MODERNIZATION OF WORKSTATION 190 FOR DECREASING THE SIZE OF R23L MANUFACTURING LINE AT AS NORMA

AS NORMA LIINI R23L TÖÖKOHA 190 MODERNISEERIMINE

MASTER THESIS

Student: Jelizaveta Sergejeva
Student code: 163012MAHM
Supervisor: Mart Tamre, Mechatronics and Autonomous Systems Centre professor, Mechatronics Programme Director

Tallinn, 2018
AUTHOR’S DECLARATION

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

“20” th of May, 2018

Author: Jelizaveta Sergejeva

/signature/

Thesis is in accordance with terms and requirements

“……” .................... 201....

Supervisor: Mart Tamre

/signature/

Accepted for defence

“......” ....................201... .

Chairman of theses defence commission: ................................................................................................. 

/name and signature/
Student: Jelizaveta Sergejeva, 163012 (name, student code)
Study programme: MAHM 02/13 - Mechatronics
Main speciality: Mechatronics
Supervisor(s): Mart Tamre, Mechatronics and Autonomous System Centre professor, Mechatronics Programme director, 620 3202
Consultants: Lennart Harju, AS Norma Industrial Engineering Development manager AS Norma, 6500 444, norma@autoliv.com

Thesis topic:
(in English) Modernization of workstation 190 for decreasing the size of R23L manufacturing line at AS Norma
(in Estonian) AS Norma töökoha 190 ümberehitus R23L liini suuruse vähendamiseks

Thesis main objectives:
1. Developing of new workstation based on existing one, with reducing of size and keeping the productivity of line and quality of production at the same level
2. Proofing the solution by calculations, technical data and tests; keeping all the AS Norma development standards
3. Result overview and analysis

Thesis tasks and time schedule:

<table>
<thead>
<tr>
<th>No.</th>
<th>Task description</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Current workplace review and topic question statement</td>
<td>28.02.18</td>
</tr>
<tr>
<td>2.</td>
<td>Development and analysis of alternative rebuilding solutions</td>
<td>11.03.18</td>
</tr>
<tr>
<td>3.</td>
<td>3D modelling, which includes creation of new parts and modelling of existing ones</td>
<td>1.04.18</td>
</tr>
<tr>
<td>4.</td>
<td>Pneumatic part, which includes component overview, choice and appropriate calculations, creation of schemes</td>
<td>13.04.18</td>
</tr>
<tr>
<td>5.</td>
<td>Electric part, which includes component overview, choice and creation of schemes</td>
<td>27.04.18</td>
</tr>
<tr>
<td>6.</td>
<td>Program part, which includes software choice, description of program workflow and program creation</td>
<td>11.05.18</td>
</tr>
<tr>
<td>7.</td>
<td>Cost calculations, which include rebuilding costs and cost reduction possibilities</td>
<td>15.05.18</td>
</tr>
<tr>
<td>8.</td>
<td>Result analysis</td>
<td>20.05.18</td>
</tr>
</tbody>
</table>

Student: Jelizaveta Sergejeva ........................................ “......” .....................201....a
/signature/

Supervisor: Mart Tamre ........................................ “......” .....................201....a
/signature/
CONTENTS

PREFACE ................................................................................................................................. 8
INTRODUCTION ....................................................................................................................... 9
1 CURRENT WORKPLACE REVIEW AND TOPIC QUESTION STATEMENT ................. 11
  1. Full line overview and description .............................................................................. 11
  2. Station 190 working principle description .................................................................. 12
  3. Description of Baltec machine ..................................................................................... 16
  4. Goal and justification of rebuilding ............................................................................ 16
2 REBUILDING IDEA DEVELOPMENT AND CHOOSING THE SOLUTION ............... 18
  2.1 Rebuilding possibilities .............................................................................................. 18
     2.1.1 Two Baltec machines near each other, connected by forward conveyor .......... 18
     2.1.2 Two Baltec machines near each other, connected by reverse conveyor .......... 20
     2.1.3 One Baltec in initial position, second one is turned by 90 degrees .................. 21
     2.1.4 One Baltec in initial position, second one is turned by 180 degrees, connected by simple conveyor ........................................................................................................ 22
     2.1.5 One Baltec in initial position, second one is turned by 180 degrees, connected by reverse conveyor, same operation’s order ................................................................. 23
     2.1.6 One Baltec in initial position, second one is turned by 180 degrees, connected by reverse conveyor, reverse operation’s order .............................................................. 23
  2. Comparing table ............................................................................................................ 24
3 PNEUMATICS .................................................................................................................. 27
  1. Baltec scheme ................................................................................................................ 27
  2. Stop gates ....................................................................................................................... 28
  3. Valves ............................................................................................................................ 29
  4. Pushing plate .................................................................................................................. 32
  5. Air preparation block ..................................................................................................... 33
  6. Scheme .......................................................................................................................... 34
4 ELECTRONICS .................................................................................................................... 35
  1. Buttons .......................................................................................................................... 35
  2. Safety door switches ...................................................................................................... 37
  3. Sensors .......................................................................................................................... 37
     4.3.1 Pallet position detection sensor ............................................................................ 37
4.3.2 Plate position detection sensor .................................................... 38
4.3.3 Baltec sensor .................................................................................. 38
4.3.4 Sensor for pallet last position ......................................................... 38
4.3.5 Sensors for detail detection ............................................................ 39
4. Lamps .................................................................................................... 39
5. Drive unit ............................................................................................. 40
5 CONTROL .............................................................................................. 41
  1. Baltec controller RC10 ....................................................................... 41
    5.1.1 Relay .......................................................................................... 42
  2. Controller ........................................................................................... 42
    5.2.1 CPU .......................................................................................... 43
    5.2.2 Power supply module .................................................................. 44
    5.2.3 Signal modules ........................................................................... 44
    5.2.4 Communication processor ......................................................... 45
    5.2.5 Function modules ........................................................................ 45
    5.2.6 Interface modules ....................................................................... 46
  3. Accessories ......................................................................................... 46
  4. Scheme ................................................................................................ 46
6 3D MODELLING .................................................................................. 47
  1. Parts which remain the same ............................................................ 47
    6.1.1 Baltec riveting machine ............................................................... 48
    6.1.2 Riveting unit fixing plate ............................................................. 49
    6.1.3 Foundation plate ......................................................................... 49
    6.1.4 Conveyor mountings .................................................................. 49
    6.1.5 Lifting unit .................................................................................. 49
    6.1.6 Frame .......................................................................................... 50
  2. New parts ............................................................................................ 51
    6.2.1 Additional table .......................................................................... 51
    6.2.2 Lightning ..................................................................................... 56
    6.2.3 Plate for button fixing ................................................................. 57
    6.2.4 New conveyor ............................................................................. 57
    6.2.5 Return unit .................................................................................. 59
    6.2.6 SICK sensor fixing ...................................................................... 59
    6.2.7 Operator’s button fixing plate ...................................................... 59
6.2.8 Pallet position sensor fixing ................................................................. 60
6.2.9 Legs ......................................................................................................... 60
6.2.10 Station positioning .................................................................................. 60
7 PROGRAMMING .......................................................................................... 62
  1. I/O list ......................................................................................................... 62
  2. Control logic .............................................................................................. 63
  3. Software ..................................................................................................... 64
  4. Communication ......................................................................................... 65
  5. Program blocks .......................................................................................... 66
8 COST CALCULATION ................................................................................... 67
  1. BOM ........................................................................................................... 67
  2. Licenses ..................................................................................................... 68
  3. Work hours ............................................................................................... 68
  4. Cost reduction possibilities ........................................................................ 69
9 RESULT ANALYSIS ....................................................................................... 70
SUMMARY ......................................................................................................... 71
KOKKUVÕTE ..................................................................................................... 72
LIST OF REFERENCES ...................................................................................... 73
APPENDICES ..................................................................................................... 77
  Appendix 1. Baltec scheme ........................................................................... 77
  Appendix 2. Additional plate strength calculation ........................................ 78
  Appendix 3. Station 70 program ................................................................... 85
GRAPHICAL MATERIAL .................................................................................. 89
  1. R23L modified manufacturing line .............................................................. 90
  2. Station 70 button set fixing plate ............................................................... 91
  3. Station 70 Operator’s button fixing plate .................................................... 92
  4. Station 70 Additional table ......................................................................... 93
  5. Station 70 Conveyor .................................................................................. 94
  6. Station 70 Frame for one Baltec machine .................................................. 96
  7. Station 70 Full frame ................................................................................ 97
  8. Station 70 Work flowchart ....................................................................... 98
  9. Station 70 Schemes (includes both electric and pneumatic schemes with appropriate connections) ................................................................. 100
PREFACE

Given work was initiated by AS Norma, a manufacturer of safety belt components. The aim of the project is to decrease the size of R23L manufacturing line by rebuilding of its stations and keep the quality of production and line productivity and the same level. Given thesis covers the modernization process of station 190, which provides bracket riveting on retractor assembly. The main thesis work was done at AS Norma using standards and equipment determined by Autoliv. Lennart Harju was a consultant from Norma side.

Modernization result is creation of station 70 (according to the new numbering rule for rebuilt line) with win in size and rebuilding cost, keeping the same cycle time, following all the ergonomics rules and compatibility with other line parts. The process of new station development is described in given master thesis step by step.
INTRODUCTION

AS Norma is producing safety belts for cars. In addition to manufacturing of safety systems for cars, Norma is also a manufacturer and distributor of safety equipment components for the international automotive industry. As the production amounts are growing, new details start to be produced; some production lines become old and cannot provide the robust production of necessary amount of details. Also, there are new lines coming to Norma and finding a suitable place for production becomes a problem. That’s why the decision to rebuild a R23L production line to decrease its size and provide work robustness was made. The process of rebuilding the station 190, which will be station 70 in the rebuilt line, was taken as main problem for the given thesis. This workstation is the final part in retractor assembly line where riveting takes place, and it will be separated from the main line in the final version of project.

The main problem stays on changing the work algorithm. An existing workflow should be studied and changed according to the new position of machines so, that the quality of riveting remained the same. Also, the workstation size needs to be reduced. New positions of pallet should be taken into consideration to replace inner components like stop gates and pushing plate (this plate is used to put the pallet with detail up to riveting machine) correctly. The arrangement of start and stop buttons and their synchronization should be reviewed. As the station becomes separated, the controller also will be changed to the new one, so I/O modules should be chosen and I/O list should be created. According to the changes, some additional components may be needed. Moreover, a station should have indication lamps and emergency stop button. Another issue is ergonomic standards, which cover operator’s posture, distances to taken components, safety devices for hands etc. As the detail goes from previous station, it is necessary to consider its weight and distance between stations. All these aspects may differ during the development. It is also planned to review the Baltec working principle. Some existing solutions from Norma may be considered, if possible.

The success of the research will be measured after the final testing of new device, based on next points:

- Quality of product – should remain the same, number of defect details should stay on the same lever or become lower,
- Cycle time – possibly reduced,
- Ergonomics rules – completely considered,
• Size of the new station compared with previous one – smaller,
• Correlation with other line parts – successful,
• All the rules of Norma and Autoliv should be followed,
• Cost – possibly low.

This work is in the field of interest of Norma AS. The software for work is also determined by Norma, so it will be Siemens S7 for PLC programming, Siemens NX for CAD modelling and DesignSpark Electrical for schematics. As the rebuilding of the full line is in the same time deadlines as given project and connected to other projects, the result of this work is significant and should be satisfactory in terms of reliability and functionality.

Thesis chapters are divided by the development steps: creation and development of idea, component review and choosing, 3D modelling and program writing. Appendices contain the development results: schematics, drawings, program text.
1 CURRENT WORKPLACE REVIEW AND TOPIC QUESTION

STATEMENT

1. Full line overview and description

Today a high capacity early 90s retractor assembly line is used to build R23L. Line was built for high volume serial production (max 11 operators). Current line R23L is situated in NRS AMG1 on the 1st floor, adjacent to NRS CLT assembly area. Now R23L consists of 28 stations, which include manual assembly stations for operators, manual or automatic control stations and preassembly stations, which provide some assembly components used by operators in next steps. Line provides retractor assemblies of several types, 15 for this year, 68 at all, which have similar shape, but may slightly differ by components used.

Figure 1.1.1 Current R23L line (taken from PLM Autoliv inner service)

Assembly starts from fixing the retractor housing on the pallet via special attachment. Then goes 3 manual assembly steps with automated visual control between them. Station 70 is automated pressing, then goes manual assembly and visual control – till station 130. Station 130 is a Sluko machine which checks the quality of future retractor by testing the locking function of the roller and the tilting sensor during the tape acceleration. Every client has its own requirements for test results, which are not necessary to review in terms of chosen topic. Station 140 is manual assembly
and station 150 is semiautomated screwing. On station 180 putting a manufacturing label takes place and then assembly is placed on pallet with another fixing part and covered with a bracket. Then it goes to station 185 with visual control and 190, where riveting from both sides takes place. At the end, on station 240, an operator provides a visual control and packs ready detail in appropriate box. Stations 201, 250 and 260 are preassembly stations. The amount of details per working day (8 hours) is about 200.

2. Station 190 working principle description

One of the workstations is a 190 workstation, where 2 Baltec riveting machines provide bolt riveting on the two sides of a bracket of retractor assembly, which is shown on Fig.1.2.1 – here a bolt positioning can be seen. As line produces parts for both left-handed and right-handed cars, the position of bolts differs. There are several positions on the conveyor for a pallet with detail, which should be unchanged. Now this workstation is a part of the full line in terms of control, also it uses same forward conveyor as the full line. According to pallet positions, two Baltec machines are staying back to back, and 2 Bosch turning devices help to put the pallet in the right position while it is moving from one machine to another (Fig. 1.2.2). Cycle time is estimated as 22,65 s for both rivetings and moving.

Figure 1.2.1. Retractor assembly drawing – example (taken from PLM Autoliv inner service, supplier information is hidden)
Station 190 components can be reviewed from Fig 1.2.3. Station includes:

1.1-1.2 Baltec riveting press with appropriate supply components
2.1-2.1 Pushing plate for detail moving from the conveyor to the riveting unit
3.1-3.4 Stop gate with proximity sensor – used to detect pallet position and stop it in place determined for correct riveting
4.1-4.2 Double-acting cylinder, which pushes the lifting unit up
5.1-5.2 Door switch, which use prevents injuries during station maintenance
6.1-6.2 Button set for emergency stop and station operation
7.1-7.2 Drive unit for conveyor belt moving
8.1-8.1 Turning unit for placing the pallet to the correct position before the second riveting
9.1-9.2 Frame, which consists of Bosch 30x30 mm profiles with plexiglass and supply legs
10 Conveyor profile with belt

Pallet moving is shown by arrows.
Then bracket is placed onto the assembly, an operator checks the dimensions of the rolling stock at the station 240 according to the manual. If there is a mistake during the riveting, the palette stays in the station and green lamp starts to flash. In this case, an operator should follow the response plan.

