated only from outside the line area. Maintenance of the station requires access from both sides. The stations operation is completely independent from the cycle of the line, although it was discussed if it should be a part of the line's cycle of automation.

### 2.1.3   Safety

Safe use of the production line is made possible by having the whole line closed off by a safety fence. Only operators and maintenance personnel are permitted to enter the fenced area, and the machinery inside can only be jogged during their stay inside. There are no manual work operations, concerning line functions, to be done inside the fence either.

The production line has been designed by taking into account the European directives and standards on machine safety, and making risk assessments based on them. The cam press's own risk assessment will be reviewed if the solution, that is being proposed, comes to pass.

### 2.2   Cam press

The cam press is by design a fast-moving machine. Thus, it differs greatly from the usual type of press which slowly closes the dies together to produce massive and uniform force to form the desired shape onto, or to cut away from the malleable object. In comparison to the more traditional press, the cam press more than makes up for the slightly higher rate of imperfect pieces in an environment that has a focus on mass production of a simple piece. This is possible because of its high strike rate, as it is ready to strike again as soon as the previous cycle has completed its course.

1. Press frame
2. Flywheel
3. Wet clutch and brake
4. Pinion drive shaft
5. Main Gear
6. Counterbalance
7. Crankshaft
8. Adjusting screw
9. Hydraulic overload
10. Slide
11. Knockout
12. Slide plate (detachable)
13. Bolster
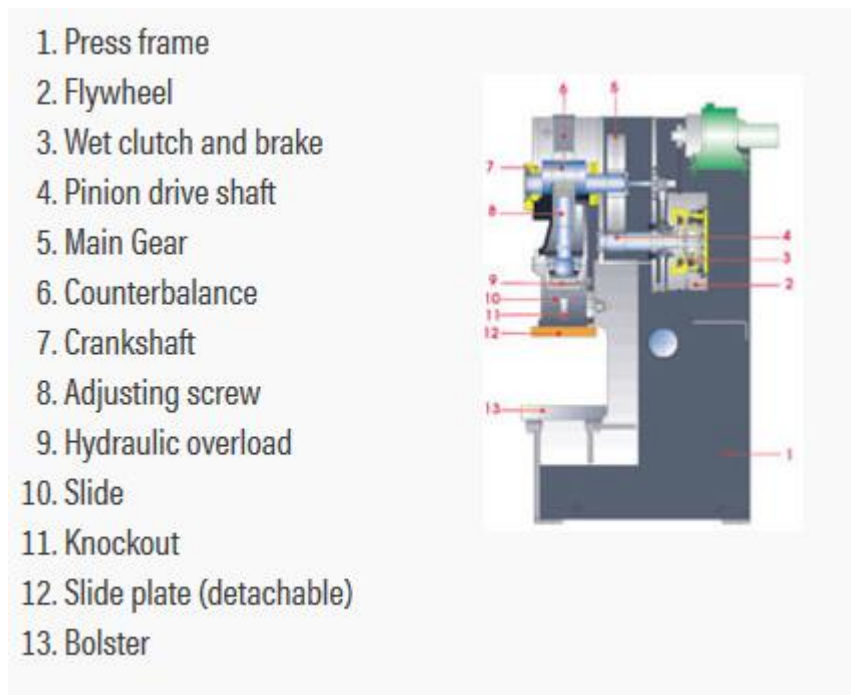
Picture 4. Profile picture of the important parts of a mechanical, C-type press. (Stamtec, Inc., 2019.)

### 2.2.1 Amada's functionality and limitations

Amada TP-110 is a mechanical, C-type press (called that due to the type's outwards appearance, that appears to resemble letters C or G), that has a maximum rating of 110 tons of force. The machinery works by having an electrical motor drive a large flywheel, in which kinetic energy is stored and later consumed in the motion of 360-degree cycle of the press, or shorter a stroke, to have the dies make the piece. Each downstroke slows the flywheel roughly 10 to 15 percent, which then the motor tries to remedy by increasing the energy on the flywheel during the upstroke in preparation of the next cycle. In the case that flywheel slowdown exceeds 15 percent in continuous use, the motor does not have the required time to restore the lost energy and the press will slow down too much. Resulting in a situation where after several strokes the press will jam in the BDC. To initiate a stroke, an electric control is utilized for clutch and brake, which then disengages the flywheel to the press drive. Typical clutch and break components are spring applied, with either pneumatic or hydraulic release. Clutch and brake stopping times have a critical role in determining the speed the press can be run at and the safety of the operator and die. (Cattel, 2008.)
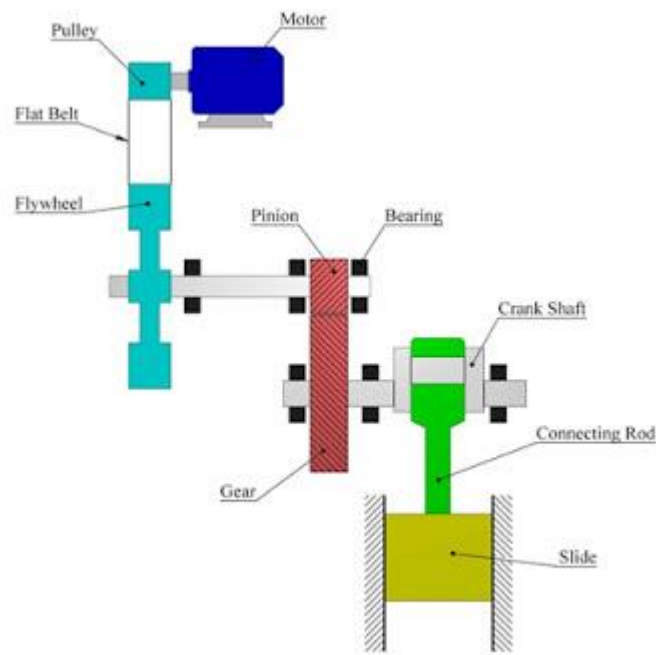
Picture 5. Schematic of the functionality of electric motor driven presses. (Machine design and analysis blog, 2017.)

Flywheel driven presses have the typical use in piercing, blanking, bending and very shallow drawing with progressive dies. With the usual tonnage being between 30 and 600 tons. As a rule of thumbs full press energy becomes available after reaching half of the top press speed and the press stroke length is always kept as short as possible. The SPM (strokes per minute) with this drive type is 125 to 250 on the low end, to an excess of 1000 on the high end. (Cattel, 2008.)

## 2.3 Original state of the machinery



Picture 6. Amada TP-110 during installation to its new production line.

In the original state of the cam press, control has been performed with a control pedestal which has had option for both manual and automatic use. Additionally, the cam press could have been used with a footswitch on manual operation mode.

All of the possible modular options for the press were drawn in the original electrical schematics, but only the bare minimum was initially installed onto the press and no modular options were retrofitted either. No alterations were made to any of the physical properties compared to the schematics. These formerly mentioned points made the modernization process a whole lot of easier and streamlined.

### 2.3.1 Controlling systems and components

Original usage controls have been mostly hand operated from the control pedestal, which houses two-hand operation pushbuttons, two pushbuttons for automatic run mode, which have to be pressed at the same time as two-hand operation buttons on automatic mode, a 5-position key switch for operation mode selection and an

emergency pushbutton. The pedestal has a 3-meter-long cable connecting it to the electrical cabinet, giving it the possibility to be moved around the machine and workspace.

Another way to control the press has been the use of a footswitch, which has been used mostly if there has been a need to manually feed a sheet into the dies and to hold it in place. To enable the use of the footswitch, a selective switch has to be turned to a position that gives the control completely from two-hand operation to the footswitch. In addition to the afore mentioned impediment, the footswitch can only be used on Safety Once- and Once-modes. (Jabatan & Kesihatan, 2015.)

