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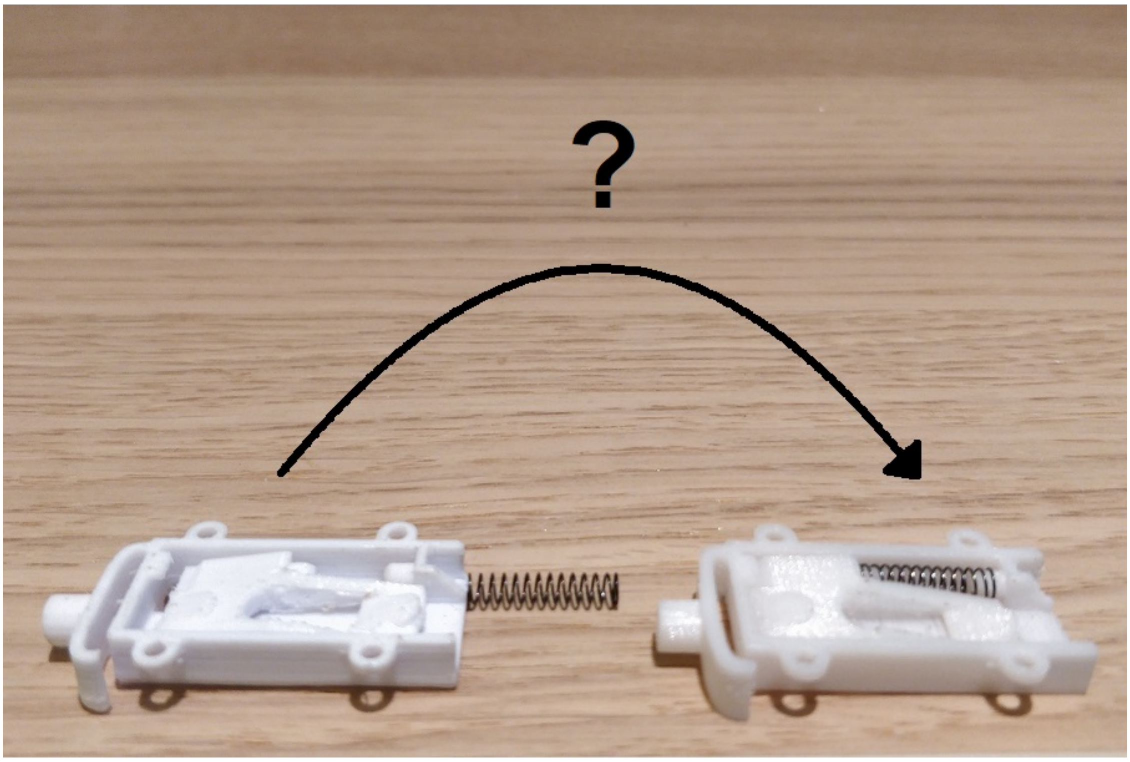

Automation of complex assembly task

The installation of a small spring in a product

Master's thesis in Systems, Control and Mechatronics

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Department of Electrical Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

MASTER'S THESIS 2019

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Cover: The product and the spring, on the left placed separately and on the right the product with the spring installed.

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Abstract

Today, things are shipped from all over the world in a large scale, this is not sustainable in the long term. Therefore we need to keep production local and find solutions that stops offshoring and brings back production that already have been offshored. Part of this solution is to be able to automate tasks that would traditionally have been offshored to be performed manually in low-wage countries. In this thesis, one such task is investigated, the installation of a small spring in a product. The possibility of automating the installation is first examined to identify what the difficulties are and finally how they could be solved, resulting in a working prototype that can be implemented in production with only minor changes.

Keywords: production, automation, spring, assembly, installation, small parts, pneumatic, mechanism.

Acknowledgements

I would like to thank the company for providing an interesting task and a good workplace that I have been able to use throughout the duration of the thesis work, which has provided good access to both resources for prototyping and help from the staff. I also want to thank my supervisor and examiner Jonas Fredriksson for the guidance and the positive words along the way.

Mathias Nilsson, Gothenburg, November 2019

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1

Introduction

In this thesis problems with the automation of installation of a small spring in a product and the solutions for them will be handled. Springs are typically hard to handle since they can be both compressed and flexed, which may lead to that the spring ejects from its position and fly away if handled incorrectly. The small size of the parts does not make it easier either since it becomes harder to accurately position and get a good grip on them [1]. The spring are in this case used to hold the safety shutter in a power outlet closed, as can be seen in figure 1.1. But the final idea can be applied to any similar application.

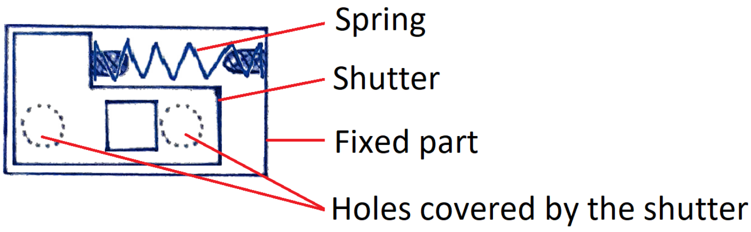


Figure 1.1: Safety shutter

1.1 Background

Assembly of small parts and especially hard to handle parts like springs has typically been done manually due to them being difficult to handle with automation [1]. Due to the manual assembly being labour intensive the assembly task tends to be placed in low-wage countries rather than being kept in a high-wage country like Sweden. This is done to be able to maintain a competitive price on the product which is an important factor for most customers.