100% visual control should be provided for every detail to estimate the riveting quality [1]:

1. Checking the riveting. The first and last roller in the batch must be measured with a callipers. The size of the large riving must be 8,5 - 9,3 mm; a small one is 5,6 – 6,4 mm. (see Fig.1.2.4)

2. Visual control of the screws. The screws must be outside the bracket of 1 ± 0,5 mm. (Fig 1.2.5)
Figure 1.2.5. Screws should be outside of the bracket

3. Quality control of the outer cover riveting.

4. Checking the spindle and the print cartridge orientation.

Figure 1.2.6. Final control steps

The workflow of station 190 starts from putting the detail on the pallet and pressing a button on station 180, then pallet is starting to move – firstly control of labeling (provided at station 185) takes place, then 2 rivetings on station 190 and visual control on station 240.
3. Description of Baltec machine

Baltec factory manufactures the different types of riveting systems for fastening technology. The company has marketing, engineering and service companies in Europe and the USA, and also provides riveting solutions for Norma.

The RN-281 model is used in R23L line. The riveting procedure lasts 2,5 s for each side. The forming tool of Baltec machine describes a rose-petal path. In doing so a flowing material deformation with the least possible force is obtained. Baltec provides [2]:

- Excellent surface structure of the riveting,
- Low component loading,
- Long life cycle of machines and tools.

The riveting positions may lay at different heights, for chosen model the distance between tools can be from 15,5 mm to 85 mm. Air pressure used is between 1-6 bar and riveting time can vary from 0,1 to 5,9 s. Riveting force starts from 5,8 kN and can reach 17 kN. Other parameters can be found from appropriate documentation [3].

The complete workstation consists of [3]:

- Riveting unit with drive motor
- Stable cast stand and pedestal
- Vertical adjustment and clamping
- Machine controller
- Complete compressed air maintenance unit
- Machine lamp

High performance RC-10 controller provides cutting-edge riveting process monitoring. It has 6 control parameters available, Ethernet and USB interfaces and fast data recording and analysis [3]. Detecting lamps make error diagnostics come easier.

4. Goal and justification of rebuilding

Main change reason is need to improve process robustness. Old line and its parts are not reliabale,
no external technical support is available, due to that it is not suitable for safety belt component production, which requires high reliability and quality of assembly parts. Old line takes a lot of valuable floorspace. Norma assembly division needs to utilize this space for running and future serial product processes.

R23L line takes 45 m² of plant floor space now, the aim of the project is to reduce this size to 16 m², put it to another floor and rebuild the inner workstations – from small changes for some stations to the full rebuilding of others. Also, it is necessary to keep the productivity on the same level or increase it, but the quality should stay as high as it was before. New line must be easy to maintain and designed to be manned by 1 operator.

The way pallet goes during riveting is too long for the new line. The goal of this work is to provide an effective rebuilding of one workstation, based on ergonomic and other standards, to reduce the size of a workstation and full line by keeping the same productivity and quality level. Low rebuilding costs are also a goal.

The rebuilding idea is based on idea to do the workstation 190 as independent station, not related to the main part, and provide the control separately. This approach allows to use a reverse conveyor to remove the pallet loop and effectively reduce the size of the workstation. Reverse conveyor usage needs changes in working algorithm and new PLC program, as the direction of moving is determined in program code. Most of the old parts like sensors and stop gates are planned to remain the same, if riveting machines will be correctly positioned. Detail positioning task has a high important and the most effective and fast way to correctly solve it is 3D modelling – it helps to see the component compatibility in terms of size and placement position. One of the issues is that old line does not have an appropriate documentation, so all the electrical and pneumatical schemes should be done from 0, with replacing the components to more suitable if needed.
2 REBUILDING IDEA DEVELOPMENT AND CHOOSING THE SOLUTION

2.1 Rebuilding possibilities

2.1.1 Two Baltec machines near each other, connected by forward conveyor

For any of rebuilding solutions set of components has changed, which will be explained in further chapter. New components include:
8. Operator’s button
11. Return unit
12. Pallet position sensor

In this solution, two machines are near to each other. The simple forward conveyor is used and additional defect controls are removed, so an operator puts the necessary details on the pallet in the right order, then presses a button and goes till the end of station, where he takes the ready production and checks it visually for mistakes. This solution does not require the rebuilding of inner part, including metal plate with pneumatic cylinder from one side, which lifts the pallet to the riveting unit, stop gates and inductive sensors. As all the components are placed near to each other, the loop with rotational parts can be removed and the size becomes smaller – the loop has size 715x1350 mm. This workplace can be placed perpendicularly to the full rebuilt line, if it is necessary.
to keep the size as small as possible, or along the line (near the last workstation), which actually makes the full line longer and the need to relook the place for new line occurs. The conveyor part will be enough long, because distance between components and frames of riveting machines should be kept, also both machines have doors, which should be easily opened. The conveyor is fixed by steel mounting plates, one inside each frame near Baltec; Borch legs fix the ends of conveyor with motor, other part is fixed by Baltec machine frame legs. In case of any rebuilding a conveyor becomes separated from the line, so fixture should be controlled – Baltec frames are not enough to eliminate vibrations, so Borch legs at the end of conveyor are also needed. Now the position of Baltec is so, that both Baltecs work with the same upper part of detail. Rotational parts may be used to turn the detail correctly before it reaches the second machine. Also, there is a fixing plate on the machine tool, which fixes the detail during riveting and eliminates shifting. If both machines stay in the same position, shift of the second machine for correct bolt position is needed, so this can lead to the rebuilding of second frame and the fixing plate should be turned by 180. It is possible to put two Baltecs under 1 frame – this gives some win in size (not necessary to have space between frames, easy to use 1 door for both machines), but it is not more than 100 mm. But the cost of this rebuilding becomes larger. Work order remains the same as it was in the old station. If the station is along the line, an operator should go straight from start to the end of line, which is ergonomically not problematic. If the workplace is positioned perpendiculary to the line, the operator may make additional movements like turns to reach his workplace and take components. This becomes ergonomically problematic. There is an EMS standard for ergonomics, which determines requirements and permissions for operator’s work [4]. The points about worker posture which are necessary to cover it this work, are next (see Fig. 2.1.1.2):

- The distance to workpiece (primary zone) is 0-250 mm from the table edge.
- The distance to material shelves/components used in each cycle is max 350 mm.
- The working space within a line is sufficient to maintain full range of motion required to do the job task. The minimum working space for an operator is 800 mm.
- Height of touch panel is between 1400 – 1780 mm (centre line).
- Emergency switch/button is easy to be reached.
- Max. head flexion and bending head to the sides while working is 0-20°.
- Upper arms are elevated max. 30° during most of the work.
- Max. abduction (arms lifted to the sides) or arms crossing is 45°.
- Max. extension (arm “stretched” behind) is 20°.
- Back bending forward and to the sides and back rotation is between 0-20°.
- Side bending is 0-15°.
• Rotation of the elbows (forearms) is less than 60°, elbow “excursion” is less than 60°.
• Wrist works around its neutral position (max 30° flexion/extension and max 20° deviation).
• Pinching postures occur less than 1/3 of manual cycle time; max. 3hrs/day.
• There are good solutions for nests/shelves that the operator works with neutral wrist.
• There are no postures during working/reaching below knee height.
• The lowest height for unloading boxes/components by operator is 500 mm.
• There are no postures while positioning of items/tools/jigs/material which require reaching above shoulder level.
• The max feeding height of shelves/racks (for line feeder) is 1300 mm.
• Hitting items/tools with the wrist and palms (as on the pictures) doesn't occur.

Figure 2.1.1.2 Ergonomics standards illustration

Cycle time for this workstation will be estimated as: 2,5 s for each riveting procedure and about 8 s for movings, which totally gives 13 s. During this time the operator must move to the final position to take the detail for further packing. The Pronomic device will be placed at the end of line, with empty box on it. Distance to start, stop and emergency buttons will be correct, because here is possibility to place them anywhere on a frame, but distance to components may become ergonomically incorrect and require additional places for shelves.

2.1.2 Two Baltec machines near each other, connected by reverse conveyor

The principal scheme of this approach is the same as previous, but now the reverse conveyor is used. This approach is more suitable in terms of positioning of workstation, because operator does not need to change his position. Cycle time is 5 s for two rivetings and about 11 s for forward and
reverse moving. Despite the fact that it became longer, this approach has some win in cycle time for other operations, so operator can unite riveting and packing – for example, he has additional shelf for ready production, so when he comes from previous workplace, he already have one pressed detail. Operator can put it to this shelf and start next detail riveting; while it takes place, he can pack the ready detail, or leave it and go to the beginning of the line and start to produce new details. The packing takes place for several details at one time. In terms of mechanical design, this approach has same problems like previous one. Ergonomical problems are mostly solved for this case. Size of this workstation is the same as it was, but if the goal is to eliminate operator’s turnings and additional movings, the station placing makes full layout bigger, but still in range of 16m² floor space for the full line. Work order inside the station remains the same, though work order for operator may differ.

2.1.3 One Baltec in initial position, second one is turned by 90 degrees

This approach is more compact, due to the fact that part of workstation may be turned into full line center or placed closer to station 65. This approach uses rotation part in the middle of conveyor (marked by number 14), which eliminates the need to rebuild inner parts and change machine positions – but cost of this rebuilding increases. Frames of machines remain the same. Size of the full line can become larger – depends on second Baltec positioning (it may be turned to the other side also) and full workstation positioning – if for any reason it needs to stay perpendicularry. But this positioning will be more ergonomically correct than turned one. Cycle time becomes much larger because of longest pallet path with turning unit. Work order is the same or can be provided in other direction in terms of using a reverse conveyor – it gives win in time for other operations, but full cycle time becomes longer because of turning part – it gives additional 2-4 s.
2.1.4 One Baltec in initial position, second one is turned by 180 degrees, connected by simple conveyor

This approach is similar to the first one, but in this case one machine is turned by 180 degrees – see Fig 2.1.4.1.
This approach gives more win from the mechanical point of view - no inner shifts are needed, frames remain the same (it is possible to use one frame, but it has no sense). Cycle time remains the same – about 13 s. Positioning is also flexible – it can be perpendicular to the line with known ergonomic issues or stay along and line becomes a little bit wider, but still in 16m² floor space area for the new line. This approach gives no time for other operations. Work order remains the same as initial. Here comes another issue - rebuilding of the inner part. Now one machine is rotated and pallet goes inside from other side. So, stop gates must be repositioned to keep the correct screw position. Problem is that lifting part is solid and needs additional cuts for correct stop gate positioning, but it is not possible because of pneumatics and rollers under the lifting plate. So, solution needs additional shifts and conveyor becomes larger.

2.1.5 One Baltec in initial position, second one is turned by 180 degrees, connected by reverse conveyor, same operation’s order

This approach is mechanically the same as previous one, but now a reverse conveyor is in use. In this case, after the first riveting a pallet may go till the end of conveyor and do the second riveting after starting the reverse direction. In this case, no additional rebuilding is needed. Conveyor part is still long, despite the eliminated shift, because a pallet should move away from the last machine to eliminate the possibility of the stop gates to interfere the reverse moving, and this gives additional length. Using the reverse conveyor remains the same cycle time and gives more time for other operations, so the work order becomes more flexible. Positioning is still flexible and ergonomic standards are kept.

2.1.6 One Baltec in initial position, second one is turned by 180 degrees, connected by reverse conveyor, reverse operation’s order

This approach uses the same idea, like previous one, but now machines are turned by 180 degrees comparing with previous version. The work order also changes – firstly second riveting, then first one. Here a pallet does not go out from second frame, so conveyor length and full line length becomes smaller. Cycle time in this case is also less. This version is still flexible, ergonomically correct, does not require inner rebuilding.
2. Comparing table

For making an analysis easier, comparing table 2.2.1 was created. Any of given solutions needs new PLC program and all the schematics, so these parameters are not included in the comparing scope. Distance to buttons will be correct for any solution, only the position can change – from left or right side.

Comparing to others, the last approach is most suitable. This approach will have some win in the cycle time – because the long way of pallet is eliminated and time for additional operations has become. Using of reverse conveyor also saves the cycle time, because in previous version of workstation an operator should go to the other line part to take the ready assembly. Most of the components remain the same, so the cost of this rebuilding will be low. Size of the new station becomes smaller. Ergonomic issues depend only on positioning. This approach will be taken for further developing.
Table 2.2.1 Comparison of rebuilding solutions

<table>
<thead>
<tr>
<th>Solution</th>
<th>Size</th>
<th>Estimated cycle time</th>
<th>Cost</th>
<th>Ergonomics</th>
<th>Mechanical rebuildings</th>
<th>Work order</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Baltec machines near each other, connected by forward conveyor</td>
<td>Two machines + gaps between components Medium conveyor length Size of line depends on positioning Win in size for same frame solution</td>
<td>13 s</td>
<td>Inner rebuildings Rotational parts (optional), Shelves (optional)</td>
<td>Need to go till the end of station after each detail producing. Flexible positioning may create additional turns and bends for operator’s back May be hard to reach the detail shelves. Small working space if positioning is incorrect</td>
<td>Inner shifts of Baltec and rebuilding of fixing plate Rotational parts may be used to change position – grow in time, cost, size</td>
<td>Same, no time for additional operations</td>
</tr>
<tr>
<td>Two Baltec machines near each other, connected by reverse conveyor</td>
<td>Smaller gaps between components Medium conveyor length. Flexible positioning</td>
<td>16 s</td>
<td>Reverse conveyor + new stop gates, inner rebuildings Rotational parts (optional), Shelves (optional)</td>
<td>No need to go till the end, still danger of additional turns and bends, problems with reaching details and lack of space</td>
<td>Shifts inside, fixing plate rebuilding</td>
<td>Same, time for additional operations</td>
</tr>
<tr>
<td>One Baltec in initial position, second one is turned by 90</td>
<td>Flexible positioning , long conveyor, more compact for correct positioning</td>
<td>13 - 15s</td>
<td>Turning units, reverse conveyor + stop gates (optional), shelves (optional)</td>
<td>Less moving, may need additional turns, easy to add component shelves</td>
<td>No inner rebuildings for machines, rebuilding of conveyor</td>
<td>Same or in other direction, no time for additional operations for simple conveyor, win in time for reverse one</td>
</tr>
<tr>
<td>One Baltec in initial position, second one is turned by 180, connected by simple conveyor</td>
<td>Flexible positioning , medium conveyor length, gaps between components, no win for one</td>
<td>13 - 15 s</td>
<td>Inner rebuilding, shelves (optional)</td>
<td>Risk of turns and bends, additional movements, may be hard to reach components</td>
<td>Pushing plate and mechanism rebuilding, replacing of stop gates, shifts</td>
<td>Same order, no time for additional operations</td>
</tr>
<tr>
<td>frame solution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One Baltec in initial position, second one is turned by 180, connected by reverse conveyor, same operations order</td>
<td>Flexible positioning, long conveyor, no win for same frame solution</td>
<td>20-22 s</td>
<td>Reverse conveyor + stop gates, shelves (optional)</td>
<td>Risk of turns and bends, additional movings, may be hard to reach components</td>
<td>No rebuildings, only adding of sensors</td>
<td>Same order, time for additional operations</td>
</tr>
<tr>
<td>One Baltec in initial position, second one is turned by 180, connected by reverse conveyor, reverse operations order</td>
<td>Flexible positioning, conveyor becomes shorter, no win for same frame solution</td>
<td>18-20 s</td>
<td>Reverse conveyor + stop gates, shelves (optional)</td>
<td>Risk of turns and bends, risk of lack of space and problems with components reaching</td>
<td>No rebuildings, only adding of sensors</td>
<td>Reverse order, time for additional operations</td>
</tr>
</tbody>
</table>
3 PNEUMATICS

1. Baltec scheme

Every station includes pneumatic equipment, which is chosen according to Autoliv E1434063 standard [5]. The main pneumatic unit is a riveting press. The principal scheme of Baltec pneumatic part is given in Appendix 1[6]. This scheme was taken from the RN280 model manual. As the factory Baltec is RN281, the only change is that its riveting spindle is operated with a 5/2-way valve, actuated by a continuous current with a return spring. This means that the riveting spindle only has down control, up takes place with the valve de-energised via a return spring. This scheme has no rebuildings in terms of this project, but it should be shortly described for understanding the station working principle. So, the machine’s riveting spindle has double-acting cylinder inside, turned down by current (controller signal) and turned up by return spring inside 5/2 valve. Throttle is used to provide smooth up moving. Every machine has its own filter, lubricator, adjustable pressure relief valve and pressure gauge, placed on the one side of machine housing; Baltec uses Bosch and Numatics solutions. This block is connected to the air source and not related to other pneumatic components of the line.