The press has only one key switch and it is used for changing the operating mode. There are five positions on the switch and they correspond with Safety Once, Once, Off, Inch and Continuous. The key for this switch should always be in the possession of a competent or authorized personnel, such as Line-leader, Supervisor or Die-Setter, to prevent machine abuse, with adjustments, maintenance without supervision or unacknowledged fault situations. (Jabatan & Kesihatan, 2015.)

The differences in mode selections and their usage, with prerequisites are listed below.

- Once: In this mode, after the stroke has been initialized, the machine will only do one cycle and stop after reaching T.D.C. Once is the most used mode in operating press machinery. (SFS-EN 692 2006, 17.)
- Safety Once: This mode has the same principality as Once-mode, with the exceptions of press usage being initialized with footswitch control and that safety of the operator is reliant on second layer of safety features such as safety guards, hand tools or light curtain sensors. (The American Society of Mechanical Engineers, [Ref. 20 September 2019].)
- Off: In this mode the initialization of a stroke is impossible and is as such the used mode for maintenance and die changing operation. Off mode also enables the use of following operations; Bolster movement (in and out), Slide adjustment (up and down) and Cushion adjustment. (Jabatan & Kesihatan, 2015)

- Inch: The jogging mode, that is used when dies are being set or after a fault has occurred. The mode is intended to be used solely by die setters and other service personnel, as safety regulations and standards prohibit the usage from production operations. Slide movement in Inch-mode is incremental and dependent on four factors with part-revolution clutch: a) time of engagement of the Inch-control; b) length of the stroke; c) speed of the press; and d) position of the slide within the stroke. (The American Society of Mechanical Engineers, [Ref. 20 September 2019].)

- Continuous: An automatic mode which repeatedly initializes a new stroke after the previous cycle comes to an end. To use, separate push buttons have to be pressed at the same time with two-hand controls and to disengage, either press the two-hand controls once more or press the stop button on the T-stand. (SFS-EN 692 2006, 15.)

Logic/operating functions for the press are controlled with contactor control circuits. This subject will be addressed throughout parts 2.3.2 and 3.1.

Flywheel speed control, subsequentially the press power, is done with Eddy current system, in which the motor rotates at set speed and the rotary motion is then transferred onto the pulley by slip speed technology. This subject will be gone through in part 2.3.3 in detail.

Half of the pneumatic system is controlled with simple 2/2 electromagnetic valves that include Air Blow Off- and Overload-systems. The most important part of the pneumatic system, the brake and clutch control, is controlled by SERPAR Crossflow twin valve system. As instigated by SFS-EN 692-standard and re-enforced by European directive 2006/42/EC. The both standards give similar statements that on mechanical presses and other hazardous machines with pneumatically operated clutches and brakes double valves at least should be used. Double valves without self-monitoring should only be used if current regulations permit this or if the valve is equipped with a control system, which in conjunction with the safety control system, enables the monitoring of valve and machine. (Directive 2006/42/EC, 2006; SFS-EN 692, 2006)
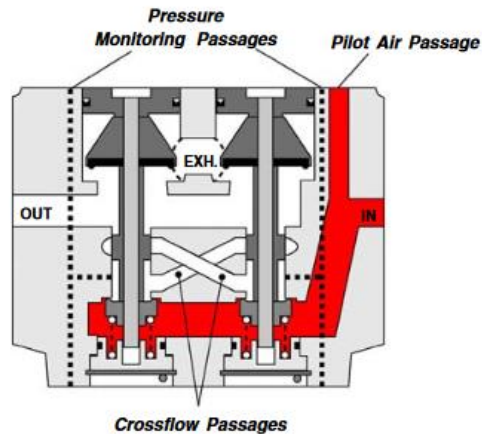
Picture 7. Crossflow valve in deactivated/resting state. (ROSS EUROPA GmbH, 2005)

The way Crossflow twin valve is made to be the epitome of safety with heavy machinery with pneumatic controls can be explained by taking a look at its structure. As per the name would suggest, the twin valve has two independently actuated valves, that are operated by solenoids, in a common housing. Within the housing both valves have shared inlet-, outlet- and exhaust ports. During normal operation the solenoids, that are located on the inlet side, are actuated simultaneously pulling the valve assembly to open position and working as a regular 3/2 single valve system. In a case where one of the valve assemblies malfunctions, either by failing to open or close properly, the design will allow less than 2 % of the inlet pressure to build up at the outlet port which is not sufficient for actuating the system. Instead the pressure will be dispersed through the exhaust port. Due to the presence of the second valve assembly, that is sometimes called redundant. The likelihood of malfunction on both assemblies during the same cycle is considered extremely remote. (ROSS EUROPA GmbH, 2005.)
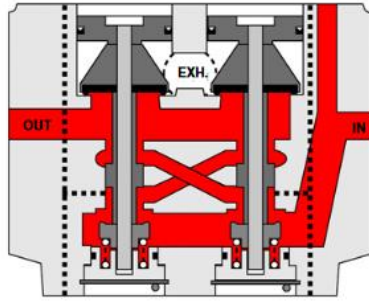
Picture 8. Crossflow valve normally actuated. (ROSS EUROPA GmbH, 2005.)
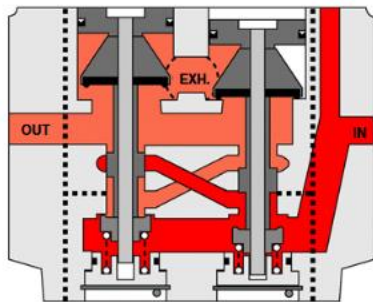


Picture 9. Crossflow valve in a state of malfunction. (ROSS EUROPA GmbH, 2005.)

The clutch and brake system is of the part-revolution clutch type, which is either pneumatically or hydraulically actuated and can be disengaged at any point of the stroke to stop the slides motion. This is a considerably safer option and can be used on all kinds of presses regardless of tonnage. Compared to the alternative of full-revolution clutch type that always disengages at the T.D.C, with a mechanical release. Full revolution clutch also has only manual possibilities for early disengagement. Part-revolution type clutch and brake system allows for usage modes such as Inch to be used. Below in picture 9 is a cross section of part-revolution clutch and break. In which can be seen the plate connected to the shaft that drives the slides motion, being pushed by springs onto the brake elements on the left. On the right side is shown the actuated state when the hydraulic/pneumatic pressure disengages the break and makes contact with the flywheel. This causes power to be transferred into the slide. Plainest explanation for part-revolution clutch and brake would be that it is a reverse-function car transmission. (Jabatan & Kesihatan, 2015.)
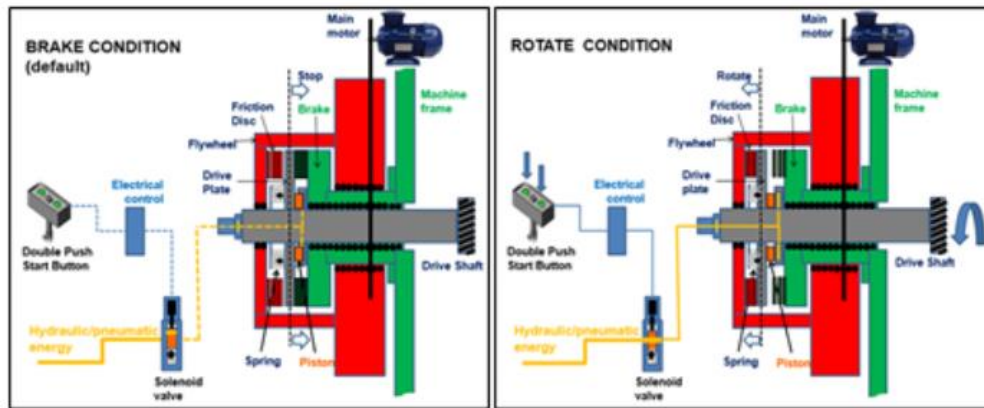
Picture 10. Cross section of part-revolution clutch and break with operation. (Jabatan & Kesihatan, 2015.)