Offshoring comes with its own set of difficulties, for example long lead times, less control over the production and also less control over the working conditions for the workers that would do the assembly [2]. The environment is also an important factor when deciding where to manufacture products, by producing them closer to the customer unnecessary emissions [3] from transports are avoided. In addition, the availability of electricity from clean sources are much better here in Sweden [4]. Another thing to consider is that there also is a value in being able to say that the product is made in Sweden. Therefore there is a desire to place the production locally. To be able to compete with the cost of manual assembly in a low-wage country and instead place production in Sweden, automation is needed.

1.2 Purpose

The purpose of this project is to investigate if the task of installing a small spring in a product can be automated, what problems that arises and what it takes to overcome them. The end goal of this effort is to be able to keep the production here in Sweden close to the product development and the customers, instead of opting for manual assembly in a low-wage country.

1.3 Description of the problem

The problem is how to grip and insert the spring in the correct position by using automation, with enough speed and reliability. To get a better understanding of the problem, it is broken down into three main questions:

1. What is it that makes the insertion of the spring so difficult to achieve with automation? Is it at all possible to automate it?
2. If it is possible to automate it, would the speed and reliability be high enough for production with the current design of the parts?
3. Would a redesign of one or more of the parts make automated assembly possible, or with higher speed and accuracy if already possible without any redesign?

To determine whether a concept is good enough it need to:

- Be able to successfully insert the spring into the assembly
- Be able to complete at least 4 cycles per minute
- Be reliable enough so that no one have to be monitoring the process constantly

Partly tied together with the reliability, it would be good if the position of the loose shutter is not critical when installing the spring, otherwise a step for verifying and adjusting its position need to be added. Before the spring is installed the shutter can be anywhere between either of the positions that are shown in figure 1.2. The position shown to the left is preferred as this is the position the shutter will have after the spring is installed.

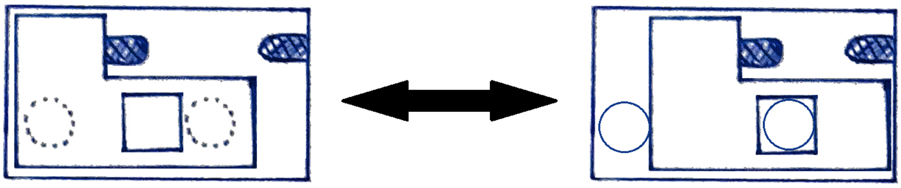


Figure 1.2: Shutter positions

1.4 Delimitations

The focus of this project is handling the spring and installing it in the product, therefore the material logistics around the process is not in focus. Due to uncertainties around the production of the product, since it is still in development, temporary fixtures will be created to hold the material in place during assembly.

During this project a SONY SRX-611 SCARA robot, as seen in figure 1.3, is available for testing, and could possibly be used later on in the production. SCARA stands for *Selective Compliance Articulated Robot Arm*, this type of robot consists of two arms with three joints and are good for vertical assembly [5]. At the end of the robot arm there is a revolving tool changer which can take up to 6 tools. The solution will be limited to either using a SCARA robot, with some kind of tool, or constructing a separate mechanism, since this is the available equipment at the company.

Figure 1.3: SONY SRX-611

1.5 Outline of the thesis

In Chapter 1 the problem is introduced with its background, the purpose of the project is described, the problem is formalized and the delimitations are presented. In Chapter 2 the concept generation is described, including analysis of the manual method, presentation of different elements that could be used in a solution and presentation of a number of different concepts. In Chapter 3 the concepts are analyzed and a final concept is chosen. This concept is then further developed in Chapter 4 into the final working prototype. In Chapter 5 the results from tests performed with two prototypes are presented. In Chapter 6 there is a discussion around the initial questions from the problem description, the design choices during development and things that need to be developed further before the solution could be implemented in production. Finally in Chapter 7 the thesis is concluded with some final words.

2

Concept generation

To find a good solution, the problem must first be analyzed and multiple concepts need to be created as a starting point to minimise the risk of overlooking a good solution. Then in Chapter 3 the concepts are evaluated and compared against each other before deciding how to proceed with each one of them.

2.1 Analysis of manual assembly

When looking at how a person would do it manually, the spring would be gripped at one end and inserted at an angle. Then it would be compressed against the spring seat of the moving part until it is short enough to pass by the knob on the second spring seat, then it is pushed down into final orientation where it snaps into place on the spring seat. One thing to note is the importance of compressing the spring against the spring seat of the moving part, since this moves it into correct position. Doing it the other way around complicates the insertion of the spring a lot.

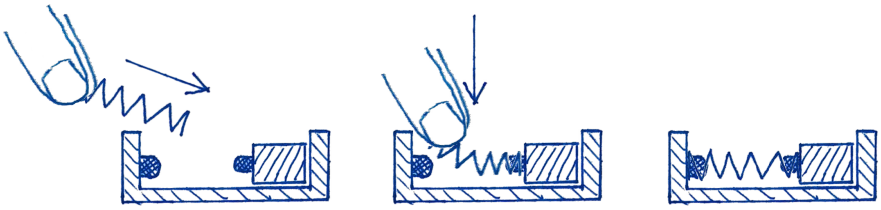


Figure 2.1: Sketch of manual assembly

2.2 Analysis of the robots limitations

The robot that is available for this project is a SCARA robot, which have 4 degrees of freedom. The end effector of the robot can be controlled in x, y and z axis, but it can only be rotated around the z axis, as can be seen by the coordinate system in figure 2.2. This makes the robot suitable for picking up objects and moving them to other locations, as long as it only needs to be rotated around the z axis. Using the analysis of the manual assembly one problem can directly be identified, and it is that when inserting the spring it is first inserted at an angle and then released vertically. The conclusion from this is that some other form of mechanism is needed at the end effector to change the angle.