Figure 3.1.1. Baltec machine and it’s pneumatic components
2. Stop gates

Current line has standard pneumatic Bosch VE2 stop gates, which are suitable for chosen conveyor type (choosing the conveyor will be described in chapter 6.2.4). The position of stop gates can be seen from Fig.3.2.1. This is a tilting stop gate, which can be opened without causing wear on the workpiece pallet contact surface. This device stops one or more accumulating workpiece pallets at the defined stop surface of the workpiece pallet. When the pressure is released, the stop gate is closed by a spring and the workpiece pallet is stopped. It can be mounted inside the tracks, directly on the conveyor section [7]. The reversible operation for this type is not permitted, so this component should be changed for both machines, 4 at all.

![Figure 3.2.1. Pushing plate with stop gates](image)

The simpliest way of this part rebuilding is using the ready solution for the reverse conveyor. This is VE2/S or bi-directional stop gate, which is done specially for conveyor sections that are cycled in both forward and reverse. This stop gate has the same size as VE2 and can be mounted inside the tracks the same way, so no other shifts and rebuildings required. It can be mounted on the right or left inner side of a conveyor section and has mounting areas for proximity switches, which are used to monitor workpiece pallet position, either present or clear[7] [8].

It uses 4..6 bar pressure and can stop pallet of different size with up to 140 kg load on it. The VE 2/S can only stop workpiece pallets coming from one direction. When the pressure is released, the stop gate is closed by a spring and the workpiece pallet is stopped. Two VE 2/S stop gates are needed to stop pallets coming from both directions, since pressure must not be exerted on the stop gate by pallets traveling in reverse, this way the bi-directional stop allows pallet pass through in reverse operation. The stop must be actuated down to allow pallet pass through in both forward and reverse operation [7].
Actually, it is not needed to have stop gates for both directions, the problem stayed the on fact that VE2 blocks other direction moving. So using 4 stop gates is enough. As the pallet does not move out, the last stop gate may be VE2 and may have UP position permanently. Thus, the rebuilding requires 3 new stop gates. The symbol diagram is taken from manual[8] and presented in Fig. 3.2.2. Stop gate has single-acting cylinder with return spring.

![Figure 3.2.2 VE2/S stop gate circuit diagram](image)

3. Valves

It is clear from the manual, that stop gate needs 3/2 valve. No trotting or control valve is needed, because the pushing part moving should not be smooth (in the manual this part is also marked as optional). According to Fig. 3.2.2, a 3/2 normally closed valve with direct solenoid and return spring should be chosen.

Based on VE2/S manual, it is known what it has 4 mm push-in fitting and 4-6 bar working range; cylinder stroke length is 20 mm, bore is 35 mm and 0,02 litres per stroke[7]. Flow rate is needed to choose the correct valve. Festo offers equations for SI-units related to flow rate; here a flow rate to extend and retract the cylinder should be calculated separately. These solutions require knowing of cylinder piston rod diameter and areas of extend and retract sides. Bosch manual does not provide this data, so the flow rate will be calculated based on gas flow equation for volumetric flow [9]:
\[ Q = 1360 \times Cv \times \sqrt{\frac{\Delta P}{sg(T)}} \times \sqrt{\frac{P_1 + P_2}{2}} \]  
(3.3.1)

where \( Q \) – volumetric flow in standard cubic feet per hour,
\( sg \) – specific gravity,
\( T \) – absolute flowing temperature, \((F + 460)\),
\( P_1 \) – inlet pressure, psia,
\( P_2 \) – outlet pressure, psia,
\( \Delta P \) – pressure drop, \((P_1 - P_2)\),
\( Cv \) – valve coefficient from tables.

Despite the fact that Festo uses SI units for pneumatic equipment parameters determination, U.S. units will be used to keep the correct coefficients and use appropriate table values.

\[ 1 \text{ psi} = 0,0689476 \text{ bar}, \text{ so:} \]
Inlet pressure 6 bar = 87,0226 psia
Outlet pressure 5 bar = 72,5189 psia (taken based on operating range of 4…6 bar)
During air flow through pipes on a distance in the plant air distribution system, the pressure may drop by 5 - 15 psi. Because of this, it is necessary to require air pressure at the input to be 10-20% higher than the operating pressure. Pressure drop is taken as 20%, or 72,5189 * 0,2 = 14,5038 psia.

Air valves are sized for flow capacity \( (Cv) \) based upon a given cylinder piston size, stroke and travel time requirements. \( Cv \) us actually a flow coefficient that measures the amount of air a device can pass. The following formula can be used for air valve sizing:

\[ Cv = \frac{Area \times Length \times Compression \ Factor}{Pressure \ drop \ factor \times Time \times 29} \]  
(3.3.2)

where:
\( Area \) - effective cylinder piston area, square inch,
\( Length \) - simply the total cylinder stroke distance, inch,
\( Compression \ factor \) - taken from the table based upon supply pressure rating,
\( Pressure \ drop \ factor \) - taken from the table. [10]

Volume of the cylinder is:
\[ V = A \times s \]  
(3.3.3)

where \( A \) – area of piston rod, \( mm^2 \),
\( s \) – stroke length, mm.
Area of piston rod will be equal to:

\[ A = \frac{0.02 l}{20 \text{ mm}} = \frac{20 000 \text{ mm}^3}{20 \text{ mm}} = 1000 \text{ mm}^2 \]

0.02 l = 0.02 dm\(^3\) = 20 000 mm\(^3\)

1 mm is 0.0394 inch, so
1000 mm\(^2\) = 1.55 inch\(^2\)
20 mm = 0.787 inch

Time will be taken as 1 s.

Pressure Drop Factor = 33,5
Compression factor = 6,4

Table values are taken based on supply pressure of 72,52 = 80 psi and pressure drop 14,5 = 15 psi

\[ C_v = \frac{1.55 \cdot 0.787 \cdot 6.4}{33.5 \cdot 1.29} = 0.008 \]

Special gravity of air is 1,000 for normal conditions [11].

\[ Q = 1360 \cdot 0.008 \cdot \sqrt{\frac{14.5038}{1}} \cdot \sqrt{\frac{87.0226 + 72.5189}{2}} = 370,0766 \text{ SCFM} \]

Given value is calculated in standard cubic feet per hour (SCFM). SCFH of gas is measured at 60° F (519,7R) and 14,696 psia. CFH (cubic foot per hour) is measured at any temperature and pressure. Converting the flow rate from SCFH to CFH can be calculated as follows:

\[ \text{SCFH} = \frac{P_{\text{actual}}}{14.696} \cdot \frac{519.7^{\text{R}}}{T_{\text{actual}}} \cdot \text{CFH}_{\text{actual}} \]  (3.3.4)

where:

SCFH - Standard cubic feet per hour,
P_{\text{actual}} - Pressure of gas, psia,
T_{\text{actual}} - Temperature of gas, (°F+460). [9]
20°C = 68°F

T_{\text{actual}} = 68 + 460 = 528

\[ \text{SCFH} = \frac{72.5189}{14.696} \cdot \frac{519.7^{\text{R}}}{528} \cdot \text{CFH}_{\text{actual}} \]

370,0766 = 4,857 \cdot \text{CFH}_{\text{actual}}

\[ \text{CFH}_{\text{actual}} = \frac{370,0766}{4.857} = 76,194 \text{ cu ft/h} \]

Festo equipment flow rate is determined in litres per minute.
1 Cubic Feet Per Hour is approximately 0.4719 Liters Per Minute:

76,194 cu ft/h = 0.4719 \cdot 76,194 = 35,9596 = 361/min
The most suitable valve is Festo MFH-3-M5 valve with manual override. Solenoid coil and socket should be ordered separately. All the technical data is available from the manual. The silencer was chosen from standard accessories and it is AMTE-M-LH-M5. Connectors and electrical accessories are also chosen from standard accessories list – L-push-in fitting QSML-M5-4 (suitable for 5mm valve connection and 4 mm fitting of stop gate) and MSFG-24/42-50/60 24VDC 50 Hz solenoid coil with standard plug socket [12].

An electrically actuated 3/2-way valve controls the single acting cylinder next way: when the valve is actuated, air flows from 1 to 2 (see Fig. 3.2.2); the piston rod of the cylinder is moving to outer position. When the valve is de-energized, it switches back to normal position and the mechanic spring in the cylinder drives the piston rod back.

4. Pushing plate

The inner part of pushing plate is shown on Fig 3.4.1. It consists of oiled rollers, which are connected to the pushing plate above. A cylinders piston rod has a metal attachment, so when the plate needs to go up, it pushes the first roller, which goes between next ones and lifts up the plate.

Figure 3.4.1. Pushing plate inner part

The cylinder used is double-acting, because the fixation of both positions is needed. Other parameter is stroke length, which is about 100 mm for this mechanism. The Borch double-acting cylinder with adjustable cushioning, used in this application, can remain the same. 5/2 MT2H-5/2-4,0-L-S-VI-B valve with spring reset and solenoid is used to control this type of cylinder. Two
silencers are used on ports 3 and 5. Trottles are used on both ends of cylinder to provide smooth moving. Valve terminals 03 VIMP-/VIFB-0,MIDI are used.

5. Air preparation block

Preparation and control of compressed air is required to protect the pneumatic equipment and ensure the long life of machines. The air goes through multiple devices during the work of pneumatic system and takes oil, moisture and small particles in. The purity of air used increases both the running performance and the efficiency of pneumatic systems.

Air preparation systems usually include the following components:

- **Air filter.** The air filter provides removing of particulates and moisture separation. This insurer proper operation of the full system and reduces wear on mechanical parts. The air filters often include manual, semi-automatic or automatic drains to remove trapped liquid that has been separated from the air. [13]

- **Regulator.** Each pneumatic system has an optimal operating pressure (6 bar, according to Autoliv standard) and exceeding this pressure results in excessive wear and may damage equipment. Regulators are used to maintain a suitable outlet pressure regardless of the inlet pressure and flow rate requirements. Although higher pressure than required may make the machine run faster, it can cause excess wear and tear due to the banging caused by fast cylinder motion.

- **Lubrication System.** Lubricant (oil) using as an additive to a compressed air helps to reduce friction and wear.

- **Safety Valves.** The air preparation system should start with a manual shut-off relief valve to remove air in case of maintenance. For additional safety, it is also required to dump the air during an emergency stop. For this purpose, a soft start valve is used, it dumps air when power is shut off. The soft start valve also keeps the pneumatic equipment from damage when air is applied. [13]

Air preparation block can also remain the same. It is one of Festo standard completations - LFR-1/4-D-MIDI-KG (1,370 l/min flow measured at p1=10 bar, p2=6 bar, Δp=1 bar), which is now out of use (the current available version is MS)[14], with standard accesories set. It provides two outlet air connections for compressed air supply. It includes:
• Manually actuated on-off valve HE-...-D-MIDI C843,
• Filter regulator with 40 µm grade of filtration, lubricator and manometer block LFR-D-MIDI C843,
• 3/2 normally closed on-off valve with solenoid coil 24V DC HEE-....-D-MIDI-24 C843,
• Pneumatically actuated soft-start valve HEL-D-MIDI C843,
• Branching module,
• Pressure switch [14].

Figure 3.5.1. Air preparation block and it’s scheme

6. Scheme

The principal scheme of rebuilt pneumatic part is located in Graphic material 9.9. It includes: stop gates and pushing parts scheme, air preparation block scheme and Baltec machines pneumatic scheme. Stop gates and cylinders fir pushing plates are connected to the same air preparation block and use same Festo wiring. The last stop gate was not included, because it will have permanent UP position, therefore, it does not need air supply. Batec schemes are general; they are needed to show the correct output for controller – DesignSpark automatically generates I/O numbering which is easy to follow. Air preparation block scheme takes much space and it was separated from the main one to make scheme symbols and connections more clear. Component’s list with component name and its designation in the scheme are given in the end of scheme set.
4 ELECTRONICS

Autoliv has a separated standard for choosing the electrical components – E1434063 „Components list applicable for AEU Suppliers and AEU Plants“ [5] (last revised in 2014), which determines suppliers and product groups according to necessary main parameters like voltage, working range for sensors, sizes etc. These parts are combined with each other and usually do not need additional intermediated parts like adapters, voltage converters and so on. Some components have been removed from production and replaced by newest versions (for example, buttons); these versions can also be used, if their technical parameters allow to connect them with other line components to provide the same functionality.

1. Buttons

New station needs several buttons to control its work:

- Start button – this button starts work inside the workstation. It is used after emergency stop or simple stop, to turn the electricity and air supply on.
- Stop button – this button stops the station. It is used in case of some troubles in station work and stops inner work in workstation, but does not reset the electricity and air supply. It also does not reset sensor parameters.
- Reset button – this button resets the workstation parameters to initial ones. It can be used after stop button.
- Emergency stop button – in case of emergency (risk for injury for operator, breaking the machine or some trouble in work flow – for example, detail gets stuck in the machine) operator should press this button immediately. This button stops all the processes inside the workstation. All the parameters and outputs go to initial position. The pneumatic air supply is also off.
- Operator’s button – this button is needed to start the conveyor work. After placing the bracket on the detail, operator presses the button and the pallet starts to move. This button is used at the beginning of each cycle.

According to the standard, all the buttons which are used to start and control the process have normally opened contacts – this means that function will be started after pressing the button and...
closing the electrical chain. Stop and emergency buttons are normally closed – they will break the chain and stop the machines after pressing.

Initially every Baltec station had its own set of buttons, which included start and stop buttons, emergency stop, button for changing the model (by turning this button operator can choose, which model is in work – left or right handed) and one button for choosing additional model parameter, which is out of use in current station work. Now the workstation parts are close enough to each other and turned by 90 degrees, so it will be more comfortable to have 1 set of buttons close to operator, which will work synchronously for both machines. This solution will satisfy ergonomic standard. As the operator does not change his posture, all the buttons will be placed in front of first Baltec frame. It is possible to do stop/reset buttons separately, but it creates more additional loops in program and actually is not needed – in case of trouble inside one of the machines, the work of the second one has no sense. The operator’s button remains the same.