The feedback of the state of cycle comes from mechanical lever switches, will be referred as LS from this point onwards, that monitor cams attached to a rotating rod connected to crank shaft. This type of measurement of slide position, based on the angular position of the crank throw in comparison to the common reference point of T.D.C is called Crank angle. (The American Society of Mechanical Engineers, [Ref. 20 September 2019].)

### 2.3.2 Electrical systems

The machinery holds three different AC-voltage ranges, with three transformers and several phase amounts. 380 V 3-phase mains for the motor, 200 V 3-phase for lubrication systems and 1-phase for eddy current motors control board, 100 V single-phase for contactor operations.

As the machine was built 1959, its electrical control system has been ever since the now outdated contactor system which at the time was prevalent. The amount of contactors utilized by this old system has been two main contactors and 25 process control contactors.
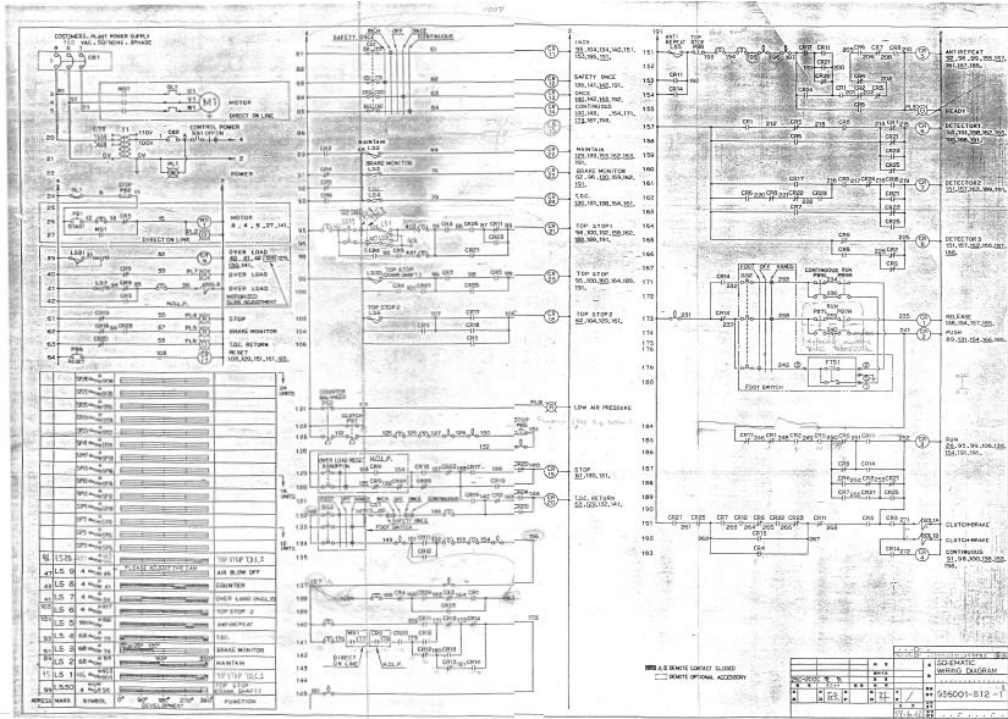
Picture 11. The original wiring diagrams.



Picture 12. The old contactor control system within the electrical cabinet.

### 2.3.3 Eddy Current system and the drive motor

Motor in an Eddy Current-system is an induction type motor, meaning it is actuated by AC-power. (Chapman 2005, 230). In more detail the motor in the system is design class D. Typical characteristics for class D motors are very high starting torque

and low starting current, but at a cost of having high slip at full load. This is achieved by having the rotor bars made smaller and from higher resistance material compared to type A motors, The high rotor resistance causes peak torque to shift to a very low speed, as well as full-load slip to increase up to 17 percent or more from the typical 7 to 11 percent. These characteristics make type D motors ideal for applications requiring the acceleration of extremely high-inertia-type loads, especially large flywheels used in punch presses or shears. (Chapman 2005, 416–423.)
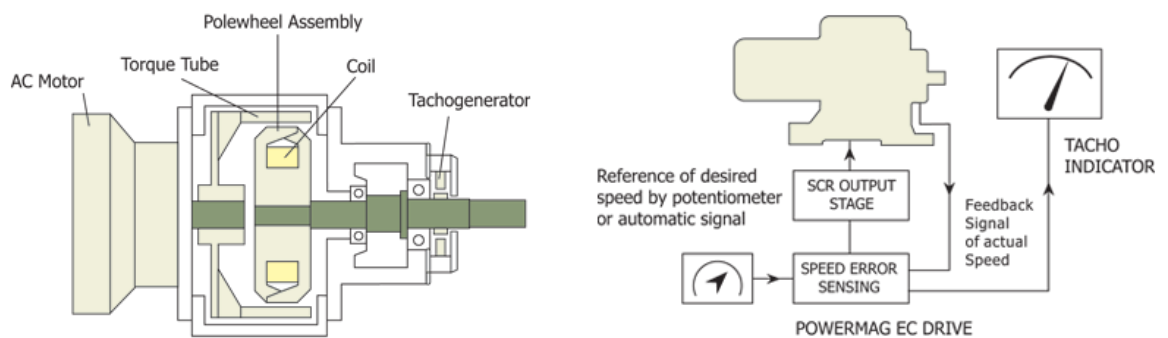


Picture 13. cross section of a Eddy Current clutch and control feedback loop explained. (Powermag Control Systems (P) Ltd., 2017.)

The Eddy Current system works by having an AC-motor that was detailed in previous paragraph rotate at its nominal speed, that is defined by rotor slip (see Terms and Abbreviations), turning the drum part of Eddy Current clutch. Drum has excitation windings that are supplied with a DC-current from Eddy Current Drive/Field Exciter and Controller (EDC). This current with the rotary motion of the drum, cause a magnetic attraction to occur between the drum and inductor coils on the output shaft. With a higher current more power in terms of speed and torque will be transferred into output shaft. The way the amount of current is controlled in excitation windings is done by giving the drive/controller unit an analogue value (in this case with a 10k ohm potentiometer) that is then compared to a feedback value generated by a tachometer generator at the output shaft. Terminology for this control can be either Degree of coupling or Slip speed. (The-Crankshaft Publishing, [Ref. 29. September 2019].)

# 3  PLANNED STATE OF THE MACHINERY

This is the part which will be going through what kind of changes are being proposed for the project with their reasoning behind them and impact on the machinery. All of the new components that are being implemented into the project are also being introduced and explained.

## 3.1  Planned changes into control scheme and operations

The control for normal usage in production will be given to Siemens ET200S PLC, which would be installed in the old electrical cabinet and function as a slave PLC to the production lines master PLC. The PLC program that has been created for this solution, has been made by having the original electrical schematics as the foundation for the core function in the program and then expanding upon that core necessary and wanted additions were made.

In the end the program has come to utilize following amounts and types of I/O; five fail-safe digital inputs, 31 digital inputs out of which one comes from master PLC, four fail-safe outputs, eight digital outputs out of which three are sent to master PLC, one analogue output and a Profinet connection between PLC and HMI. These connections amount to five digital input-, two digital output-, one analogue output-, one digital f-input- and one f-output-modules on the PLC rack (see picture 14 for reference).