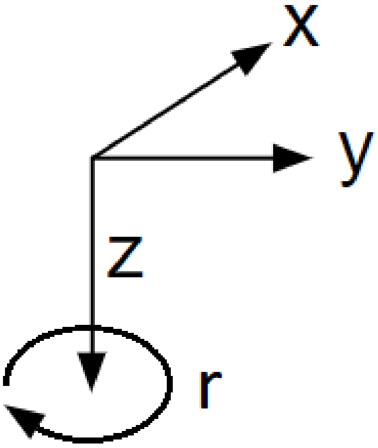


Figure 2.2: Coordinate system for the end effector

2.3 Analysis of separate mechanisms

A separate mechanism can be built to perform any motion that are desired, depending on the complexity of the mechanism and the choice of actuators. While a robot is flexible and can do many different things, limited by of its degrees of freedom and the tool attached to the end effector, a separate mechanism is usually designed to do a specific task. This make them less flexible in the sense of that it cannot be reused for producing something else, by just running a different program, but individual components may of course still be usable for other applications. On a more positive note, a dedicated mechanism can often be made much more compact then a solution with a robot and may also be able to do the task quicker than a robot.

As just mentioned, we have a choice of different actuators, which can be divided into three main types: Hydraulic, Pneumatic and Electric. All types of actuators can in some way or another create either rotational or linear motion.

2.3.1 Pneumatic actuators

Pneumatic actuators are either fluid motors or cylinders and are powered by compressed air. To control the actuators valves are used, these can be either electrically or manually controlled valves. Since the compressed air have the ability to expand in the cylinder or motor it is hard to control the actuator to a specific position, therefore pneumatic actuators are only used to move something from one fixed endpoint to another fixed endpoint. Due to this fact, there are usually only sensors that detect either endpoint, since it would be hard to stop somewhere in between. One of the key features of pneumatic actuators are that they typically are very fast and can give relatively high forces in a compact format.

2.3.2 Hydraulic actuators

Hydraulic actuators are very similar to pneumatic actuators, the big difference is that hydraulic liquid is used instead of air. Just like with pneumatic, valves are used to control the actuators, but since the liquid is almost incompressible it can transfer bigger forces and gives much more precision in control. This makes it more interesting to fit some kind of encoder to know the position also in between the endpoints. Some of the disadvantages are that it is typically slower than pneumatic systems due to the higher inertia of the liquid, that the liquid must be drained back to a reservoir to create a closed system and that if there is a leak in the system it becomes very messy.

2.3.3 Electric actuators

Electric actuators depends on some kind of electric motor to either create rotary motion directly or via gearing, or a linear motion using a screw or a belt. The electric motors can be divided up into conventional electric motors and stepper motors, where the conventional motors typically are used in a servo configuration where the motor is geared down to create higher torque and more precision, and an encoder are attached to know the current position and control the servo in a closed loop.

The stepper motors are often not equipped with encoders since they can be exactly controlled as long as they are used within their specification. Instead one endpoint is identified and the motor are then controlled in open loop, which helps bring the cost down. Stepper motors usually also have higher torque at low speed and high holding torque to keep a constant position, at the cost of a higher energy consumption and more heat in the motor when standing still at a position. Due to the higher torque they usually do not need to be geared down which may simplify construction and installation. On the other hand, stepper motors torque becomes limited at higher rotation speed due to their design, unlike conventional motors that do not have this problem until much higher rotation speeds.

2.4 Solutions to similar problems

During research it was very difficult to find any papers handling the same type of problems, most results that showed up was companies that offered complete solutions without any details about any specific solutions. The best source of inspiration that was found are videos online [6], [7] that are showing automation processes, and also discussion with the staff at the company.

2.5 List of concepts

To find a good solution to the problem and to avoid getting locked into the first idea that comes to mind, which could be far from optimal, as many concepts as possible must be generated. The concepts are then evaluated in Chapter 3 to find which concept is best suited for further development.

2.5.1 Robot concepts

Here are concepts based on using the available SCARA robot presented:

1. Simply grabbing the spring by its ends with parallel grippers, compress it and drop it into its final location.
2. Somehow pick up the spring in one end, place the other end at the spring seat and then compress it in a similar fashion as would have been done manually.
3. Picking up the spring using a rod which goes through the center of the spring and somehow grip it so that it does not fall off, then use the rod to guide the spring into position and push the spring off from the rod using a pneumatic actuator, as pneumatics already exist at the end effector attachment.