Figure. 4.1.1. Current button set

All Norma workstations use Telemecanicue (Scheindler electric now) buttons for manufacturing process control and Baumer capacitive proximity sensors as operator’s buttons. The last one is easy selectable – proximity sensors are enough cheap, compact and have more flexibility to position – they can be locked even on the conveyor frame. Operator’s button can be taken from current 180 station, which goes before riveting. It is Baumer CFAM 18P1600 S14 capacitive proximity sensor, normally opened, with 8-mm operating distance [15]. One of emergency switches from current workstation can also be used for the new one – they have HALJ 174H49 normally-closed model from Telemecanicue – despite the fact that now this model is out of stock. In future it can be replaced by its newest version HALK178, which have similar parameters and same certifications[16].

The set for start, stop and reset button should be replaced. Based on Autoliv standard, the buttons were taken from the same supplier. New station includes 3 buttons, usually they have LED lamps inside to show which button is active. Start and reset functions should have normally open contact, while stop button is normally closed – this choice is suitable in terms of other station components working principles. XAWF310EX is in stock now and it was chosen. It has 3 flush buttons with green,
red and black lights. The contacts go NO-NC-NO respectively [17]. Compact size and comparability to other electrical parts make it suitable for the project.

2. Safety door switches

Safety door switches are placed inside the frame, they are used to detect when mechanical guards are closed. The operator unlock the switch by opening the door, this leads to disabling the system from starting unexpectedly. After finishing operations inside the machine he removes the switch into initial position. The system remains off until the operator does work and locks the door again. This provides operator’s work safely in the hazardous area.

There is no sense in changing the current switch to the new one, so it remains the same. It is Schmersal AZ 16-02ZVRK model, which is in normally close state [18]. It has high level of contact reliability with low voltages and 0.7A operating current. Screw connections make it easy to place on Bosch profile or plexiglass door wall.

3. Sensors

Current station has a lot of sensors to detect and keep track of pallet movements through the workstation for further operation control. The rebuilt station should keep the necessary inputs to remain the production process correctly and have some additional control points according to the changing of working algorithm. Current sensors, which remain the same, include next 3 parts.

4.3.1 Pallet position detection sensor

Every stop gate has a proximity sensor in front of it. These sensors are used to detect exciter plates on the sides and bottom of workpiece pallets to switch the correct stop gate on. As pallet goes right over the sensor, the working distance is enough small. As the idea of detecting function does not change, same sensors may be used for the new stop gates. PEPPERL+FUCHS NBN4-12GM50-E2-V1 sensor is used, with 4mm working distance and 10-30 V operating voltage [19]. This normally open, 24 VDC, short circuit protected switch is PNP (sourcing) and has a 12 mm threaded body. Normally open switching function means that sensor is not active till the pallet reaches it – in that case the
connection closes and high signal goes to controller. 4 sensors are needed to fix 4 positions. Bosch mounting kit should be used to position proximity switch at the stop gate. SH2/UV part is used in given application, which is compatible with given sensor. The switch bracket can be used to fix an M12x1 sensor in place for sensing of the workpiece pallet position from below.

4.3.2 Plate position detection sensor

Every lifting unit has 2 sensors, which detect the plate position. Sensors are placed from both sides of the plate; when it is up, signal is off (no metal plate within sensing range), when it is down, signal is on. Actually, the working principle is the same as for previous sensor, only operating distance differs. 4 sensors are needed for both plates. BES 516 325 BO-C-PU-05 model from Balluff is used [20]. It also has PNP, NO output function, but operating distance is 2 mm. 24V DC operating voltage makes it easy to connect with other equipment. Mounting holes are located inside the lifting unit.

4.3.3 Baltec sensor

Every machine has a rotation sensor inside, which detects the rotation of riveting stroke [6]. It is used to detect when the riveting has finished, so taken signal is used to finish the controller work (see chapter 7.2). There is no available data about sensor model, but as soon as it is programmed through its own controller and this program does not correlate with rebuilding one, this data can be out of scope.

According to changed algorithm, a pallet position should be fixed, when pallet goes out of station after both rivetings, to stop the conveyor reverse moving. Also, is necessary to check the detail position on the pallet, to prevent the situation when operator forgot to place the bracket or detail got stuck inside the machine; this control is necessary to provide in both the machines.

4.3.4 Sensor for pallet last position

This sensor will be used to detect the pallet, when it goes out from the second riveting machine to the operator. Operator’s conveyor side is equipped with drive unit (see chapter 4.5.1), which blocks the sensor placement on the conveyor, so it will be placed on the additional fixing plate. It should
also have PNP, NO output and 24 V DC voltage. One of Norma existing solutions, which fulfill these requirements and electrical standard, is Contrinex DW-AS-503-M12 sensor [21]. It is located on the edge of one line’s conveyor and detects pallet position on the turning unit. This sensor has 6 mm operating distance, which is enough for chosen purpose, as the switch can be placed close enough to the pallet.

4.3.5 Sensors for detail detection

According to the last standard for new lines programs, checking the position is not enough to proof the correct work and eliminate operator’s mistakes, so checking the detail presence on the pallet is also important. Standard proximity PNP NO sensors can be used for this purpose, because both detail and bracket are from metal. Sensor should be placed in the middle of the pushing plate, perpendicular to it – this will guarantee that this solution will work for both positions. As the pushing plate goes up, sensor cannot be mounted directly on the conveyor edge; also, there is about 2 cm distance between bracket side and conveyor edge. So the operating distance should be min. 50 mm. Taking into account suitable Autoliv suppliers, SICK sensor solution can be used. IQ80-60NPP-KK0 inductive proximity sensor is the most suitable: 10-30 V DC operating voltage, 60 mm sensing range, PNP and NO functions and compact size make it an ideal solution [22]. Mounting plates are also available from the supplier.

4. Lamps

Signaling or stack lamps are needed to show the current state of workstation. Current stations do not have indication lamps, so new ones should be chosen. Standard requires usage of Scheindler electric LED lamp solutions. Here 2 lights are needed: green for showing the station correct work and red for mistake. Red light may be flashing, but it is not necessary. Buzzer for this station is not needed, because operator will pack the ready detail while new one is in work, so he will be near the station and can see the trouble. 24 V operating voltage is suitable, because this voltage is used for other parts also. Another parameter is type of mounting; vertical mounting is more flexible, it can also be placed on the operator’s eye level, while horizontal mounting requires placing on the top of the frame. Based on this, XVMB2RGSB indicator bank was chosen [23].
5. Drive unit

Autoliv uses standard Bosch conveyor solutions, so the most preferable way to rebuild the conveyor is using standard conveyor parts. They include conveyor profile with belt (see chapter 6.2.4) and two transverse parts from both sides. These parts are drive and return modules. Current conveyor type is a transverse conveyor with silly belt. Transverse conveyors are designed to transfer pallets for short transport distances and also suitable for cycle-independent workstations. Standard transverse conveyors are reversible. As speed and other parameters of the conveyor are not planned to be changed, current drive unit may be used. It is AS2B/M module [7]. Module motor powers the conveyor belt. AS2B/M has the gearbox mid-mounted, between the rails, which makes the solution more compact. Module set already includes all the necessary hardware to mount it to a belt conveyor section. Official manual from Bosch contains module drawings [7].

Current and preferred transportation speed is 12 m/min or 0,2 m/s on conveyor sections and transfers. The way pallet goes to one side is approx. 1,5 m (see chapter 6.2.4), which gives total 3 m for both sides moving. Using the preferable transportation speed gives 5,95 s till second pallet position (near the conveyor end), 3,84 s to the first position and 2,085 s till the operator – 11,9 s at all, two rivetings give 5 s, and lifting unit moving takes about 1 s to each side – 4 s for both machines. The total cycle time will be 21 s. Nominal speed can be increased to 15 or 18 m/min [7], but workstation is the last step and operator will not wait the end of riveting cycle, so this speed can remain. The voltage and frequency converters are already in scope.

Workpiece pallet should be moved toward a drive unit. In normal operation, the maximum load capacity for transverse conveyors is 60 kg forward and 30 kg in reverse; the conveyor will move one detail per cycle, so this capacity is suitable[7].

Motor also requires contactors for switching forward and reverse [24]. These contactors are taken from Schneider Electric, based on motor 0,55kW power and operating voltages:

- Forward moving contactor LC1K09106BLS207, NO contact [25]
- Reverse moving contactor LC1K09016BLS207, NC contact [26]
5 CONTROL

1. Baltec controller RC10

Baltec machine has its own RC10 controller [27] to provide the control of riveting process. Riveting machine control RC 10 comprises a basic unit with modules for different levels of configuration. It has 50 Hz and 120/230 V operating parameters, with 24 VDC output.

The control is fitted with a straightforward operating and display panel layout. All operating elements necessary for the operator are arranged on a front-mounted sealed keyboard. The LED-display provides information to support the operator. Riveting time is set as 2.5 s according to production technology of chosen detail. All the technical data is available from the manual, which is absent in open sources and was provided by the supplier.

In principle, the riveting procedure comprises two functions: the operation of the spindle motor and the operation of the riveting spindle. The duration of the riveting procedure is normally defined by the riveting time. Two modes of operating of the spindle motor can be selected in setup: switched on continuously or switched on only during the riveting (parallel to the riveting spindle). The riveting procedure is active all the while the input "Riveting activation" is active. The riveting procedure is active during the programmed riveting time. Several safety modules (SIMOD) are available for activating a riveting operation:

- SIMOD AM for riveting activation via a single control contact (manual switch, footswitch, external control), only continuous activation,
- SIMOD AMS, as for AM but with bypass facility (pulse activation, bypass initiator),
- SIMOD 2HMR for riveting activation with two-hand control, only continuous activation,
- SIMOD 2HMRS, as for 2HMR but with bypass facility.

The riveting time only expires after reaching the initiator "End position". The end of riveting is determined not by the riveting time but by means of a limit switch (μCom).
The control unit is connected to the mains supply via the feed cable. The controller input should be connected with the main controller to activate the riveting function. A supplier said that RC 10 controller does not propose this type of control—it works separately by activation by foot-switch or two-hand button. So, the connection with the new controller will be provided through a switching relay, which will activate the RC10 controller after getting the signals from appropriate sensors. This is done for both the machines.

5.1.1 Relay

Relays use an electromagnet to operate movable contacts from an open position to a closed position. For this application, 2 simple NPN relays are needed to switch the machines separately. Controller has 24 VDC input with max. supply cable back-up fuse 16 A and uses 50/60 Hz frequency and 120/230/400/440 V AC range. Based on standard, Siemens relay from SIRIUS 3RS18 series can be chosen. This type of coupling relay is available for electrical isolation, amplification and signal adjustment between the controller and I/O. 3RS1800-2AP00 works in given range and has 1 coupling channel [28]. The type of terminal was chosen as spring instead of screw. Screw type relays may loosen, especially if there are vibrations (AC power is already a reason for vibrations, and conveyor may give additional vibrations), or significant temperature changes. Another issue is unappropriated connection. Loosen of a flexible cable after some time is also possible. All these risk factors may lead to end-up in down-time, which leads to troubles and production loss. Spring-type helps to avoid these risks.

2. Controller

Autoliv E1434063 standard determines Siemens as a standard for CPU. Siemens offers a wide range of controllers, where SIMATIC S7-300 universal controller series is mostly used in Norma applications. This series is suitable for low and medium applications and usually it is used for full line control; according to current plan, it can be used for other line parts or future additional rebuilding. Siemens remains the standard for safety belt production control since its controllers are powerful, flexible, compact and cost-effective, also they are built of separate modules and can be
expand if needed. Parameters can be configured in the TIA portal. Number of supported inputs and outputs is up to 65536 discrete / 4096 analog channels. The main features of the controller:

- local and distributed input-output application;
- communication capabilities via MPI, Profibus Industrial Ethernet / PROFINet, AS-i, BACnet, MODBUS TCP;
- real-time work functions;
- hardware and software errors processing functions;
- ability to use distributed I/O structures and simple inclusion in various types of industrial networks.

S7-300 have a modular design and allow the use of:

- CPU module (CPU), designed to execute the user program and control all the nodes.
- Power supply module (PS), which allows the controller to be powered from the network of 120/230 V or from a source of 24/48/60/110 V.
- Signal modules (SM), designed for I/O digital and analog signals with various electrical and time parameters.
- Communication processors (CPs), designed to connect the controller to PROFIBUS, PROFINET, Industrial Ethernet, AS-Interface, Internet or PtP (point to point) connections.
- Function modules (FM), capable of independently solving problems of automatic control, positioning, weighing, high-speed signal processing, etc. FM are equipped with a set of built-in I/O channels and are able to perform information processing at their local level, which allows reducing the load on the CPU of the controller.
- Interface modules (IM) that provide the ability to connect one or more of expansion racks to the base unit (CPU rack).
- SIPLUS modules for extended environmental conditions.

Signal modules and communications processors can be connected in any way without restrictions. The system configures itself.

5.2.1 CPU

There are several CPU compatible with Siemens S300 series, including standard applications and applications with additional possibilities – for example, compact models with build-in I/O modules. As there are no special requirements to control, standard CPU is enough. Next step is determining
the size of plant. Actually, it has several machines and can be determined as small, but due to the plans of using given controller to other line parts control, medium plant CPU is more suitable. Two CPUs are suitable in this case, which differ by communication type: one has only PROFIBUS DP, while other has PROFINET IO possibility also. It is preferred for Norma to use PROFINET, so CPU 315-2 PN/DP is the best choice. The production code is 6ES7315-2EH14-0AB0, 24 VDC, 12Mbit/s. It has 384 KB work memory and needs micro memory card to be implemented [29]. 6ES7953-8LJ31-0AA0 512 KB micro memory card is used [30], it provides the using of 1024 function blocks in programming, which is enough for given application.

5.2.2 Power supply module

Siemens has several power supply module types. They are needed to convert the line voltage of 120/230 AC to 24V DC controller operating voltage. This voltage is also used to supply sensors and actuators. They vary by output current – 2, 5 or 10 A. Module contains:

- Output voltage indicator.
- Line voltage selector switch - it allows to select a line input voltage of either 120 V AC or 230 V AC.
- On/off switch for 24 V DC output voltage.
- Terminals to connect cables for the network input voltages, the output voltage and the grounding conductor.

Based on CPU datasheet, its current consumption is 750 mA, so 2A is enough. But other devices also will use this supply, so taking 5 A block is wiser. PS307 (6ES7307-1EA01-0AA0) block is the most suitable solution [31].

5.2.3 Signal modules

Signal I/O modules are used to collect inputs and outputs for further processing for flexible adaptation of the controller to the respective task and making a connection between sensor and actuator signals. For the full station control, 20 digital inputs and 11 digital outputs (see chapter 7.1) are needed. Now Festo I/O modules are used, but it is better to replaced them by Siemens standard solution, which provides flexible process connection and compact design. The modules
are mounted on the DIN rail, and connected to the adjacent modules by means of bus connectors. There are no slot rules, the addresses of the inputs are determined by the slot.

Available number of slots in the module may be 8, 16, 32 or 64. 20 inputs need 32-input block, while 11 outputs may use 16-input block. If the line becomes wider, modules can be added. Next modules were taken from standard S-300 supply:

- Digital inputs: 6ES7321-1BL00-0AA0 from SM 321 series, 32 DI, 24 V DC [32]
- Digital outputs: 6ES7322-1BH10-0AA0 from SM322 series, 16 DO, 24 V DC [33]

### 5.2.4 Communication processor

To connect a CPU with PROFINET to get the model bit address (see chapter 7.2), additional module is needed. 6GK7343-1EX30-0XE0 from CP 343-1 series was chosen [34]. It is used to connect a control unit to Industrial Ethernet via ISO and TCP/IP, PROFINET IO controller or PROFINET IO device. It has integrated 2-port switch ERTEC 200 and communicate with S7 software. Possible functions: fetch/write, send/receive with and without RFC1006, Multicast DHCP, NTC- CPU Sync, diagnostic, initialization via LAN, 2x RJ45 connection for LAN with 10/100 Mbit/s.