In addition to previous paragraphs listing, the project has following types of hardware which are not connected to the rack. HMI (Siemens KTP700 Basic PN) and Arduino UNO board connected with Pololu Dual Motor Driver Shield board, that are used to adjust Eddy Current systems control board EDC.

Picture 14. Complete Rack setup with annotations.

As this solution won't be replacing the old Eddy Current system but removes the potentiometer that was used to adjust the slip speed of the clutch, there became a need to have a replacement control system for EDC. Considering EDC is powered and functions with 200 VAC, the choices became limited from the start, for PLC's normal operating voltage is 24 VDC and analogue output voltage measly 10 VDC (Siemens AG, 2007). Meaning the utilization of motorized rheostat was mandatory. Even though the PLC would have been more than capable of doing the adjustment of rheostat (Bourns PSL Slide Potentiometer was chosen for this project). It was decided that Arduino board would be set as a slave for this task. To protect the PLC and it's modules to an extent from possible malfunctions and lessen the burden of computing for the PLC.
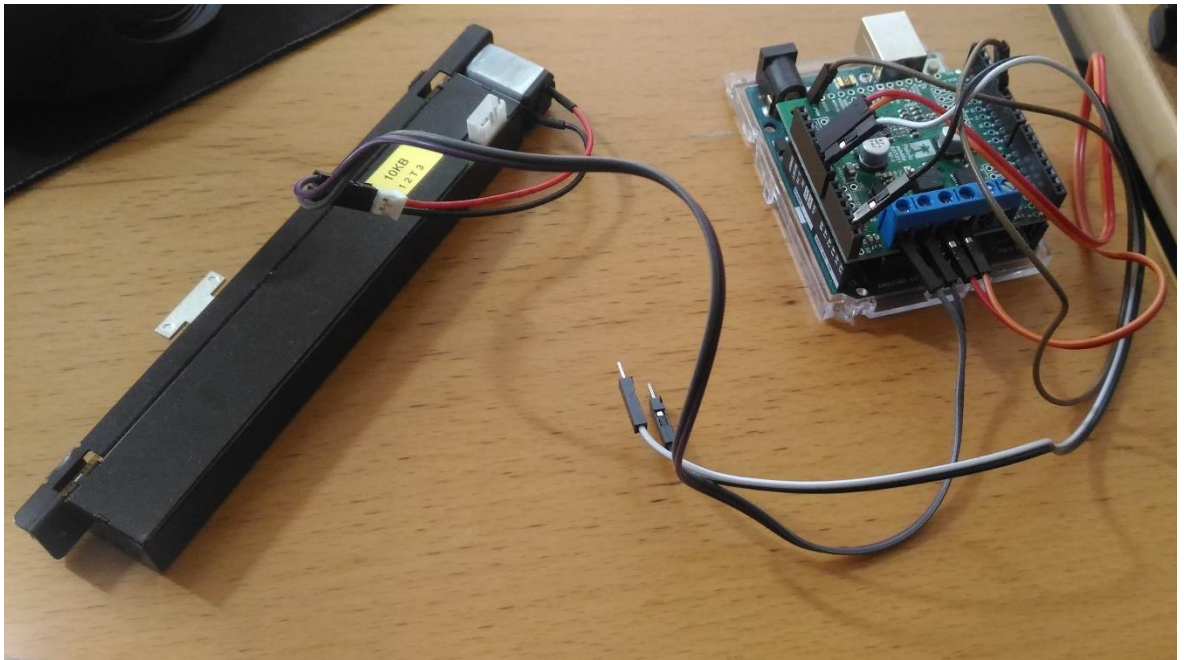
Picture 15. Unplugged Arduino and Pololu motor shield combination wired with Bourns PSL slide potentiometer.
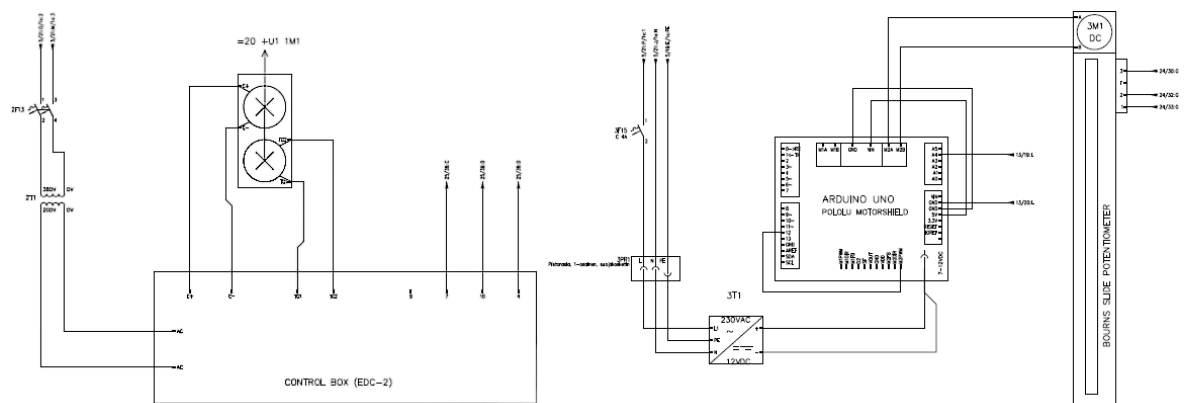


Picture 16. Combined wiring diagram of EDC and Arduino system.

Arduino boards addition to the project brought up the need for an electrical socket with a plug-in 230 VAC to 12 VDC power adapter to be installed inside the electrical cabinet (seen in picture 16). This was required as Arduino's operating voltage is 7-12 VDC. Arduino's I/O system also required special attention on communication with PLC, as the I/O systems rated voltage range is 5 VDC. The latter was remedied by limiting the value PLC's AO-module receives internally to match Arduino's ADC system. (Arduino AG, [Ref. 2. October 2019].)

Control pedestal and footswitch would still be left for manual control for maintenance and the possible fault situations. Although, the pedestal would still be renewed with a one that doesn't have the possibility to use automatic mode, meaning the absence of auto-push buttons on the sides. Even though it could be said to be only a cosmetic change, for the usage is blocked within the plc program. Footswitch's functionality will be converted from strike permission into electromagnetic pneumatic valve control. That then operates the pneumatic cylinder for lifting the pressed and cut out plate in between the dies.

There will also be change with the key switch system. This solution proposes that the system will be made to be two stage process. Which means the number of key switches will be doubled, the first one staying at its previous location at the control pedestal and the new addition would be placed on the cover of electrical cabinet in the vicinity of HMI. Both will retain the original five mode choices (Safety Once, Inch, Off, Once, Continuous), and will have to be in unison with each other in order to give usage permission. The permission is always rescinded if either switch has been operated and will have to be acknowledged from HMI.

As the operating voltage for process control has been reduced and changed type into 24 VDC, there also has to happen renewal on the instrumental side. Such as the electromagnetic valves, that are part of the pneumatic system and control clutch and brake functions.

The LS system will stay as is, with the only modification being that it will be rewired into the PLC. LS's are still the preferred method of feedback as it is mechanical, with little to none wear, meaning the tolerance within measurement is extremely low. Changes within mechanical measurement such as this should only be possible if the machine is for one reason or another dis- and reassembled. (Bairwa, 2018.)