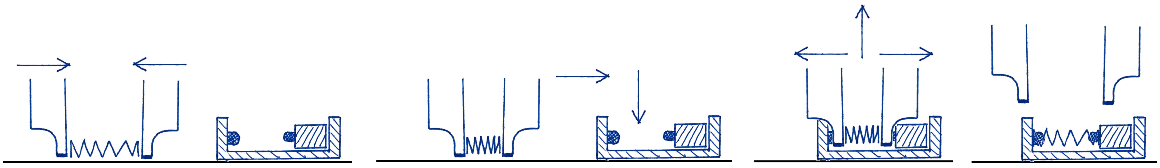


Figure 2.3: Sketch of concept 1

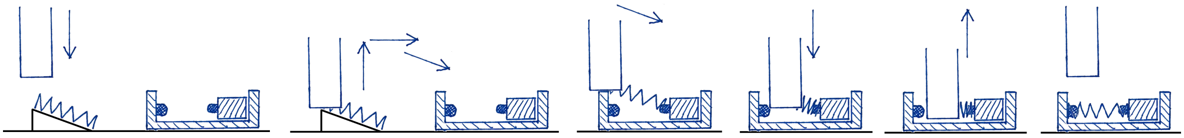


Figure 2.4: Sketch of concept 2

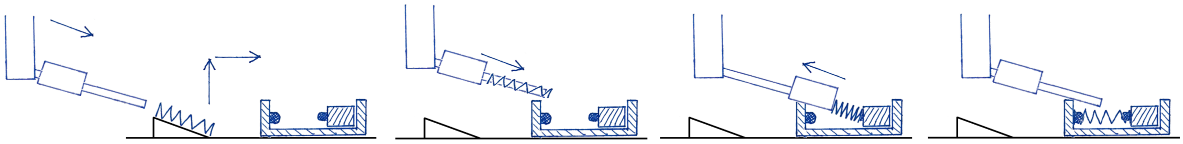


Figure 2.5: Sketch of concept 3, 5, 6 and 7

2.5.2 Separate mechanism concepts

Here are concepts based on building a custom separate mechanism presented:

4. Moving the spring into a camber where it is compressed and then pushed into its location.
5. Similar to concept 3, but instead of using the robot to move the rod, a separate mechanism is constructed, using actuators to move the rod assembly linearly up/down to move it out of the way and pick up a new spring.
6. Similar to concept 3, but instead of using the robot to move the rod, a separate mechanism is constructed, using actuators to move the rod assembly linearly left/right to move it out of the way and pick up a new spring.
7. Similar to concept 3, but instead of using the robot to move the rod, a separate mechanism is constructed, using actuators to rotate the rod assembly to move it out of the way and pick up a new spring.

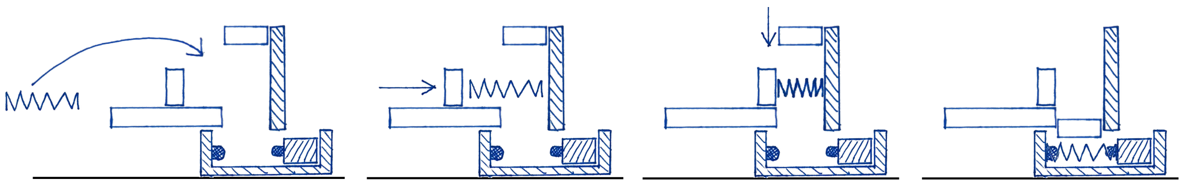


Figure 2.6: Sketch of concept 4

For all of the above concepts the type of actuators also need to be decided, the different types of actuators are presented in Section 2.3.

3

Evaluation of concepts

After the concept generation in Chapter 2 there are many concepts that need to be singled down into one final concept to refine into a solution. To do this, a decision matrix are first used to eliminate concepts and after that the remaining concepts are evaluated to find which one that are going to be developed further. In the case of a separate mechanism solution the type of actuator also need to be decided.

3.1 Decision matrix for concepts

The decision matrix chosen in this case is a simple Pugh matrix [8]. In the Pugh matrix one concept is chosen as a baseline, either an existing solution if it exists or for example the concept that is believed to have the highest potential, and the other concepts are compared against that baseline regarding a number of criteria. The outcome could be either + (better), *s* (same) or - (worse), the baseline naturally gets *s* for all criteria. The outcome are then summarized for each concept, where + adds a point, *s* does nothing and - subtracts a point. The concepts with lowest scores are dropped. In this case, concept 7 is chosen as the baseline based on the feeling that it was the best concept.

Pugh matrix	Concept 7 Rod rotating	Concept 1 Parallel gripper	Concept 2 "The human way"	Concept 3 Rod (robot)	Concept 4 Chamber	Concept 5 Rod (linear up/down)	Concept 6 Rod (linear left/right)
Ease of picking up spring	s	+	+	s	s	-	-
Stability of grip	s	-	-	s	s	s	s
Ease of release	s	-	-	s	s	s	s
Ease of construction	s	+	-	s	-	s	s
Can move the shutter into correct position	s	-	-	s	-	s	s
Cost of equipment	s	-	-	-	s	s	s
Speed	s	-	-	-	s	s	s
Sum	0	-3	-5	-2	-2	-1	-1
Rank	1	4	5	3	3	2	2

Table 3.1: Pugh evaluation matrix for concepts

3.1.1 Evaluation

Concept 1, 2, 3 and 4 will be dropped due to them performing worse than the other concepts, which leaves concept 5, 6 and 7. These concepts happen to all be separate mechanisms using a rod to pick up and guide the spring. The difference between the three concepts are the motion of the rod when it is moved to pick up a new spring. *Concept 5* moves the rod up, *Concept 6* moves left or right and *Concept 7* rotates the rod assembly left or right and at the same time upwards.

The benefit of the last concept is that the rod could be positioned so that it could pick up the spring while the rod is horizontal or even pointing up, so that the spring basically can slide on. For *Concept 5* and *Concept 6* the rod will always be angled down which could cause problems when picking up the spring.

Therefore *Concept 7* is chosen to be developed further.

3.2 Actuator type

Since the chosen concept is a separate mechanism, the type of actuator also need to be decided. Out of the three actuator types (pneumatic, hydraulic and electric), hydraulic actuators are out of the question directly out of two reasons, first since it is messy with hydraulic fluid if it were to leak, and secondly the actuators are typically larger and made for applications where much larger forces are required.