### 5.2.5 Function modules

Function modules are used to suit the most varied tasks. They independently execute the technological tasks like counting, measuring and motion control. This way they reduce the load on the main CPU, in cases, where a high level of dynamic response and accuracy is needed. Although using, for example, counting module may reduce the size of the main program, it will increase the cost of rebuilding and give no win in terms of cycle time. Currently there is no need in this type of modules.
5.2.6 Interface modules

Interface modules are needed to connect expansion racks to the main unit. Now there is no need to expand the system, so this module can be added later, now it is out of scope.

3. Accessories

Standard accessories like wirings, mounting kits etc. from suppliers are used to connect parts between each other. Mostly they remain the same or taken directly from Autoliv storehouse (for controller parts, as S-300 is mostly used and parts from old or rebuilt lines are available). This part is not important in terms of rebuilding process and will be out of scope.

4. Scheme

The principal scheme of rebuilt electrical part is located in graphical material, 9.9. All the parts are connected to the same Siemens controller, excluding conveyor part and Baltec machines – they use plant voltage. Plant voltage source, step down transformers, circuit breakers, thermal switch and fuse were excluded from choosing, because these parts are already determined by the plant and not connected to the rebuilding process. CP is also not included in the scheme, as it does not work with components directly, but only provides data communication. I/O modules are marked in the line diagrams and not included in the control scheme to save the space. Component’s list with component name and its designation in the scheme are given in the end of scheme set.
6 3D MODELLING

3D modelling is one of the most important parts of the rebuilding, because it is related to ergonomic standards, which should be fully observed. Modelling includes creation of new parts and parts which remain the same – these drawings are needed to take into consideration sizes of parts and distances between them. As now the detail is taken from previous station by hand, it is necessary to consider its weight and distance between stations. It is important to check ergonomic parameters like height of the station, distance to components etc. due to the fact that standards were reviewed since the station was created.

3D model must be created according to the next rules:
1. Simplicity is on the first place. Number of details should be possibly small and created so, that one detail can have several usage possibilities.
2. Production operations should be possibly cheap and easy.
3. Drawings should be understandable and contain all the necessary information.
4. Dimensions should start from exact points/surfaces.
5. Correct tolerances and roundings should be used.
6. If functional rules are kept, the weight of detail can be lowered. In this case, the cost of production also reduces.
7. Standard approaches can be used if possible.
8. Angles should be rounded (straight angles can hurt worker).
9. Detail parts should have the same thickness if possible.
10. Distance between holes is enough to do them at the same time.

NX 10 software was used for modelling [35].

1. Parts which remain the same

In terms of CAD design, most of the parts remain unchanged. These parts were done roughly, taking into account mostly gauge dimensions. CAD models of Baltec machine and electronical components were taken from the suppliers. These parts do not need separate drawings.
6.1.1 Baltec riveting machine

Baltec model includes:

- Riveting machine itself,
- Plate for machine,
- RC 10 controller,
- Plate on which controller stays on,
- Lamp,
- Oiling system for Baltec,
- Wiring.

Baltec model with accessories was taken from the supplier site and changed to keep the necessary sizes, oiling system was added separately. Filter and lubricator are supplier parts, mounting was created based on gauge dimensions of existing one. Wirings are out of scope. Final model is on Fig. 6.1.1.1. Machine model does not need ergonomics control. This part requires correct positioning inside the frame: the position of riveting unit affects on pallet position – therefore, on position of stop gates, SICK sensor and lifting unit. As the solution does not require inner shifts and rebuildings, the correct position was determined by measuring the needed distances inside the current frame. Position of other inner components will be determined according to Baltec position.

Figure 6.1.1.1. Baltec model
6.1.2 Riveting unit fixing plate

This plate is placed on the riveting unit end and it is used for detail fixing. This part was created on Norma and does not belong to main Baltec accessories set. Attachment was created according to real device measurements and fixed by reuse examples bolts.

6.1.3 Foundation plate

8-mm steel plate is used as a foundation for Baltec machine inside the frame. It is placed into profile connector spaces and also connected with Baltec plate by mounting plates.

6.1.4 Conveyor mountings

Mounting plates are used to fix the conveyor position. 3-mm steel 90-degree flanged joints are used for this purpose. They connect conveyor edge with Baltec foundation plate. Conveyor profiles are fixed between each other by motor unit from one side and drive unit from second one. Dimensions remain the same as real.

6.1.5 Lifting unit

Model of lifting unit is a bit complicated (see Fig. 3.4.1), it includes cylinder, set of sensors, oiled rollers, lifting plate, mountings and connections.
In terms of rebuilding design, it is necessary to know its length, including cylinder length, and position according to Baltec fixing plate. So, the model was simplified (see Fig 6.1.5.1) to keep gauge dimensions correctly. Plate position sensor models were excluded as they are built up into the plate part, this does not affect on size. Wirings are out of scope. Position of the plate was kept as the real one.

Figure 6.1.5.1. Lifting unit model

### 6.1.6 Frame

It was decided to remain frames the same, because creation of new one gives no win in terms of size and ergonomics, but increases the rebuilding price a lot. Current frame of machine consists of Bosch 30-mm profiles with 45x60 mm profile legs and plexiglass walls. Profiles are connected with inside-inside gussets and corner connectors. Every frame has 3 walls and one door, which also uses Bosch accessories – standard handle and hinges. 2 walls have orifices for conveyor. Frame drawings are the same as real device and they are represented in graphical material, 9.6, 9.7. Main parameters which should be checked are height of orifice and width of frame. First one determines the height of working table, second one is needed to calculate the distance to buttons. These parameters were measured and now they are next:

- height from the floor to orifice is 760 mm. Considering the conveyor profile height of 95 mm, Baltec plate height of 100 mm and pallet height of 28 mm, the working height is 983 mm. Height of the detail gives additional 40 mm. Suitable height for work should be 980-1080 mm [4], so the ergonomic standard is kept.
width of the wall side with orifice (this side will be placed in front of operator) is 750 mm. Based on standard, height of touch panel is between 1400 – 1780 mm [4] and buttons should be easy to reach. Also, distance to parts used infrequently is 415 mm. The orifice takes 440 mm from the left side (considering two 30-mm profiles), so the distance from operator’s place to the right profile is 750 – 440 = 310 mm. There are no obstacles for placing the buttons, so height can be taken as 1600 mm from the floor, and all the distances are suitable for ergonomic standard.

Figure 6.1.6.1. Frame model

2. New parts

6.2.1 Additional table

Additional plate was meant to be used for putting the ready production. This will reduce the cycle time – after the first detail production, at the beginning of each station cycle operator can take the ready detail, put it on additional table, place next detail on the pallet and start the operation; during the riveting he has a time to check the product visually and pack it. The most suitable place for additional plate is free space near conveyor: it is wider than conveyor, so detail can be placed freely.

Size

340 mm width is taken according to the free space near the conveyor. Length of the main surface for detail is determined as 260 mm: pallet length is 240 mm and detail takes about half of it, so 260 mm is enough to freely place one detail or put two together. Connection flange length is taken as 140 mm – approximately the same as the return unit height (see drawing 9.4).
Detail production

As one of widely used Norma solutions, this detail may be done from sheet metal (stainless steel) by bending as a common and vital process in manufacturing. Usually bending changes only the shape of the work piece, while the volume of material and thickness remain the same. At the same time, in addition to creating a desired geometric form, bending is also used to impart strength and stiffness to sheet metal (this increases a moment of inertia), as it creates both compression and tension inside the material. [36]

Bending is provided by press located at Norma, which reduces rebuilding costs and time, so here is no need to choose the type of bending press, pressing force etc. Press allows to bend stainless steel plates by 90 degrees with thickness up to 5 mm, using thicker material is not possible. Minimum thickness used at Norma is 2 mm, this one was taken. Holes for connection should be done by laser cutting. M6 T-bolts are used to connect 30 mm profiles with other parts, so 6,2 mm holes are created.

For given case, main plate bending and edge bending will be provided. Edge bending will give additional stiffness and eliminate sharp edges. Some parameters should be checked before the process.

One of the parameters is a minimum bend radius. The tensile strength of metal fibres increases when the ratio of the bend radius to the thickness of sheet \((R / t)\) decreases. If this ratio decreases beyond a certain limit, the surface of material starts to crack. This limit is called minimum bend radius for the material and is related to inner radius. Minimum bend radius is generally expressed in terms of the thickness of material. This is a standatized parameter and can be estimated using special tables. For soft steel it is 0,5t, which gives the minimum radius equal to 1 mm [36]. But one of the bending rules for given press is that bending radius must be at least the same as the folding material thickness or more. Bending radius was determined as 3 mm, because this radius was generated automatically inside NX software for detail with chosen parameters.

Another parameter is called bend allowance. The bend allowance is the length of the neutral axis in the bend. This determines the blank length needed for a bent part, or correct flat pattern. The BA can be estimated by the next equation:

\[
L = \alpha \times (R + kt)
\]

(6.2.1.1)

where, \(L\) - bend allowance, mm,

\(\alpha\) - bend angle, radian,
$R$ - bend radius, mm,

$t$ - thickness of sheet, mm,

$k$ - constant, whose value may be taken as $1/3$ when $R < 2t$, and as $1/2$ when $R > 2t$. [36]

In given case, $\alpha = 90$ degrees = 1,571 radians, bend radius is 3 mm, sheet metal thickness is 2 mm and $k$ is taken as 0,33.

$L = 1,571 \times (3 + 0,33 \times 2) = 5,749$ mm

This length will be rounded to 5,8 and added to the detail width.

Bend deduction is a parameter closely related to bend allowance. It determines the gain of total length in the part due to the bending, in other words, the amount of material which should be removed from the total length to get the correct flat pattern. This parameter will be taken into account as a minimum flange length. The flange lengths are always measured to the apex of the bend. Bend deduction is determined as [37]:

$$BD = 2(R + T)\tan \frac{\alpha}{2} - BA$$ (6.2.1.2)

Taking the same parameters as for previous calculations, BD will be equal to:

$$BD = 2(3 + 2)\tan \frac{90}{2} - 5,749 = 4,251$$ mm

**Strength calculations**

Assembly mass depends on car type and varies between 520-550 g. For calculations it will be rounded to 600 g. Force which will affect on the plate is:

$$F = Q = mg$$ (6.2.1.3)

where $m$ – detail mass, kg,

$g$ – gravitational acceleration, m/s$^2$.

$$F = mg = 0,6 \times 9,81 = 5,886 \, N,$$ or $0,005886$ kN. This is a resultant of a distributed load.

The width of the detail is 120 mm or 0,12 m and the length is equal to the pallet length – 240 mm.

The position of detail may vary – it depends on operator; also, the weight of the detail is not the same in every point. For simplifying the calculations, the load will be taken as distributed and will be placed in the middle of plate. Plate construction for calculations will be simplified and replaced by clamped beam with rectangular cross-section.
The impact on parts, structures and elements of mechanisms can be set by distributed loads, measured in kN/m. The resultant is equal to distributed load affecting on length of the load [38]:

\[ F = Q = q \cdot l \]  
(6.2.1.4)

So, distributed load can be calculated as:

\[ q = \frac{Q}{l} = \frac{0.005886}{0.12} = 0.04905 \, \text{kN/m} \]

Now it is necessary to build diagrams of support reactions and calculate internal efforts and movements. The diagram is shown on Fig. 6.2.1.1. Detailed calculations can be found from Appendix 2. [39] [40]

![Figure 6.2.1.1. Reaction diagram](image)

Calculation results are next:

**Reaction of supports:**
- \( Ra = 0.005886 \, \text{kN} \);
- \( Ma = -0.000756 \, \text{kNm} \).

**Internal efforts:**
- \( Q_{\text{max}} = 0.005886 \, \text{kN} \);
- \( M_{\text{max}} = 0.0007564 \, \text{kNm} \).
Movements:
θ_{\text{max}} = 5,213e^{-5}\text{ kNm}^2/\text{EI};
w_{\text{max}} = 1,086e^{-5}\text{ kNm}^3/\text{EI}.

The maximum moment in the beam is M_{\text{max}} = 0,0007564\text{ kNm}. For this value, the rectangular cross-section of the beam can be checked.

Bending strength condition is [41]:

\[ \sigma = \frac{M_{\text{max}}}{W} \leq [\sigma] \quad (6.2.1.5) \]

where \( M_{\text{max}} \) – maximum moment in the beam, kNm,
\( W \) – cross-section ratio, m^3,
\([\sigma]\) – allowable normal stress for chosen material, MPa.

A rectangular cross-section has the ratio of the sides [43]:

\[ W_z = \frac{bh^2}{6} \quad (6.2.1.6) \]
\[ W_y = \frac{hb^2}{6} \quad (6.2.1.7) \]

where \( h \) – height of the cross-section, m,
\( b \) – length of cross-section, m.
\( h = 0,002\text{ m}, b = 0,34\text{ m}, [\sigma] = 138\text{ MPa} \) for chosen steel [42].

\[ W_z = \frac{0,34\cdot0,002^2}{6} = 2,267e^{-7}\text{ m}^3 \]
\[ W_y = \frac{0,002\cdot0,34^2}{6} = 3,853e^{-5}\text{ m}^3 \]

The maximum normal stresses are:

\[ \sigma_z = \frac{0,0007564\cdot10^3}{2,267e^{-7}} = 3,337\text{ MPa} \leq 168\text{ MPa} \]
\[ \sigma_y = \frac{0,0007564\cdot10^3}{3,853e^{-5}} = 0,02\text{ MPa} \leq 168\text{ MPa} \]

It is seen that the stresses are more less than critical, so 2 mm thickness is enough.

The maximum tangential stresses for a rectangle are [44]:

\[ \tau = \frac{3\cdot Q_{\text{max}}}{2\cdot A} \quad (6.2.1.8) \]

where \( Q_{\text{max}} \) – maximum load, kNm,
\( A \) – beam cross-section area, m^2.
\( \tau = \frac{3\cdot0,005886}{2\cdot0,002\cdot0,34} = 0,013\text{ MPa} \)

It can be concluded, that 2 mm steel plate is enough for retractor assembly support.
6.2.2 Lightning

Now the workstation needs separate lightning. Choosing a suitable lightning prevents premature fatigue, improves concentration and reduces the risk of errors. There should be no glare and reflection on the workstation, free of shadows and flickering, do not create strong contact with operators eyes and follow an ergonomic standard. The main parameters for choosing a lamp are:

- **height** – according to Bosch frame standard, distance between the table top and light should be 1.25m [45],
- **lightning strength** - following values should be fulfilled: assembly of large components needs 300 lux, assembly of smaller components/computer work - 500-700 lux, precision work 1000 lux. For given type of work 700 lux is enough [4].
- **light fixing** - Bosch 30x30mm profiles will be used to fix the lamp – it is same profile type as frame. Standard gussets are used to connect them between each other. According to needed height and lamp placing (in the middle of pallet position), next profile lengths were used: 435 mm, 220 mm, 690 mm.