## 3.2 Renewed electrical systems

To modernize the electrical system, some visually drastic changes will happen. As the solution has thus far given out, the greatest change will happen in the form of process controlling equipment which will leave the electrical cabinet looking rather

sizeable for the required instrumentals. For considering you will only be needing the space of roughly four to five contactors with the wanted PLC and its modules, as the primary process control equipment. Then the space required for Arduino-Rheostat control can be added to this, which equates to a rough estimate of one contactor, and lastly, also taking two contactors worth of space, the 3-phase 400 VAC to 24 VDC transformer to power the new PLC and its affiliates. So all in all the new system by this solution would be taking roughly the space of eight contactors, and by comparing that to the current system. Where the number of contactors is 25, there will be a decrease of 13 in required space in the electrical cabinet.

There will be only one contactor assembly (Siemens SIRIUS 3RA2) left in the electrical cabinet within this solution and those are the new main contactors, that control the usage of the motor in the Eddy Current system. Even while this solution leaves the contactors in, they will still be renewed as both a precautionary method, for they are possibly multiple decades old, and the system needs contactors that can be actuated with 24 VDC.
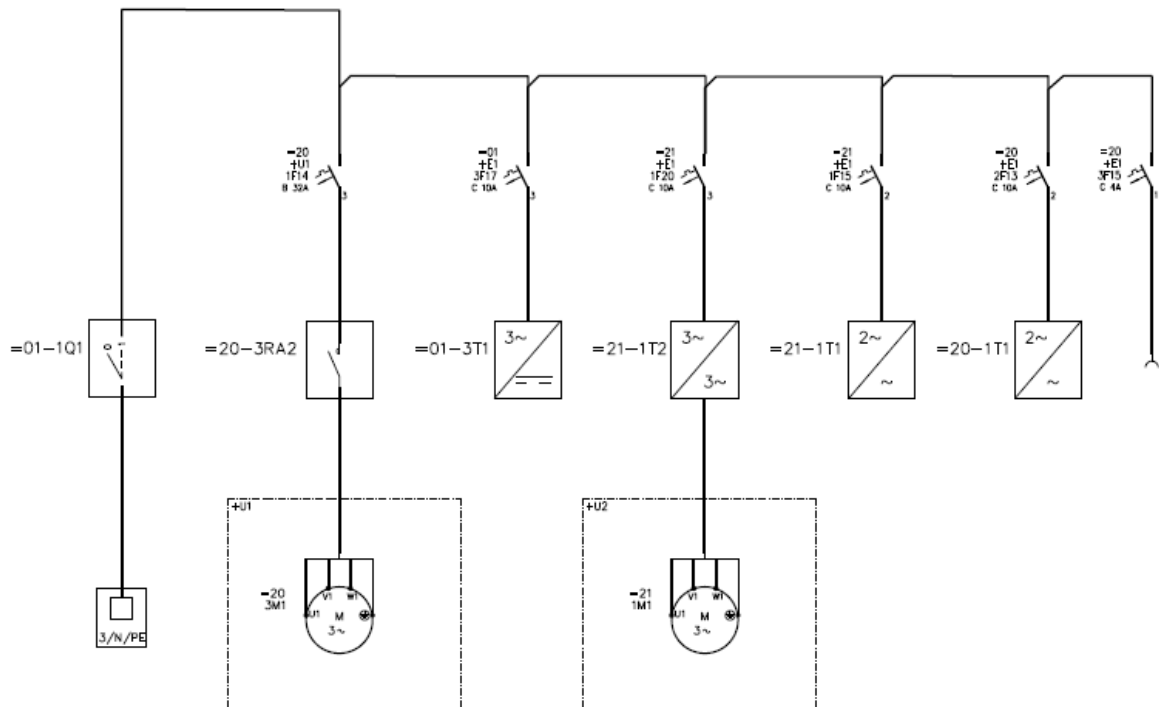


Picture 17. Main circuit diagram.

## 3.3   Reasoning for drive system retainment

As stated in 3.1, this solution will not be changing the old Eddy Current motor for a newer one. There were few things to consider whilst making this decision and the one that was found to be the one with most impact was how the Eddy Current handles within emergency situations. As per Eddy Current's style of operation no additive energy will be transferred in the system and no strain will be caused onto the driving motor as the flywheel is physically separated from the motor. (Refer to 2.3.3. and picture 13.)

There is also no real need to change the Eddy Current system as it has shaft bearings and drive belts as the only parts that experiences real wear in the system. And if the decision to renew the system would be made, the EDC, Eddy Current clutch and the motor would all have to be changed together. In which case there would have to be consideration on the subject of "Does the Eddy Currents better safety behavior and rare need of maintenance outweigh its energy inefficiency compared to a system where you would use a VFD-controlled motor?". In the European region industries have opted for the latter method of control, whereas North American industry still has the preference on having Eddy Current systems as the drive. As can be understood from the disagreeing Dynamatic and their shared insight upon the matter. (Dynamatic Drive Source International Inc., 2019.)

## 3.4   Current state of the machinery

Currently before any of the proposed modifications have been made, the control of the usage of the cam press in the production line has been given to the master PLC situated on the line and as such been controlled with the original contactor control circuits.

# 4 MODERNIZATION OF CONTROL SYSTEM AND DOCUMENTATION

This part will focus on describing what has been done during the course of the project. Attention is paid to the planning process and the phases it incorporated.

## 4.1 Hardware check-up

The first phase of the project was hardware check-up, where the components of the machinery were checked by the frequency and functioning of their use as well as their necessity for operation. With this information the preliminary choices between removal or replacement were made. The finalized decisions were made in phase three which is discussed in 4.3. At that point there was a complete logic program and a full picture of the needed components.

The framework that was given for the decisions by the client was that the contactor control circuits were to be removed and replaced by PLC-control and that the old control interface would be replaced. Otherwise, free reign was given over the choices concerning the component decisions in the project. Such decisions were renewal of the T-stand, operation of the footswitch and retainment of the Eddy Current system.

This was the phase where the necessity of the Eddy Current system was thought through, before the programming phase. Even though the program was made to be easily modified if it was required to be alternated to work with the second option for the motor control (VFD).

## 4.2 Program building and planning

The second phase of the project was about building a logic program based on the framework established in phase one, doing research on the requirements for the project and starting electrical planning to accompany the mechanical planning made in phase one.

The programming tool/environment for this project has been Siemens' own TIA-Portal version V15.1, in which the program was compiled in ladder type of programming, using the original wiring diagrams as a base. After this the program was edited to establish the required expanded features. These features were taken from standards such as SFS-EN ISO 14 121-1 and -2, that handle aspects of machine safety.

Standards regarding the project were an integral part for the project as they define the minimal component features, safety values and parts of programming that have to be present. After the afore mentioned were acquired, the programming was started from transcribing.