Since the pushing of motion is linear, a pneumatic cylinder is ideal since it is quick and naturally linear, electric actuators would need to first transform rotational movement to linear movement. Another advantage with pneumatics is the low weight and compact size of the actuators, even the rotational pneumatic actuators.

A possible drawback of pneumatics is that it require a source of compressed air which would make the whole package bigger if an air compressor would need to be included. Fortunately compressed air is commonly used in production environments and are therefore usually available from a centrally placed air compressor. If compressed air is not available, some form of electric actuators would be the best choice.

In this case compressed air is available, therefore pneumatic actuators will be used.

4

Development of the chosen concept

Here the development of the concept chosen in Chapter 3 is documented, starting with presenting the concept more in depth and presenting a simple functional model which will give a better idea of the concept. Then in Section 4.2 more details regarding the design choices during development of the different parts are described. Finally in Section 4.4 two prototypes of the solution is presented.

4.1 Chosen concept

The chosen concept is a separate mechanism with the idea that the spring is picked up on a rod which will help guide the spring. When the spring is picked up, the rod is swiveled down, aimed at the location where the spring is supposed go. After that the spring is pushed of the rod so that it is compressed against the spring seat of the moving part and then slips into its correct location. Finally the rod is swiveled away, to pick up the next spring.

4.2 Functional model of the concept

At first a simple functional model was created with help of CAD and additive manufacturing, also known as 3D printing, see figure 4.1. Although far from rigid in its construction and only operated by manual manipulation, it was very promising as it was no problem installing a spring by manipulating the pusher.

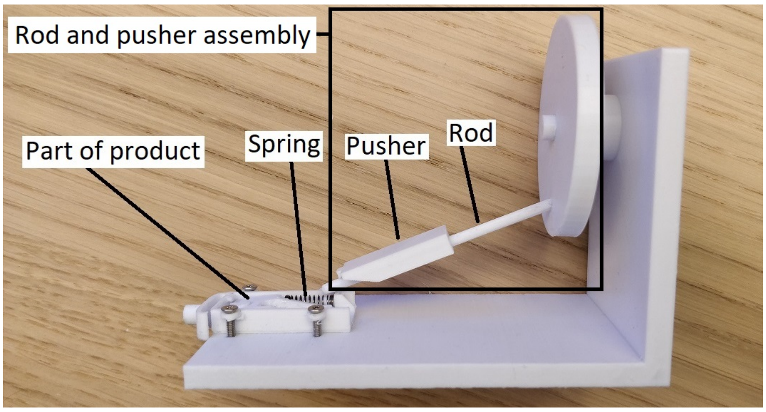


Figure 4.1: Functional model

4.3 Details on the construction

In this section further details of the design choices on the different parts of the mechanism will be presented and motivated. All these parts are then assembled into prototypes, which are presented in Section 4.4.

4.3.1 Angle of the rod

The angle of the rod, and thereby the spring while it is being installed, is important since a to shallow angle would make it hard for the spring to clear the first spring seat but still aim at the opposing spring seat. A to steep angle would instead make it hard to accurately hit the spring seat of the moving part if the part was not perfectly positioned beforehand. Tests were performed with prototypes for angles of 15°, 20°, 25° and 30°, where 20° was found to be the best angle.

4.3.2 Geometry of the pusher

The pusher has two main tasks, picking up the spring and then pushing it into place. To pick up the spring a small hook was added to the front of the pusher, as can be seen in figure 4.2. This hook grabs the first coils of the spring and makes sure that it does not slide of until it is being pushed into its location.

The push angle is set to 70° as it is the complementary angle to the 20° angle the rod have, this makes the push angle parallel with the surface around the location of the spring, effectively confining it to its place and makes sure that it cannot fly away.

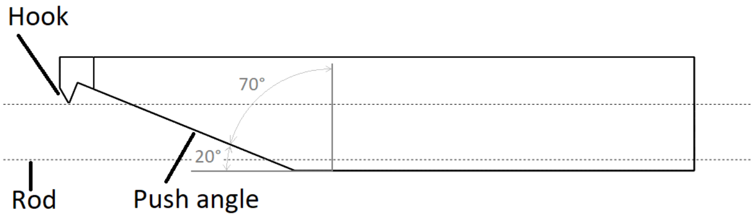


Figure 4.2: The pusher, first version

Further tests with longer springs more similar to the final version showed that the steep push angle of 70° made the springs bend so that the end of the spring pointed upwards instead of sliding off the pusher and on to the final spring seat. This was caused by that the spring only were pushed on the top part of its end coil, and to sort this out a surface with shallower angle was added to push the spring without bending it so much. For the new surface not to collide with the surrounding parts it was made just as wide as the spring and after experimenting with different angles the final push angle was set to 30°. The 70° angle surface are still kept to confine the spring, as can be seen in figure 4.3.

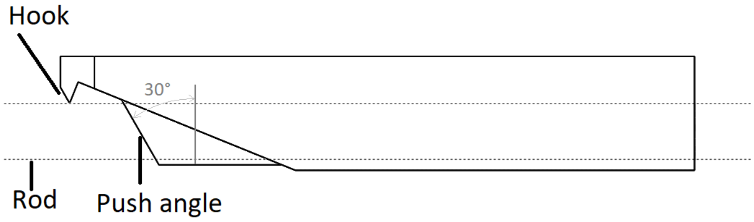


Figure 4.3: The pusher, second version

To be able to manipulate the pusher, a tab with a hole is added on top of the pusher where the rod of a pneumatic cylinder will be attached. On the bottom of the pusher a bigger hook is also added which are used to fixate the pusher when picking up the spring. This feature are described more in Subsection 4.3.4.