Usually data sheets present light strength in lumens, not in lux. One lux is equal to one lumen per square meter. Based on this, the luminous flux $\Phi_V$ in lumens (lm) can be calculated as [46]:

$$\Phi_V = E_v * A$$  \hspace{1cm} (6.2.2.1)

Where

- $\Phi_V$ - luminous flux, lm,
- $E_v$ - illuminance, lx,
- $A$ – surface area, m$^2$.

The minimum working area is taken as:

- Length: 825 mm (0.825 m) – station width
- Width: 280mm (0.28) – return unit length

$$\Phi_V = (700 + 300) * 0.825 * 0.28 = 231 \text{ lm}$$ ,

where additional 300 lux are taken as ambient light.

This value will be rounded and taken 2 times more – 460 lm, to take into account lighting of space around the station. Given value is minimum needed; actually, manufacturing light is supposed to light larger areas, so the minimum value is around 1000 lm. As Norma do not have strict rules about light manufacturer, this choice is free. The light was chosen from the local supplier, and it is V-TAC G-SERIES 18W 1440 lm manufacturing light [47], which uses plant voltage. It already has mounting plates.
6.2.3 Plate for button fixing

New set of buttons will be placed on left side from operator – this makes it closer for emergency case, aslo this standard was taken for all the line. M6 T-bolts are used to connect details with profiles, so 6,2 mm holes are needed for connection. Production technology is the same as for other components – laser cutting on 2-mm stainless steel plate. Height of placing, according to the standard, is 1400-1780 mm from the floor [4]. 1400 mm were taken from the floor till the lowest button. Emergency button and button set are separate parts, both of them have connection holes in the middle of the back side. According to the real measurements, these holes were placed in the middle of fixing plate. (see drawing 9.2)

![Figure 6.2.3.1. Button set](image)

6.2.4 New conveyor

Length

TS plus solution for conveyor is used. Two units from both side are 280 mm each and give totally 560 mm. Conveyor width is determined by the size of the workpiece pallet – 240 mm for given case. Maximum payload depends on the length of the load-bearing edge of the workpiece pallet – about 30 kg for 240x240 mm pallet. In given case, maximum payload will be equal to one pallet with attachment and detail, which gives about 1,5 kg and much less than critical. ST2/B conveyor section is suitable for payloads under 30 kg. Despite on that, ST2/B100 will be used. The difference between these two is in profile height – B100 is 20 mm higher. The same profile is used for the full R23L line. Changes in profile section will lead to change of lifting unit position, so missed 20 mm require additional plates or other inner rebuilding. The 10 mm T-slot in each side and the bottom of the aluminum belt profile allows conveyor modules or peripheral devices to be mounted using T-bolts or T-nuts, eliminating the need for special machining. Based on manual, TS plus transverse conveyors are available in any length from 240 mm to 6000 mm in 5 mm increments [7]. Conveyor length includes:
• length of two frames – 530*2 = 1060 mm,
• gap between two frames – min 20 mm,
• conveyor leg profile width and gaps – 45 + 35 + 30 = 110 mm,
• gap between the first frame and return unit, which includes a part of stop gate length (in current stations, right stop gates go a little bit out of frame), return unit mounting length and gap between two these components – 10 + 80 + 15 = 105 mm.

This all gives length of 1295 mm, which was rounded to 1300 mm.

Figure 6.2.4.1. Conveyor drawing

Cross links (which connect two conveyor profiles between each other) should be used every 2000 mm to maintain proper belt section width and alignment and not needed for this application.

**Ribbon length**

Model GT2/B anti-static polyamide transport belt is used for chosen conveyor type. Belts on both conveyor profiles should run continuously to carry the pallet on their surfaces. Due to the low coefficient of friction between the belt and the pallet frames, pallets can be stopped even while the belts continue to run, but it depends on application. Belt is available in up to 250 meter rolls. Belts should be tensioned and welded during installation; this provides a continuous loop in each conveyor section and ensures proper positive contact with the drive pulleys. Belt welding is done by special size 1 welding kit, which should be bought separately and Norma already has it. The belt welding kit includes the necessary tools for tensioning, grinding, and welding the belt ends.

According to TS plus manual, ribbon length calculation equation depends on conveyor length more or less 4 m. For given case (1,3 m), it can be calculated next way [7]:

\[
L = [(2 \times Ls + 1320) \times 0.980] + 60
\]

(6.2.4.1)

where \(L\) – belt length, mm,
\(Ls\) – conveyor section length, mm,
1320 mm – belt needed for AS 2 and UM 2 units,
0,980 – factor for pretensioning,
60 mm – belt needed for overlap at weld.
\[ L = [(2 * 1300 + 1320) * 0,980] + 60 = 3901,6 \text{ mm}. \] This value will be rounded to 3902 mm.

6.2.5 Return unit

A return unit is required to be placed on the other side of conveyor to direct the continuous loop of belt from the center channel in the conveyor rail back up to the transport level. Current workstation does not contain the return unit, so it should be chosen separately. The main parameter is conveyor width, which is determined by the width and length of working pallet – 240x240 mm for this case. This parameter cannot be changed, because pallet contains special attachment for fixing the detail before riveting. UM2/B return unit [7] is suitable for this purpose – it has suitable sizes for pallet and space inside, so additional sensor can be attached. Unit walls also contains holes for fastening. All hardware needed to mount the return unit to a conveyor section is included in the set.

6.2.6 SICK sensor fixing

As it was said before, SICK sensor for detail presence detection cannot be placed on or inside the conveyor, like other ones, additional fixing is needed; 30x30 mm profiles will be used. It is possible to connect them on a conveyor profile using standard gussets. Mounting plates for sensors itself are already provided by the supplier, so only profiles are needed. They are placed in the middle of Baltec riveting unit fixing plate, to make this position suitable for bot left-handed and right-handed model (they differ by positioning). 35 mm profile is placed between sensor and conveyor to keep the needed working distance, 165 mm profile is used to place the sensor on it – this is done to provide more flexible positioning. Final result is seen from the conveyor drawing (9.5).

6.2.7 Operator’s button fixing plate

Operator’s button is usually placed on the conveyor profile of frame profile, to be closer to the operator (especially on those lines, where same button is used several times in each cycle) and do not interfere with taken details. In case where operator takes details from previous station and also
uses additional place for putting the detail, it was decided to place the button in front of the return unit. Mounting accessories for Baumer proximity sensor are provided by the supplier, while it is not possible to place the button directly to the return unit – it has protective cover and most of the profile is solid. Additional plate was projected for this purpose, using the same technology as previous ones – bended 2-mm stainless steel plate. This plate can be fixed between return unit sides by using already existing fastering holes on it. These measurements and measurements for Baumer mounting plate were taken from devices directly. There are no standards, which should be observed for button plate size, so it has same width as the distance between return unit inner sides, connection flange width is taken according to fixing holes position. Height of plate is determined according to height of connection profile inside the fixing unit – this profile connects fixing unit blocks and can be seen from the manual drawing. Button plate will be located 15 mm higher. Plate flat pattern is presented on drawing 9.3.

6.2.8 Pallet position sensor fixing

As it was said before, Bosch standard mounting will be used [48]. It can also be mounted on the operator’s button fixing plate, but from the other side, so it will work as stop gate sensor. Holes were done according to the mounting unit drawing and can be seen from drawing 9.3.

6.2.9 Legs

Standard conveyor legs from 45x45 profiles are used to give additional support to the conveyor. They are placed on 30-mm distance from the drive unit and have approximately the same gap between legs and frame. Other part is fixed inside both frames, which gives enough support despite some vibrations during conveyor work.

6.2.10 Station positioning
Station positioning can be seen from drawing 9.1. Frame gaps for conveyors are placed symmetrically to each other, this gives 275 mm shift. 25 mm gap between two frames is enough for keeping distance between inner cylinders. Despite the fact, that they are placed parallel to each other and should not interfere, gaps are needed for flexible wiring. Inner part positioning remains the same. Air preparation block and controller block will be placed on frame’s legs.

Figure 6.2.9.1. Final version of station 70

Box with brackets is located in station 65 (previous one) on the lower shelf; according to the standard, the minimum height of it is 500 mm, the given one has 650 mm. Station 65 is used for label placing, so operator does not need to stay close to the edge; this gives an opportunity to make some additional steps from one station to another and avoid additional turning, which is less ergonomic. Pronomic machine, which is used as a foundation for packing box, is placed in the end of operator’s moving cycle. It has wheels and can be moved if needed. The distance between 65 station and 70 station detail table is about 50 mm, while distance between two station’s frames is 270 mm.
7 PROGRAMMING

1. I/O list

List of necessary inputs and outputs is based on chosen electric and pneumatic components. All the buttons and sensors are represented as input parameters, while cylinders, lights, conveyor motor and riveting machines are outputs. Door switches are also marked as inputs, because here they work like sensors – if the door switch is closed, the machine can do its work; in other case there is danger that operator does some work inside the machine and to avoid the risk of injury, the machine work should be stopped immediately after door opening. All the numbers start from 7 to make clear that variables belong to station 70. I and Q letters for input and output and numbering from 0 to 7 are related to Siemens controller program language. Positions 2 and 3 represent pallet positions inside Baltec machines 1 and 2 respectively, position 1 is final pallet position, when it goes out of station after riveting. Baltec home position sensors determine the end of riveting. Outputs for lifting units represent moving of cylinder forward and backward; usually these movings are determined as separated variables, but it makes program bigger and does not win anything.

Table 7.1.1. Inputs

| Start button | I70.0 |
| Stop button  | I70.1 |
| Reset button | I70.2 |
| Pallet position 1 – pallet out | I70.3 |
| Pallet position 2.1 (RH) | I70.4 |
| Pallet position 2.2 (LH) | I70.5 |
| Pallet position 3.1 (RH) | I70.6 |
| Pallet position 3.2 (LH) | I70.7 |
| Operator button | I71.0 |
| Emergency stop | I74.0 |
| Lifted pallet position 2 up | I72.0 |
| Lifted pallet position 2 down | I72.1 |
| Lifted pallet position 3 up | I72.2 |
| Lifted pallet position 3 down | I72.3 |
| Baltec 1 home position (sensor 1) | I72.4 |
| Baltec 2 home position (sensor 2) | I72.5 |
| Station 70A door switch | I72.6 |
| Station 70B door switch | I72.7 |
| Detail on on the pallet, position 2 | I71.1 |
| Detail on on the pallet, position 3 | I71.2 |
Table 7.1.2. Outputs

<table>
<thead>
<tr>
<th>Action</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start lamp</td>
<td>Q70.0</td>
</tr>
<tr>
<td>Reset lamp</td>
<td>Q70.1</td>
</tr>
<tr>
<td>Stop gate 2.1 (RH)</td>
<td>Q70.2</td>
</tr>
<tr>
<td>Lifting unit 2 up (cylinder)</td>
<td>Q70.3</td>
</tr>
<tr>
<td>Lifting unit 3 up (cylinder)</td>
<td>Q70.4</td>
</tr>
<tr>
<td>Stop gate 2.2 (LH)</td>
<td>Q70.5</td>
</tr>
<tr>
<td>Stop gate 3.1 (RH)</td>
<td>Q70.6</td>
</tr>
<tr>
<td>Baltec 1 start to work</td>
<td>Q71.0</td>
</tr>
<tr>
<td>Baltec 2 start to work</td>
<td>Q71.1</td>
</tr>
<tr>
<td>Conveyor moving forward</td>
<td>Q71.2</td>
</tr>
<tr>
<td>Conveyor moving backward</td>
<td>Q71.3</td>
</tr>
</tbody>
</table>

2. Control logic

Based on Autoliv standard, every program should have a flowchart. The new flowchart is in graphic material, 9.8. It describes new work sequence. Shapes are used next way:

- trapeze represents button pushing;
- rhombus is a condition – usually it is a sensor condition; if signal is on, it means "yes" in terms of flowchart and "no" otherwise;
- rectangle is action – start of working of riveting machine, cylinder moving etc.
- arrows show, which action have been chosen as next or which condition should be checked.
  In case if some action needs some time, which is not determined by separate timer, flowchart is using loops – these loops show that next control or action cannot be done before previous have not ended;
- free shapes with letters are used to show correct sequence directions between pages.

The program should work next way:

- A start button must be pressed to start the work of machines – a controller program is started and air supply is on;
- All the initial positions are checked – pallet is in position 1, riveting machines are off and lifting units stay down; there is nothing on positions 2 and 3 (stop gate sensors are checked); doors are closed, stop, reset or emergency buttons are not pressed;
- Operator presses the button to start the cycle;
• A model bit control takes place – this determines algorithms for left and right handed models respectively, the difference is in pallet position;
• Depending on model, stop gates go down to get the pallet go till the end of station 70.2 and take needed position (last stop gate for LH and previous one for RH);
• Sensor before the necessary stop gate controls the pallet presence;
• If the signal is 1, which means that pallet is above the sensor, the conveyor stops;
• Then goes checking the detail presence on the pallet using SICK sensor;
• If it is OK – the lifting unit goes up by pushing the cylinder stroke out;
• When plate reaches the end (this is determined by signals from two sensors placed under the lifting unit) – riveting starts;
• Riveting goes 2,5 s and it is controlled by inner controller – so, no additional algorithm is needed;
• When it has ended, sensor inside the Baltec detects the stopping of riveting unit, after getting the signal lifting unit goes down by pulling cylinder stroke in;
• Checking the position of lifting unit takes place, if it has reached the end – second pack of stop gates inside the station 70.1 goes up, depending on model;
• Conveyor goes in reverse;
• The same algorithm is used for second machine, the difference is in signal numbers and stop gates switching order – for left-handed models stop gates 2 and 4 should go up and 1 and 3 for right-handed model respectively;
• When both rivetings are done, pallet goes outside;
• When it reaches the position 1 where last sensor is placed, the conveyor stops;
• Stop gates go up (only last stop gate is up all the time);
• Cycle starts from the control of home positions;
• In case of emergency switch using all the devices switch off and the values of variables are reset till the using of start button. Stop button stops the work of machines, but not the full station; reset button resets the inner parameters. This part is optional for the main algorithm.

3. Software

Siemens uses its own software for controllers. The safety-related program for the CPU 315-2 PN/DP is created with the STEP 7 software. Controller may be programmed directly through STEP 7
manager or through TIA (Totally Integrated Automation) portal - an integrated software development environment for process automation systems from the level of drives and controllers to the level of the human-machine interface [49]. The last one was chosen. TIA Portal contains tools for:

- hardware parameters configuration,
- configuration of industrial communication systems,
- programming of controllers in LAD (Ladder Diagram), FBD (Function Block Diagram) and SCL (Structured Control Language),
- configuring the SIMATIC operator panels,
- testing, commissioning and maintenance of the finished systems.

This solution is more flexible and economical. TIA portal configuration description for connection establishment is out of given thesis scope.

4. Communication

The S7-300 has several communication possibilities:

- Communications processors for connecting to the bus systems like AS-Interface, PROFIBUS and PROFINET/Industrial Ethernet,
- Point-to-point connections via communication processors,
- Multipoint interface (MPI) (integrated into the CPU).