The main framework of the program was made almost purely by copying the old control circuits from the diagrams and converting them into ladder format, as can be perceived in pictures 18 and 19 after this paragraph and within appendix 1. Most of the additive function blocks in the program were ones that handled safety functions in one way or another and the rest of the bulk were ones handling the communication between the PLC and HMI. Motor adjustment function block was one of such, as it took the inputs from the HMI returning a percentile value back and guiding motor slip control through the analogue module to Arduino, rheostat and EDC.
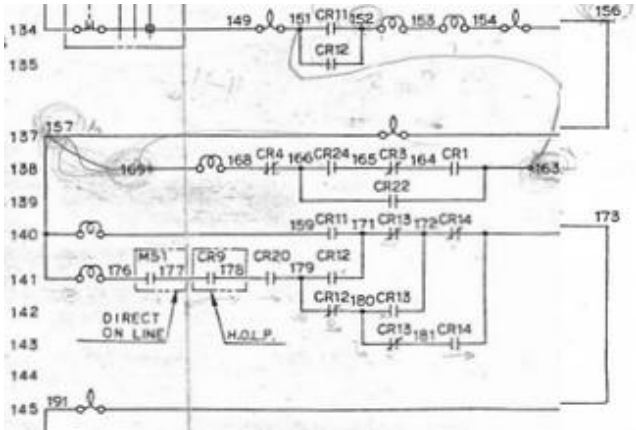


Picture 18. Original wiring diagram for the actualization of controls. When the program has been executed to this point, it is enabled to give the strike command.
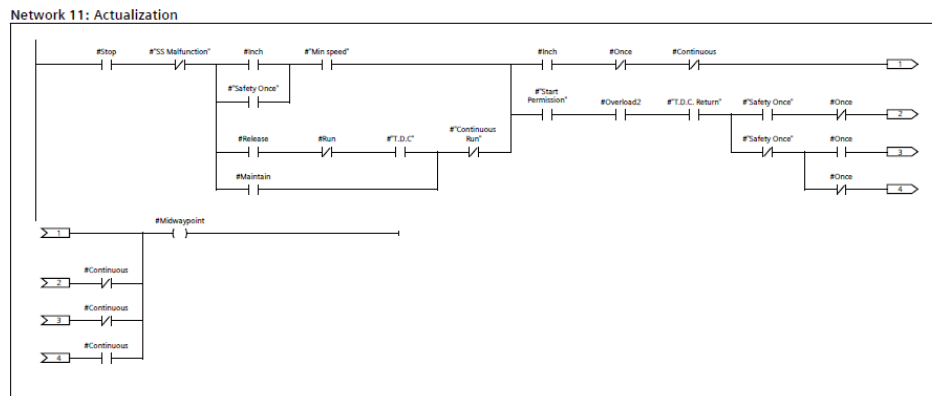
Picture 19. Remade actualization of controls in the PLC program. Here *Midwaypoint* is an internal marker in the program for it is used by multitudes of networks.

HMI was one of the features requested by the client to be added into the modernization project to ease the usage and moderation of line functions. The placement of the HMI was discussed to be either on the face of the box that houses the current analogue controls or on the door of the electrical cabinet, depending on if there is sufficient surface area on the face of the box and enough space inside it. The main interface can be observed in the appendices.

Arduino UNO board's programming, to work as the middle piece in motor slip control, was done with Arduino's own open software program called Arduino IDE. All this material can be found at Arduino's web page on the resources tab. The rheostat control was one aspect in the project that could be pre-adjusted to be correct by making a mock program on an available PLC and running test sets with it. Which was considered as essential as there seemed to be a lot of noise from the wiring, and the absence of positional feedback from the motor forced us to rely on a rough mathematical value for actuation time to be adjusted. Consequently, the mock program and its values were integrated into the project program as they had already been tuned to acceptable limits. Below in picture 20 can be seen part of the motor control program from the project PLC, that is adjusted via HMI.
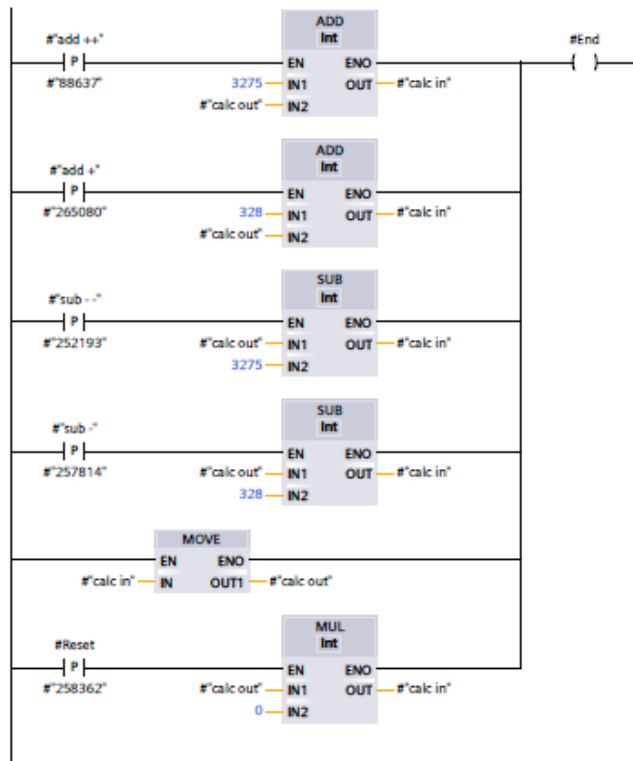
Picture 20. Part of the motor adjustment program from the project PLC.

The program is currently only a proposed solution, that will be gone through with the client and then finalized during installation and deployment of the new control equipment. The program and machinery will have to be adjusted to get them to work with each other and as a part of the production line as intended. Even though all the aspects have been thought over a multitude of times there is always something to be adjusted.


## 4.3 Electrical diagrams and finalizing component choices

The third phase covers redrawing electrical diagrams and finalizing component choices within electrical- and mechanical planning that were started in phases one and two of the project. Although, the new component choices were by the most part already selected by the redrawing, all that there was left to be done was to put them in.

Electrical planning and drawing was done with CADS Electric Pro program. In the new diagrams only the originally installed modular options were redrawn and PLC to field I/O -connections were added in place of the old contactor control circuits.

During the redrawing process all old components were checked for either replace-
ments or upgrades. This was made possible by having a table of all the program I/O
-connections and the necessary components to make the planned control schema
work as intended.

In the appendices it is possible to observe additional extracts from the diagrams.
The diagram of the oil pump needed the most modifying compared to other original
components, as it needed additional relay control to be able to communicate with
the PLC.

# 5  SUMMARY

Overall the project was quite an interesting piece of work as it had to incorporate so many aspects together. Such as, how the line and machine worked, the thought process of deciding the components and evaluating the machine drives and their control schemes.

A big part of the project was the safety-oriented planning, as we were working on large mechanical machinery that poses a great risk of injury (typically leading to severe damage- or death of the operator). The safety standards that impose the requirements and levels of operation were strictly considered when considering the parts and the control mechanics.

With the knowledge of safety requirements, it became clear what needed additional attention in the actual process of modernizing the control while building the PLC program and what had to be considered later on in the component choices when drawing the electrical diagrams. The programming phase was straightforward due to it mostly being transcribing the old wiring diagram into a ladder format, but had its progress slowed by Eddy Current control planning that introduced the Arduino board into the project as a medium for PLC and EDC. The process of redrawing the diagrams was best done after having completed most of the programming phase.

Only a fraction of the actual work has been showcased in this thesis. All the documentation and programs will be handed over to the client after the set-up of the new system is complete. There may occur some slight changes to either during the set-up phase, as the program will need to be adjusted to be precise.

Prior to the handover of the project it can be declared that the goals set at the start have been partially met. The safety functions have been heightened in addition to the safety modules to PLC and having the manual controls only to be used in special occasions, as normal operation is done on other side of the safety fence surrounding the production line. Production efficiency and fault management both have become better with the modern equipment that is faster and capable of communicating with the rest of the production line and with operator via HMI. Energy conservation is arguably better than with the alternate drive option, but the controlling functions are

more efficient in the matter than the current system. The drive source and lubrication pump were not updated in this proposition, but options for replacement will be given at the hand over to the client (see Dynamatic Drive Source International Inc., 2019).