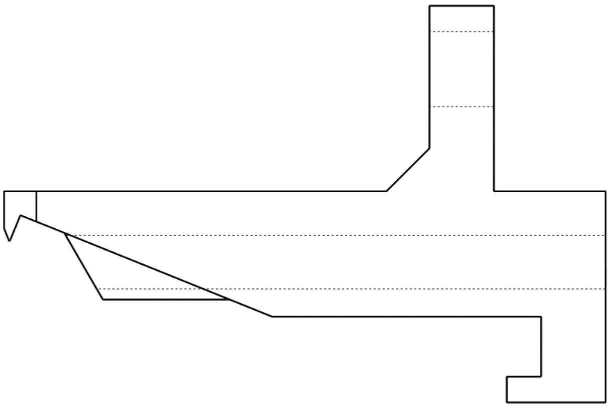


Figure 4.4: The pusher, final version

4.3.3 Receiving and presenting the springs

When researching different existing solutions for untangling and delivery of springs, a common way to transport the untangled springs are via tubes where the springs are blown forward with compressed air to where they are going to be used. This gives some flexibility to where the untangler can be placed which is convenient, therefore the design of the spring pickup is based on this delivery method.

When the springs arrive trough the tube they will not necessarily arrive separated one and one, there could be multiple springs in a row, and the tube will also be used as a buffer so that the possibly irregular flow from the untangler does not disturb the production. Due to this, the queue of springs need to be separated before the springs can be presented for pickup.
With inspiration from another spring feeding solution [6], a quarter circle shaped part that will act both as a separator and presenter are designed to fit a pneumatic rotary drive with 90° motion, see figure 4.5. The springs arrive through the tube from above and the first spring goes into the pocket, leaving about 3mm of the spring outside of the pocket and blocking more springs to enter. The part is then rotated 90° counterclockwise to present the spring for pickup, still blocking springs from falling down with its surface. Finally the part is rotated clockwise to its original position where a new spring can slide into the pocket.

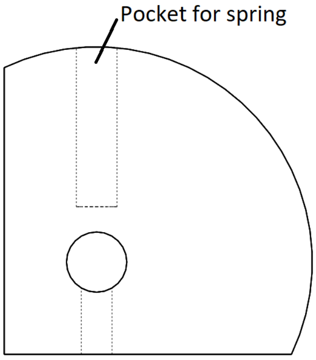


Figure 4.5: Separator and presenter

4.3.4 Spring pickup

For picking up springs the whole rod and pusher assembly are rotated 90° with the help of a pneumatic rotary drive, this also gets the rod out of the way to be able to change out the parts. 90° was chosen so that the spring can be presented horizontally so that it does not unintentionally slide out of the presenter or struggles to be picked up.

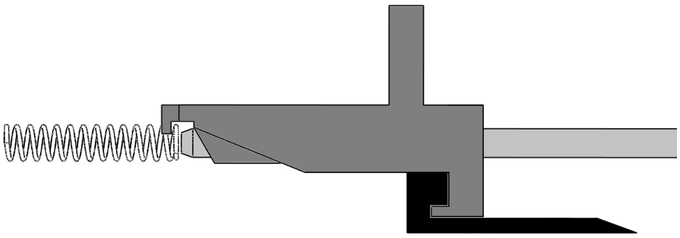


Figure 4.6: Spring pickup mechanism

To be able to pick up the spring (white), the pusher (dark grey) should ideally stop just before the end of the rod (light gray) goes inside the pusher. Since a pneumatic cylinder is used to move the pusher, the exact position of the pusher can not be controlled except for its endpoints, and the endpoints are either fully retracted where the spring is completely pulled up on the rod or fully extended where the spring is completely pushed off and the end of the rod is inside the pusher. So to be able to position the pusher as in figure 4.6, the pusher needs to be mechanically stopped before it is fully extended, which is perfectly fine when using pneumatics as long as the stop is strong enough. This is done by the lower hook on the pusher, which hooks into the fixed stop (black) which are solidly mounted to the fixed frame. To pick up a spring, the pusher is first extended and then the spring is rotated down so that it catches on the hook and are then pulled on to the rod.

4.3.5 Choice of pneumatic components

To order the correct pneumatic components the required forces were calculated and compared against the data sheet of the components to make sure that the chosen component are not to weak. All torques and forces in the data sheet is given at 6 bar air pressure, which is a normal working pressure in compressed air systems.

The main component are the cylinder that will operate the pusher, and the biggest force it will need to overcome is when compressing the spring. From the specifications on the spring it can be found that the maximum force of the spring is 2.3 N, which is when it is fully compressed. The smallest cylinder from the supplier with long enough stroke are specified at 17 N on the outward stroke and 13 N when pulling it back in [9], which is more than needed but still not to strong.

The next component to check is the rotary drive that will swing the rod and pusher assembly, including the cylinder above. The torque needed was calculated by first estimating the center of mass and the resulting lever arm and then summing up the masses, calculating the resulting force.

The center of mass was estimated to be 30 mm offset from the center of the axle when sideways, including a margin of error. The weight of the cylinder is 39.6 g, the cylinder and rod holder 41.5 g, the pusher 13.5 g and the the rod 24.4 g, this sums up to 119 g.