It was decided to do the take PROFINET [50] as the main standard, so this solution will be implemented. The SIMATIC S7-300 can be connected to the PROFINET IO bus system via a communications processor or the CPUs with integral PROFINET interface, the first variant was used (appropriate CP is chosen in chapter 5.2.4). PROFINET is an open industry standard for automation created by Siemens. The advantages of Ethernet-based networks are the flexibility of building, the ability to use the TCP / IP protocol, a huge selection of equipment for a variety of applications [51]. But Ethernet has its drawbacks, the main is the impossibility of building systems in which the time of control signals transmission is about 1 ms. Siemens has created the PROFINET system, combining the flexibility of Ethernet and the ability to work in real time. PROFINET is faster with more bandwidth and larger messages [51].

Each module in the PROFINET network has three addresses:

- MAC Address,
- IP Address,
- The device name - the logical name of the module within the general configuration.

Because PROFINET uses TCP/IP, MAC addresses and IP addresses are used. The MAC address changes when the device is replaced. The IP address is dynamic addressing. For permanent addressing, the device name is used. The CPUs of the SIMATIC S7-300 support the following communication types:

- **Process communication:** It is used for cyclic addressing of I/O modules through some bus - usually PROFIBUS DP, using of AS-Interface and profinet is also possible and called up from the cyclic execution levels.

- **Data communication:** This type is used cyclically or called via program block; it is needed for data exchange between several automation systems or system and HMI

- **Additional IT functions (WEB server, e-mailing, IP routing etc.)** are also available.

For given approach, data communication is needed – to check the model bit for further cycle choosing. PROFINET connection establishment task was outsourced to the program engineer.

### 5. Program blocks

Siemens controllers use ladder logic – this means that operations and variables are represented as blocks with connections. Several block types can be used during programming [52]:

- **OB** – Organization blocks. They determine the structure of the user program.
- **SFB & SFC** – System function blocks and system functions. They allow the access to some important system functions.
- **FB** – Function blocks. Programmable blocks with memory.
- **FC** – Functions. Blocks containing program routines for functions.
- **DB** – Data blocks. Blocks are used for storing user data. It is also possible to create a shared data blocks, which can also be defined and used by any blocks.
- **Instance DB** – Instance data blocks. These data blocks are associated with the block when an FB/SFB is called; they are created automatically during compilation.

The program includes only organization blocks. Integers and other constant data are not required. It is possible to add and call functions, but during the testing of other line parts it had some troubles with connection, so program routine was simplified. Open and closed contacts are used for sensor data, set and reset commands switch on and off the outputs. Programming principles are described in S7 manual and they were taken as a basic principle for program creation. Program is available in Appendix 3.
8 COST CALCULATION

1. BOM

As most of the components remain the same, only changed and added components will be added to the bill of materials. The prices used are mostly Autoliv offers – Autoliv and some companies are in longterm partnership, so prices are usually lower than official ones. Component price also includes transport costs. Some accessories and shield were taken directly from Norma.

<table>
<thead>
<tr>
<th>Part</th>
<th>Price in eur</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pneumatics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bosch VE2/S</td>
<td>296,94</td>
<td>3</td>
</tr>
<tr>
<td>Festo MFH-3-M5 3/2</td>
<td>186,05</td>
<td>3</td>
</tr>
<tr>
<td>Festo AMTE-M-LH-M5</td>
<td>3,12</td>
<td>3</td>
</tr>
<tr>
<td>Festo QSML-M5-4</td>
<td>35,13</td>
<td>6 (sold in pack of 10)</td>
</tr>
<tr>
<td>Festo MSFG-24/42-50/60</td>
<td>43,38</td>
<td>3</td>
</tr>
<tr>
<td><strong>Accessories</strong></td>
<td>16,4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>includes connection cables and pneumatic wiring</td>
<td></td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>581,05</td>
<td></td>
</tr>
<tr>
<td><strong>Electrics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SICK IQ80-60NPP-KK0</td>
<td>371,9</td>
<td>2</td>
</tr>
<tr>
<td>Schneider electric XVMB2RGSB</td>
<td>62,71</td>
<td>1</td>
</tr>
<tr>
<td>Schneider electric LC1K091068LS207</td>
<td>42,53</td>
<td>1</td>
</tr>
<tr>
<td>Schneider electric LC1K090168LS207</td>
<td>33,79</td>
<td>1</td>
</tr>
<tr>
<td>Siemens SIRIUS 3RS18 3RS1800-2AP00</td>
<td>57,26</td>
<td>2</td>
</tr>
<tr>
<td>Siemens CPU 315-2 PN/DP 6ES7315-2EH14-0AB0</td>
<td>1853,14</td>
<td>1</td>
</tr>
<tr>
<td>Siemens SITOP PS307 6ES7307-1EA01-0AA0</td>
<td>124,68</td>
<td>1</td>
</tr>
<tr>
<td>Siemens 6ES7321-1BL00-0AA0</td>
<td>285,09</td>
<td>1</td>
</tr>
<tr>
<td>Siemens 6ES7322-1BH10-0AA0</td>
<td>393,84</td>
<td>1</td>
</tr>
<tr>
<td>Siemens CP 343-1 6GK7343-1EX30-0XE0</td>
<td>1118,69</td>
<td>1</td>
</tr>
<tr>
<td><strong>Accessories</strong></td>
<td>209,33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>includes Siemens connection cables and wiring; mounting accessories are already in price</td>
<td></td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>4552,96</td>
<td></td>
</tr>
<tr>
<td><strong>Mechanics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bosch conveyor profile</td>
<td>93,06</td>
<td>1,3 m x2</td>
</tr>
<tr>
<td>Bosch belt</td>
<td>139,85</td>
<td>3,902 m x2</td>
</tr>
<tr>
<td>Additional table</td>
<td>62,6</td>
<td>1</td>
</tr>
<tr>
<td>V-TAC G-SERIES light</td>
<td>11,64</td>
<td>1</td>
</tr>
<tr>
<td>Lightning profiles 30x30</td>
<td>25,80</td>
<td>2 m</td>
</tr>
<tr>
<td>Plate for button fixing</td>
<td>30,3</td>
<td>1</td>
</tr>
<tr>
<td>Sensor fixing profiles</td>
<td>5,16</td>
<td>0,4 m</td>
</tr>
<tr>
<td>Bosch gussets 30x30</td>
<td>20,37</td>
<td>12</td>
</tr>
<tr>
<td>Operator’s button fixing plate</td>
<td>41,5</td>
<td>1</td>
</tr>
<tr>
<td>Bosch pallet position sensor fixing</td>
<td>8,26</td>
<td>1</td>
</tr>
<tr>
<td>Bosch legs (set)</td>
<td>71,56</td>
<td>1</td>
</tr>
</tbody>
</table>
2. Licenses

Siemens software has not free license, so these costs should also be included in final price. DesignSpark software is free.

Table 8.2.1. Licence costs

<table>
<thead>
<tr>
<th>License name</th>
<th>Period (in months)</th>
<th>Price per month in eur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens STEP 7 6ES7822-1AA04-0YA5</td>
<td>Unlimited</td>
<td>1 695.50</td>
</tr>
<tr>
<td>Siemens NX</td>
<td>4</td>
<td>330</td>
</tr>
<tr>
<td>Total price</td>
<td></td>
<td>3 015.50</td>
</tr>
</tbody>
</table>

The total price for licenses can be divided by 4, because software was used for full R23L line projecting and STEP 7 can be used for further projects. Price will be counted as 753,88 €.

3. Work hours

Given project consists of several steps which were partly delegated to other departments. All the work hours inside Norma AS should be taken into account. Working hours were taken based on number of weeks spent on different work types; 1 week was taken as 40 work hours.

Table 8.3.1 Cost of working hours

<table>
<thead>
<tr>
<th>Type of work</th>
<th>Amount of working hours</th>
<th>Price per hour in eur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame building and mechanical component placement</td>
<td>10</td>
<td>27,9</td>
</tr>
<tr>
<td>PLC programming</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Projecting (modelling+schematics)</td>
<td>336</td>
<td>5</td>
</tr>
<tr>
<td>Electrical work and mounting</td>
<td>5</td>
<td>27,9</td>
</tr>
<tr>
<td>Total price</td>
<td></td>
<td>2 148,5</td>
</tr>
</tbody>
</table>
4. Cost reduction possibilities

Taking into account all the costs, the final cost of the rebuilding is 8 577,28 €. This cost can be reduced by changing some components:

- Bi-directional stop gates can be replaced by pneumatic cylinders with POM endings. The price of this solution is about 50 €, without accessories.
- Controller can use CPU and CP with PROFIBUS only, it is enough for station connection with other line parts. This reduces the electronics part costs on 300-400 €.
- Frame building may be provided by apprentices, which reduces labour costs – the price per hour will be 3,95 €.
- It is possible to use some relays, gussets and other small components, which were used in old lines and now are out of use. This can reduce costs by approximately 250-300 €.

Thus, the total cost may be reduced by approximately 800 € and be around 7 780 €.
9 RESULT ANALYSIS

Due to the changing of time limits according to problems in R23L modified testing station development, the rebuilding was held over to the middle of summer 2018. Despite on that, project results may be estimated based on parameters set in introduction:

- Quality of product – should remain the same, number of defect details should stay on the same lever or become lower. This point can be controlled only after the starting of line work.

- Cycle time – possibly reduced or at the same level – the conveyor work was tested by the program, with necessary timers instead of riveting machines. It gave result of 21 s. Compared with previous one of 22.65 s, it is seen that the result is a little bit better.

- Ergonomics rules – completely considered – all the standards were taken into account during projecting, including Autoliv EMS standard [53]. The safety standards do not require providing the additional safety if the press operation takes place not directly to the operator. In case of more strict standards, additional button may be added – operator will be needed to press two buttons at the same time, so the possibility to put the hand inside the machine will be eliminated.

- Size of the new station compared with previous one – smaller – the area of the new station is roughly 1.86*1.105 = 2.055 m², versus old one 1.7*1.35 = 2.295 m² (taking into account the sizes of drive and return units, conveyor lengths and frame sizes), so this point is completed.

- Correlation with other line parts – successful – this point will be estimated practically after the line rebuilding, now it can be said that station 70 has its own controller and does not correlate with other line parts (excepting reading the model bit), so troubles cannot occur.

- All the rules of Norma and Autoliv should be followed – all the component choosing and projecting were done according to the standards, so this point may be considered as completed.

- Cost – possibly low – the total rebuilding cost is 8 557.28 €. In case of outsourcing the projecting part, its cost was estimated as 11 150 €, without a component price. Another alternative is using a robotics system to provide a riveting; the cost will include robot with programming equipment, small conveyor part and new frame. This will eliminate the need of using 2 riveting machines and reduce the line size, inner parts like sensors and pushing plates will be mostly eliminated. Approximate cost of this solution is 28 700 € for robotic system and 1250 € for other. Compared with alternatives, chosen way is the cheapest one.
SUMMARY

The aim of given work was to provide a rebuilding of station 190 according to several rules and specifications, to reduce the size and keep the functionality. The result of the work is a new workstation project, which satisfies the needed requirements and consists of several steps: modernized workstation idea development, creation of 3D model, choosing a new electric and pneumatic equipment according to the needs of new workstation, creation of new electric and pneumatic schemes and program writing based on new workflow. Workflow is part which have endured the most significant changes and have determined, which components are needed to be changed or added. Stop gates are the only pneumatic components which were changed to the new ones, with appropriate accessories; others have remained the same. Electric part has got several new sensors, controller blocks, buttons, relays and signalling lamps. Some mechanical mounting plates were designed and added, also station required new conveyor profile and lightning. New station is projected according to ergonomics standards and safety rules. Every step was done according to goals stated in the introduction, and the goals have been received: the size of the workstation has reduced to 0,24 m², new documentation was created and program working principle was determined. Cost of the rebuilding was estimated as 8 577,28 € and this price is the smallest compared with alternative solutions. Testing was provided only for conveyor part due to the changes in project timetables at AS Norma and gave the satisfactory result with 21 s. Full line testing is out of scope now and will be considered in future, so the quality of new station production can be estimated in August, 2018. Most of the programming part like Ethernet connection establishment and TIA portal configuration is also out of scope in terms of given thesis task. Moreover, component choosing may be reviewed to reduce rebuilding costs. It can be said that thesis results coincide with the planned solution and can be applied at AS Norma plant for new line modification.
KOKKUVÕTE

Antud töö eesmärk oli pakkuda jaama 190 ümberehituse projekti vastavalt mitmele reeglile ja spetsifikatsioonile selleks, et vähendada suurust ja säilitada funktsionaalsust kõrgemal tasemel. Töö tulemuseks on uus tööjaama projekt, mis vastab vajalikele nõuetele ja mitmendast sammust: ümberehituse tööjaama idee arendamine, 3D mudeli loomine, uue elektrilise ja pneumaatilise seadme valimine uue töökoha vajaduste järgi, skeemide loomine and programmi kirjutamine vastavalt uuele töö järjekorrale. Töövoog on osa, mis sai kõige olulisemaid muudatusi ja mille alusel tuli otsus, mis komponente on vaja muuta või lisada. Pneumaatilised pidurid on ainukesed pneumaatilised elemendid, mis muudeti uuteks koos sobivate tarvikutega; teised on jäänud samaks. Eliktri osale nüüd kuuluvad uued sensorid, kontroller, nupud, releed ja lampid. Mõned kinnitusplaadid olid projekteeritud ja lisatud, samuti uus konveieri profiil ja tööstusvalgusti olid valitud. Uus jaam on tehtud vastavalt ergonoomika standarditele ja ohutuseeskirjadele.

Iga samm oli tehtud vastavalt sissejuhuses toodud eesmärkidele ja eesmärgid on saavutatud: uue tööjaama suurus on 0,24 m² vähem, skeemid ja dokumendid on koostatud ning programmi töö järjekord on määratud. Ümberehituse maksumus oli hinnanguliselt 8 577,28 € ja see hind on kõige väiksem võrreldes alternatiivsete lahendustega.