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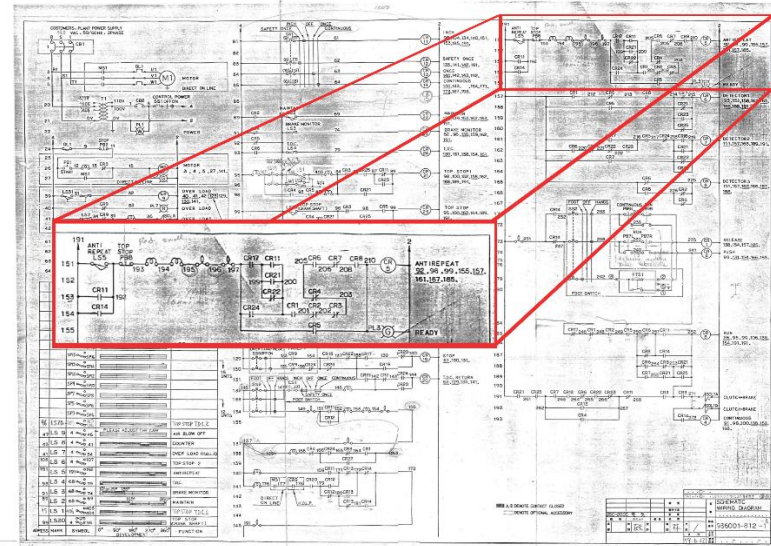
**APPENDICES**

APPENDIX 1. Example from conversion of process controls
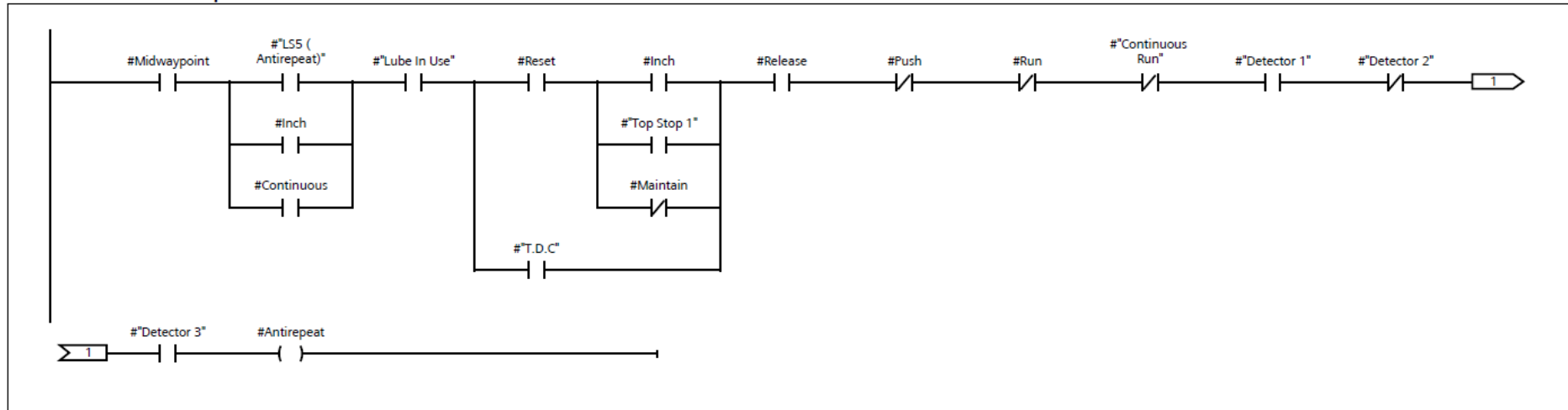
APPENDIX 2. Main interface on HMI

APPENDIX 3. Extracts from electrical diagrams

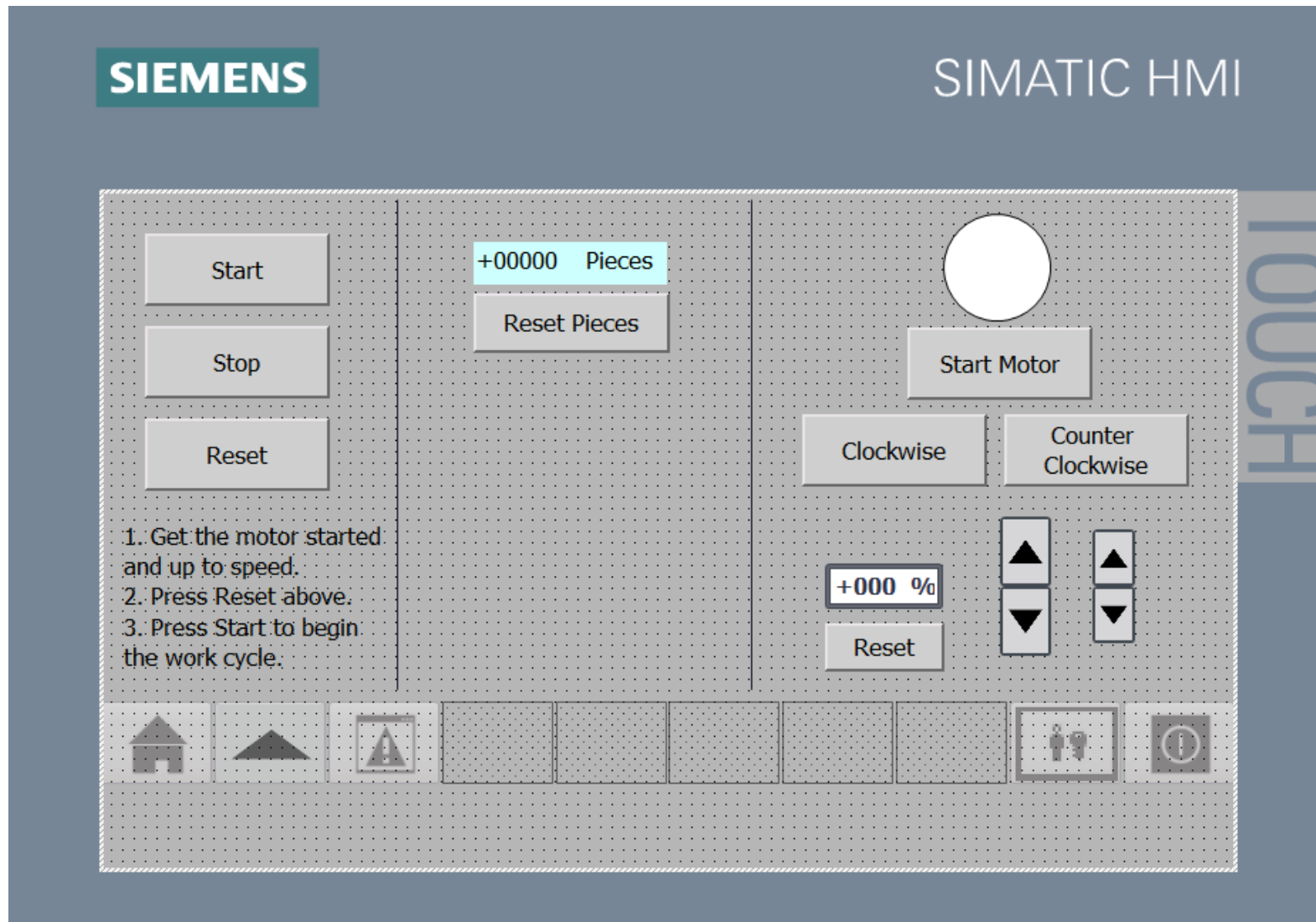APPENDIX 1. Example from conversion of process controls



The old antirepeat contactor control circuit highlighted above and the new ladder structure in the program shown below.

## Network 12: Antirepeat

APPENDIX 2. Main interface on HMI



The main interface for HMI, with a brief operation instruction included.