With $g = 9.82$ m/s^2, the resulting static force is about 1.17 N, this gives a torque of 0.035 Nm. The torque produced by the rotary drive [10] is 0.35 Nm, which definitely is enough for the task.

The last component are the rotary drive for the part that separates and presents the springs, this will require almost no torque at all, so the same rotary drive can be used without any problems.

4.3.6 Control of the system

To control the pneumatic cylinder and rotary drives, electrically operated pneumatic valves with one pressure input and two outputs are used. The valves are controlled with 24 V and have two positions, either port 2 or port 4 are pressurised from port 1. The output that currently are not pressurised are vented to the atmosphere through port 3 and 5 respectively. This means that only one valve is needed to operate the actuator in both directions.

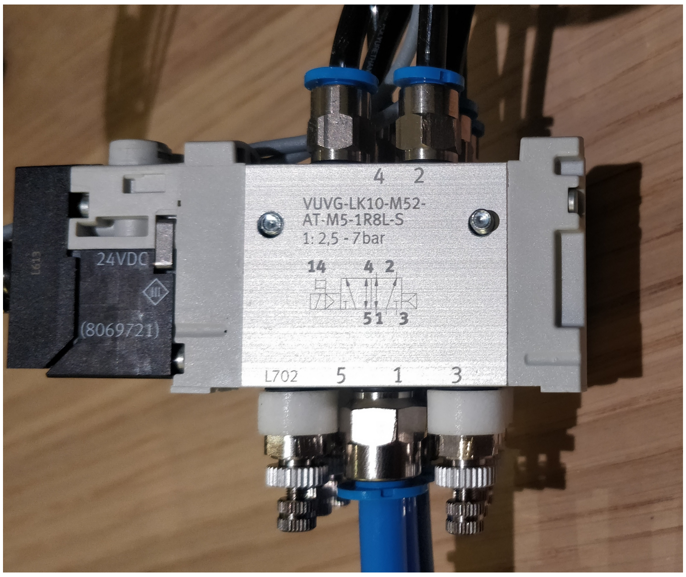


Figure 4.7: Pneumatic valve

To control the relays and program in the sequence they will operate a *Programmable Logic Controller*, PLC, is used. The PLC is a programmable computer with accessible 24 V inputs and outputs, which can provide enough power to actuate relays without additional amplification which is not the case with simpler microcontroller boards like Arduino. In this case the inputs are used for position sensors that detect when the actuators have reached their endpoints, this is used to signal that a movement is done and that the next one can start.

A big difference when programming the PLC, compared to most other programs, is that the execution can not just be stopped and wait for an event. Instead the PLC expects each loop to be executed with a certain time interval, for example every 100 ms, and if the previous loop have not finished in time the program will crash.

This makes using simple delays within the code impossible, instead states and if-statements are used to execute different tasks. The goal is to have sensors that verify that every step is completed before the next one starts, but if it in some case is needed, a timer function and waiting state can be used. The timer function changes its response to true after the desired time and the waiting state checks the response in every cycle, when the response is true it should go to the next state.

4.3.7 Material choices

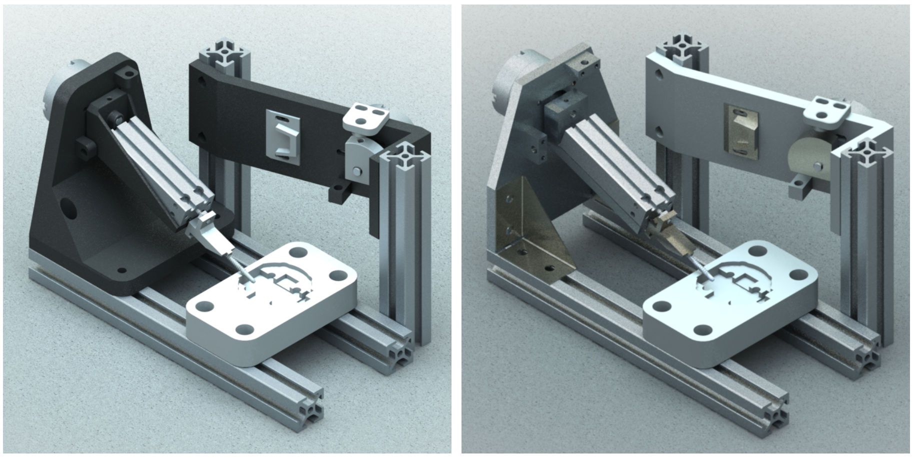
The initial functional model was completely 3D printed using PLA filament [11], which is both cheap and environmentally friendly as it is biodegradable and are made with renewable resources. The first prototype were also mostly 3D printed, with the exception for the rod that was to flexible and therefore changed to steel and the frame that was built out of 20x20 mm aluminum profiles to increase stability and to limit the size of the parts that are 3D printed which saves time.

The second prototype was built to withstand the wear of continuous operation in production, therefore the material selection was changed for some parts as they would otherwise wear out too quickly. Therefore all parts that are in direct contact with the springs, which are made of steel, must also be made of steel, and all parts that are in contact with moving steel parts must also be made of steel. Another goal was to reduce flex in the construction, to increase the reliability.

Depending on the forces on the specific part, some parts were made of aluminum for increased rigidity while other were still 3D printed. The parts that were still 3D printed were now printed in ABS plastic [12] and the reason for choosing ABS plastic over PLA is that it does not deteriorate as much over time. The parts that are now made of metal were redesigned to simplify manufacturing and avoid wasting unnecessary amounts of material. The material choice for each part of the two prototypes are presented in table 4.1.