Võiks öelda, et magistritöö tulemused ühtivad kavandatud lahendusega ja neid saab rakendada AS Norma uue liini modifitseerimiseks.
LIST OF REFERENCES

[1] R23ARH-240-01, Control steps manual at station 240
[3] Baltec characteristics [WWW]
[5] E1434063 – Components list applicable for AEU Suppliers and AEU Plants
[7] Bosch TS Plus conveyor system components [WWW]
[9] Valve flow rate calculation equations [WWW]
[10] Cv value calculation equation; pressure drop tables [WWW]
https://www.flodraulic.com/formulae/basic-pneumatic-formulas (07.03.2018)
74


[22] SICK sensor data sheet [WWW] https://sick-virginia.data.continum.net/media/pdf/0/60/860/1dataSheet_IQ80-60NPP-KK0_7900227_en.pdf (24.03.2018)


[28] Controller relay parameters [WWW]
[29] Siemens CPU data sheet [WWW]
[31] Power supply module data sheet [WWW]
[32] Input module data sheet [WWW]
https://mall.industry.siemens.com/mall/en/WW/Catalog/Product/6ES7321-1BL00-0AA0 (03.04.2018)
[33] Output module data sheet [WWW]
[34] Communication processor block data sheet [WWW]
https://mall.industry.siemens.com/mall/en/WW/Catalog/Product/6GK7343-1EX30-0XE0 (03.04.2018)
[37] Bend deduction description and equation [WWW] https://www.javelin-tech.com/blog/2017/06/sheet-metal-design-terminology/ (02.05.2018)
APPENDICES

Appendix 1. Baltec scheme
Appendix 2. Additional plate strength calculation

Given:

Beam type: Clamped from the left
Load type: Distributed load in the middle of the beam
L = 0,257 m
q1 = 0,04905 kN/m
z ε (0,0685; 0,1885) m

Reaction of supports (see Fig.1):

The sum of the moments of all forces relative to the point A must be equal zero:

\[ \sum M_A = -M_A - \sum q_i (b_i - a_i) \cdot \frac{(a_i + b_i)}{2} - \sum F_i c_i - \sum M_i \]

\[ \sum M_A = -M_A - q_1 (b_1 - a_1) \cdot \frac{(a_1 + b_1)}{2} \]

\[ = -M_A - 0,04905 \cdot (0,1885 - 0,0685) \cdot \frac{(0,0685 + 0,1885)}{2} \]

\[ = -M_A - 0,04905 \cdot 0,12 \cdot 0,1285 = -M_A - 0,000756351 = 0 \Rightarrow M_A = -0,000756351 \ kNm \]

The sum of the projections of all forces on the vertical axis must be zero:

\[ \sum Y = R_A - \sum q_i (b_i - a_i) - \sum F_i \]

\[ \sum Y = R_A - q_1 (b_1 - a_1) = R_A - 0,04905 \cdot (0,1885 - 0,0685) = R_A - 0,04905 \cdot 0,12 \]

\[ = R_A - 0,005886 = 0 \Rightarrow R_A = 0,005886 \ kN \]

To proof the calculation, it is necessary to calculate the sum of the moments of all forces relative to the point B:

\[ \sum M_B = -M_A - R_A \cdot L + \sum q_i (b_i - a_i) \cdot \frac{(2L - a_i - b_i)}{2} - \sum F_i (L - c_i) - \sum M_i \]

\[ \sum M_B = -M_A - R_A \cdot L + q_1 (b_1 - a_1) \cdot \frac{(2L - a_1 - b_1)}{2} \]

\[ = 0,000756351 - 0,005886 \cdot 0,257 + 0,04905 \cdot (0,1885 - 0,0685) \]

\[ \cdot \frac{(2 \cdot 0,257 - 0,0685 - 0,1885)}{2} \]

\[ = 0,000756351 - 0,001512702 + 0,000756351 = 0 \]

Initial parameters:

The deflection and turning in the seal are equal to zero: \( w_0 = 0; \vartheta_0 = 0 \).

Method for plotting diagrams building
Figure 1. Forces and distances in the beam

The transverse force \( Q \) in the section with the coordinate \( z \) is equal to the sum of the projections of all the forces located on the left of the cross section on the vertical axis:

\[
Q(z) = R_A - \sum q_i \ast (z - a_i) \ast H(z - a_i) + \sum q_i \ast (z - b_i) \ast H(z - b_i) - \sum F_i \ast H(z - c_i)
\]

The bending moment \( M(z) \) is equal to the sum of the moments of all the forces located on the left of the cross section:

\[
M(z) = M_A + R_A \ast z - \sum q_i \ast (z - a_i)^2 \ast H(z - a_i) + \sum q_i \ast (z - b_i)^2 \ast H(z - b_i) - \sum F_i \ast (z - c_i) \ast H(z - c_i) + \sum M_i \ast H(z - d_i)
\]

Here \( H(x) \) is the Heaviside function (equal to 0 for \( x < 0 \) and 1 for \( x > 0 \)), which takes into account only those loads that are located on the left of the section.

Figure 2. Angle of rotation and deflection inside the beam

The expressions for the angle of rotation of the section \( \theta(z) \) and the deflection \( w(z) \) are obtained by successive integration of the expression \( M(z) \):

\[
EI\theta(z) = M_A \ast z + R_A \ast \frac{z^2}{2} - \sum q_i \ast (z - a_i)^3 \ast H(z - a_i) + \sum q_i \ast (z - b_i)^3 \ast H(z - b_i) - \sum F_i \ast (z - c_i)^2 \ast H(z - c_i) + \sum M_i \ast H(z - d_i)
\]

\[
EIw(z) = M_A \ast \frac{z^2}{2} + R_A \ast \frac{z^3}{6} - \sum q_i \ast (z - a_i)^4 \ast H(z - a_i) + \sum q_i \ast (z - b_i)^4 \ast H(z - b_i) - \sum F_i \ast (z - c_i)^3 \ast H(z - c_i) + \sum M_i \ast (z - d_i)^2 \ast H(z - d_i)
\]

where \( E \) is the modulus of elasticity of the beam material, \( I \) is the moment of inertia of the section.

Here the deflection and turning in the seal are equal to zero: \( w_0 = 0; \ \theta_0 = 0 \).
Construction of the diagrams
The analytical expressions of $Q(z)$, $M(z)$, $EI\theta(z)$ and $EIw(z)$ for each section and calculation of their values at the peak points are represented below.

Section I ($0 \leq z \leq 0.0685$):

Transverse force $Q$:

$$Q_I(z) = R_A = 0.005886$$

The values of $Q$ at the edges of the segment are:

$$Q_I(0) = 0.005886 \text{kN}$$

$$Q_I(0.0685) = 0.005886 \text{kN}$$

Bending moment $M$:

$$M_I(z) = M_A + R_A * z = -0.000756351 + 0.005886 * z = 0.005886 * z - 0.000756351$$

The values of $M$ at the edges of the segment are:

$$M_I(0) = -0.000756351 \text{kNm}$$

$$M_I(0.0685) = -0.0035316 \text{kNm}$$

Angle of rotation $\theta$:

$$EI\theta_I(z) = M_A * z + R_A * \frac{z^2}{2} = -0.000756351 * z + 0.005886 * \frac{z^2}{2}$$

$$= 0.002943z^2 - 0.000756351z$$

The values of $EI\theta$ at the edges of the segment are:

$$EI\theta_I(0) = 0$$

$$EI\theta_I(0.0685) = -3.80008e^{-5} \text{ kNm}^2$$

Deflection $w$:

$$EIw_I(z) = M_A * \frac{z^2}{2} + R_A * \frac{z^3}{6} = -0.000756351 * \frac{z^2}{2} + 0.005886 * \frac{z^3}{6}$$

$$= 0.000981z^3 - 0.000378176z^2$$

The values of $EIw$ at the edges of the segment are:

$$EIw_I(0) = 0$$

$$EIw_I(0.0685) = -1.45918e^{-6} \text{ kNm}^3$$

Section II ($0.0685 \leq z \leq 0.1885$):

Transverse force $Q$:

$$Q_{II}(z) = R_A - q_1 * (z - a_1) = 0.005886 - 0.04905(z - 0.0685) = -0.04905z + 0.00924593$$
The values of $Q$ at the edges of the segment are:

\[
Q_{II}(0.0685) = -0.04905 \times 0.0685 + 0.00924593 = 0.005886 \text{ kN}
\]

\[
Q_{II}(0.1885) = -0.04905 \times 0.1885 + 0.00924593 = 0 \text{ kN}
\]

Bending moment $M$:

\[
M_{II}(z) = M_A + R_A \cdot z - \frac{q_1 \cdot (z - a_1)^2}{2}
\]

\[
= -0.000756351 + 0.005886z - \frac{0.04905 \cdot (z - 0.0685)^2}{2}
\]

\[
= -0.000756351 + 0.005886z - \frac{0.04905 \cdot (z^2 - 0.0685z + 0.002346125)}{2}
\]

\[
= -0.024525^2 + 0.00924593z - 0.000871428
\]

The values of $M$ at the edges of the segment are:

\[
M_{II}(0.0685) = -0.024525 + 0.0685^2 + 0.00924593 \cdot 0.0685 - 0.000871428
\]

\[
= -0.00035316 \text{ kNm}
\]

\[
M_{II}(0.1885) = -0.024525 \cdot 0.1885^2 + 0.00924593 \cdot 0.1885 - 0.000871428 = 0 \text{ kNm}
\]

Angle of rotation $\theta$:

\[
EI\theta_{II}(z) = M_A \cdot z + R_A \cdot \frac{z^2}{2} - q_1 \cdot \frac{(z - a_1)^3}{6}
\]

\[
= -0.000756351z + \frac{0.005886z^2}{2} - 0.04905 \cdot \frac{(z - 0.0685)^3}{6} =
\]

\[
= -0.000756351z + \frac{0.002943z^2}{2} - 0.04905
\]

\[
\times \left( \frac{z^3}{6} - 0.03425z^2 + 0.00234613z - 5.35699e^{-5} \right)
\]

\[
= -0.008175z^3 + 0.0046296z^2 - 0.000871428z + 2.6276e^{-6}
\]

The values of $EI\theta$ at the edges of the segment are:

\[
EI\theta_{II}(0.0685) = -0.008175 \cdot 0.0685^3 + 0.0046296 \cdot 0.0685^2 - 0.000871428 \cdot 0.0685
\]

\[+ 2.6276e^{-6} = 3.80008e^{-5} \text{ kNm}^2\]

\[
EI\theta_{II}(0.1885) = -0.008175 \cdot 0.1885^3 + 0.0046296 \cdot 0.1885^2 - 0.000871428 \cdot 0.1885
\]

\[+ 2.6276e^{-6} = -5.21272e^{-5} \text{ kNm}^2\]

Deflection $w$: 

81
\[ EI_{II}(z) = M_A \frac{z^2}{2} + R_A \frac{z^3}{6} - q_1 \frac{(z - a_1)^4}{24} \]

\[ = -0.000756351 \frac{z^2}{2} + 0.005886 \frac{z^3}{6} - 0.04905 \frac{(z - 0.0685)^4}{24} = \]

\[ = -0.000756351 \frac{z^2}{2} + 0.000981z^3 - 0.04905 \left( \frac{z^4}{24} - 0.0114167z^3 + 0.00117306z^2 \right) - 5.35699e^{-5}z + 9.17384e^{-7} \]

\[ = -0.00204375z^4 + 0.00154099z^3 - 0.000435714z^2 + 2.6276e^{-6}z - 4.49977e^{-8} \]

The values of \( EI_{II} \) at the edges of the segment are:
\[ EI_{II}(0,0685) = \]
\[ = -0.00204375 \times 0.0685^4 + 0.00154099 \times 0.0685^3 - 0.000435714 \times 0.0685^2 + 2.6276e^{-6} \]
\[ \times 0.0685 - 4.49977e^{-8} = -1.45918e^{-6} \text{ kNm}^3 \]

\[ EI_{II}(1,885) = \]
\[ = -0.00204375 \times 1.885^4 + 0.00154099 \times 1.885^3 - 0.000435714 \times 1.885^2 + 2.6276e^{-6} \]
\[ \times 1.885 - 4.49977e^{-8} = -7.29065e^{-6} \text{ kNm}^3 \]

Section III (0,1885 ≤ \( z \) ≤ 0,257):

Transverse force \( Q \):
\[ Q_{III}(z) = R_A - q_1 \times (z - a_1) + q_1 \times (z - b_1) \]
\[ = 0.005886 - 0.04905(z - 0.0685) + 0.04905(z - 0.1885) = 0 \]

The values of \( Q \) at the edges of the segment are:
\[ Q_{III}(0,1885) = 0 \text{ kN} \]
\[ Q_{III}(0,257) = 0 \text{ kN} \]

Bending moment \( M \):
\[ M_{III}(z) = M_A + R_A \times z - \frac{q_1 \times (z - a_1)^2}{2} + \frac{q_1 \times (z - b_1)^2}{2} \]
\[ = -0.000756351 + 0.005886z - \frac{0.04905 \times (z - 0.0685)^2}{2} + \frac{0.04905 \times (z - 0.1885)^2}{2} \]
\[ = -0.000756351 + 0.005886z - 0.04905 \left( \frac{z^2}{2} - 0.0685z + 0.002346125 \right)^2 + 0.04905 \left( \frac{z^2}{2} - 0.1885z + 0.017766125 \right)^2 \]
\[ = 0 \]
The values of $M$ at the edges of the segment are:
\[ M_{Ili}(0,1885) = 0 \text{kNm} \]
\[ M_{Ili}(0,257) = 0 \text{kNm} \]

Angle of rotation $\theta$:
\[
EI\theta_{Ili}(z) = M_\ast z + R_\ast \frac{z^2}{2} - q_1 \ast \frac{(z-a_1)^3}{6} + q_1 \ast \frac{(z-b_1)^3}{6} \\
= -0.000756351z + 0.005886 \ast \frac{z^2}{2} - 0.04905 \ast \frac{(z-0.0685)^3}{6} + 0.04905 \\
* \frac{(z-0.1885)^3}{6} \\
= -0.000756351z + 0.002943z^2 - 0.04905 \\
* \left( \frac{z^3}{6} - 0.03425z^2 + 0.00234613z - 5.35699e^{-5} \right) + 0.04905 \\
* \left( \frac{z^3}{6} - 0.09425z^2 + 0.0177661z - 0.0011163 \right) = -5.21272e^{-5} \\
\]

The values of $EI\theta$ at the edges of the segment are:
\[ EI\theta_{Ili}(0,1885) = -5,21272e^{-5} \text{kNm}^2 \]
\[ EI\theta_{Ili}(0,257) = -5,21272e^{-5} \text{kNm}^2 \]

Deflection $w$:
\[
EIw_{Ili}(z) = M_\ast \frac{z^2}{2} + R_\ast \frac{z^3}{6} - q_1 \ast \frac{(z-a_1)^4}{24} + q_1 \ast \frac{(z-b_1)^4}{24} \\
= -0.000756351 \ast \frac{z^2}{2} + 0.005886 \ast \frac{z^3}{6} - 0.04905 \ast \frac{(z-0.0685)^4}{24} + 0.04905 \\
* \frac{(z-0.1885)^4}{24} = \\
= -0.000756351 \ast \frac{z^2}{2} + 0.000981z^3 - 0.04905 \\
* \left( \frac{z^4}{24} - 0.0114167z^3 + 0.00117306z^2 - 5.35699e^{-5}z + 9.17384e^{-7} \right) \\
+ 0.04905 \\
* \left( \frac{z^4}{24} - 0.0314167z^3 + 0.00888306z^2 - 0.0011163z + 5.26059e^{-5} \right) \\
= -5.21272e^{-5}z + 2.53532e^{-6} \\
\]

The values of $EIw$ at the edges of the segment are:
\[ EIw_{Ili}(0,1885) = -5,21272e^{-5} * 0.1885 + 2.53532e^{-6} = -7,29065e^{-6} \text{kNm}^3 \]
$EIw_{III}(0,257) = -5,21272e^{-5} \times 0,257 + 2,53532e^{-6} = -1,08614e^{-5} \text{ kNm}^3$
Appendix 3. Station 70 program

Network 1: Station 70 starting

Network 2: Control of initial parameters

Network 3: Model hit comparison

Network 4: LH model start of conveyor moving

Network 5: LH model pallet and detail position control pos 2

Network 6: LH model riveting 2 times
GRAPHICAL MATERIAL

1. R23L modified manufacturing line

2. Station 70 button set fixing plate

3. Station 70 Operator’s button fixing plate

4. Station 70 Additional table

5. Station 70 Conveyor

6. Station 70 Frame for one Baltec machine

7. Station 70 Full frame

8. Station 70 Work flowchart

9. Station 70 Schemes (includes both electric and pneumatic schemes with appropriate connections)