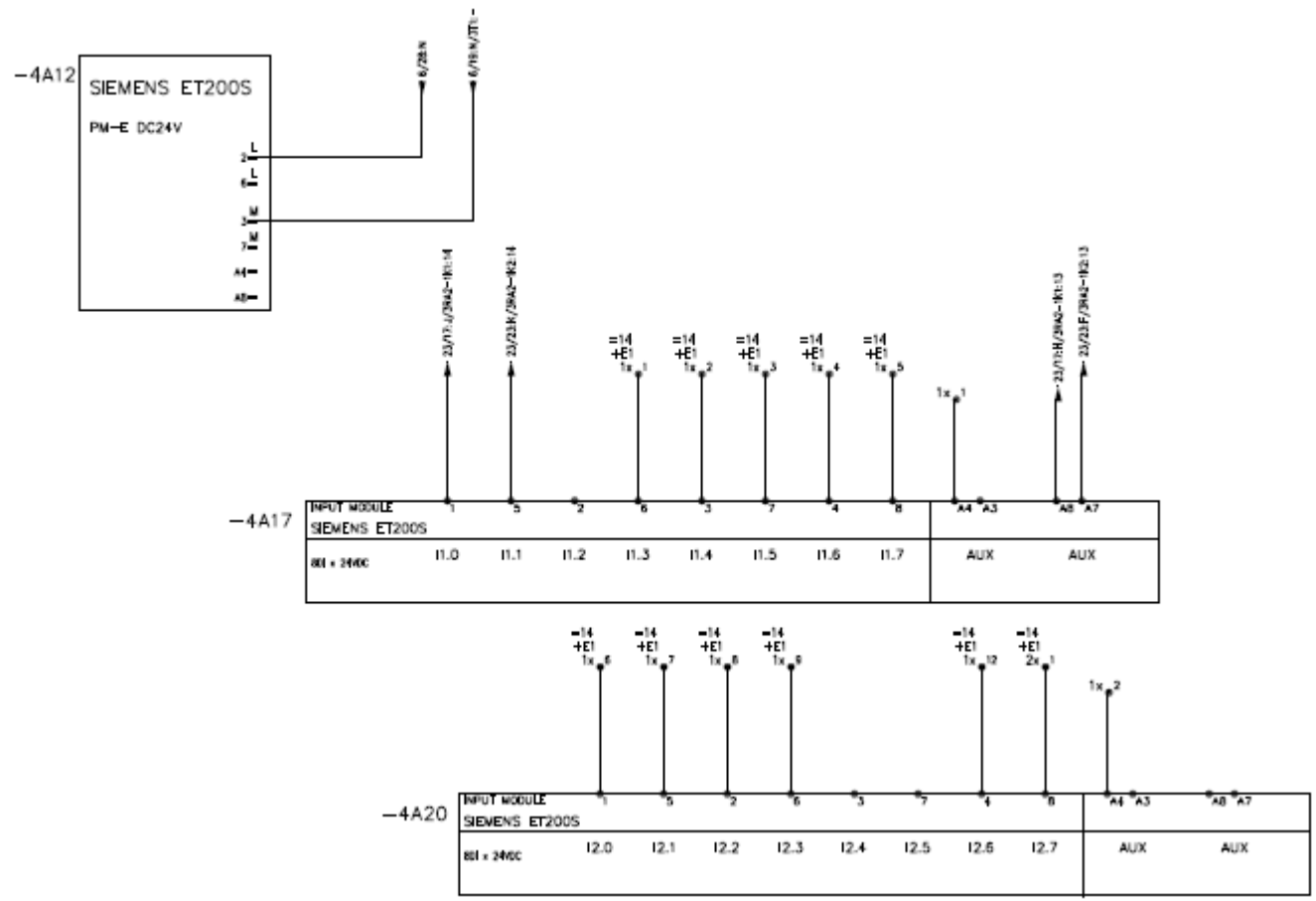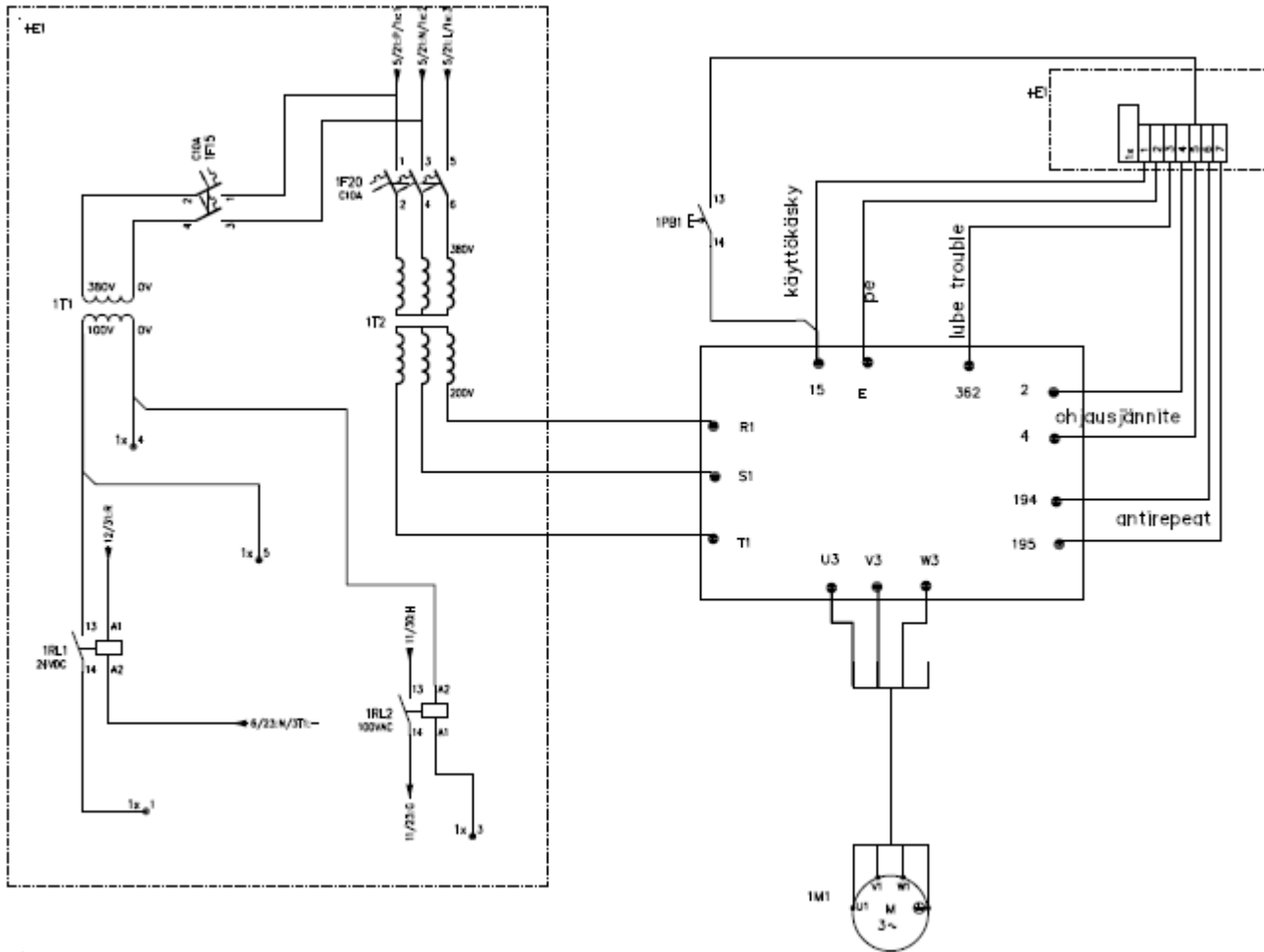APPENDIX 3. Extracts from electrical diagrams



Diagram of base power module with the depicted digital input modules, that are supplied by it.

Oil pumps updated electrical diagram.