4.4 Prototypes

All the parts described in Section 4.3 were assembled into two prototypes, where the first one was mostly 3D printed and is shown in figure 4.8a. When the first prototype was verified to work, the material was changed to metal for many previously 3D printed parts to increase reliability and wear resistance. The material choice is described in Subsection 4.3.7 and the changes are reflected in figure 4.8b.



(a) Prototype 1 with mostly 3D-printed parts

(b) Prototype 2 with mostly metal parts

Figure 4.8: Renderings of the two prototypes

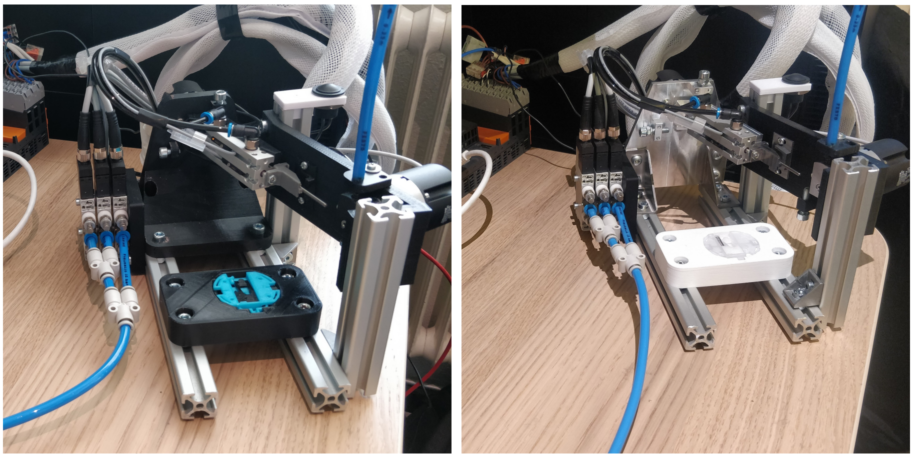


Figure 4.9: Photos of the two prototypes

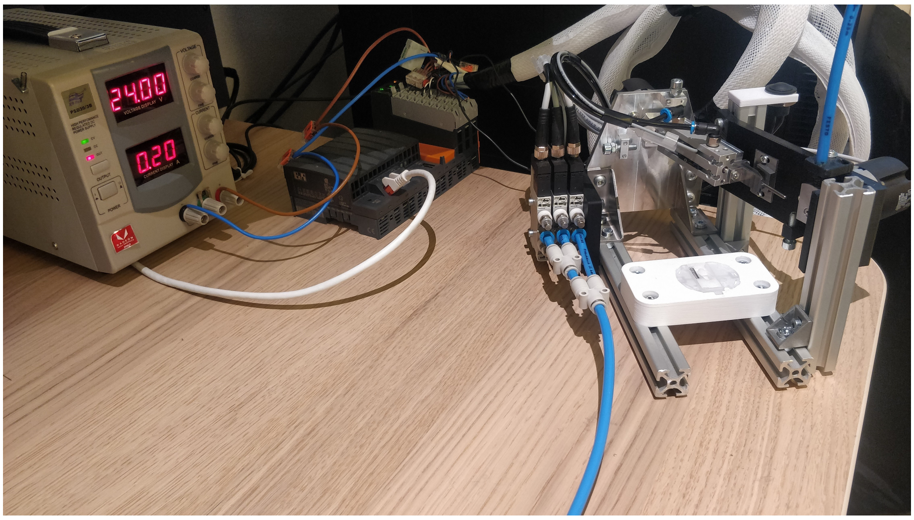


Figure 4.10: Setup of the metal prototype, including power supply and PLC

	First prototype	**Second prototype**
Base frame	Aluminum	Aluminum
Rod	Steel	Steel
Pusher	PLA	Steel
Holder for pusher actuator	PLA	Aluminum
Holder for the actuator that rotates the pusher assembly	PLA	Aluminum
Additional brackets to attache the holder above to the frame	-	Steel
Holder for pneumatic valves	PLA	ABS
Holder for the actuator that separate and present springs	PLA	ABS
Holder for the tube with incoming springs	PLA	ABS
Separator and presenter quarter circle	PLA	Steel
Stop for the pusher for when picking up springs	PLA	Steel
Fixture for the part where the spring is installed	PLA	ABS

Table 4.1: Materials used for the different parts of each prototype

5

Tests and results

After the development in Chapter 4, there are two prototypes to test. These prototypes are described in Section 4.4, where the first prototype is mostly made of 3D printed plastic and the second prototype is mostly made of metal. As mentioned in the introduction, there are three goals that needs to be achieved for the solution to be good enough for production:

- Be able to successfully insert the spring into the assembly
- Be able to complete at least 4 cycles per minute
- Be reliable enough so that no one have to be monitoring the process constantly

Since the first point is key to be able to achieve the last two, the ability to successfully insert the spring into the assembly was tested throughout the development to make sure that it was able to perform the task, which it did. Therefore the tests was focused on speed and reliability. In Appendix A the complete cycle of installing a spring is described and illustrated.

5.1 Speed

For speed, the goal was to achieve at least 4 cycles per minute. To check the performance of the mechanism the complete process of picking up a spring, installing it and returning to the initial configuration were filmed and timed. Since the supply of components were not automated only one cycle was able to be timed and a theoretical installation rate were then calculated as seen in table 5.1. As long as the supply of components can keep up with the installation rate, this number should also be possible to achieve in practice. Since the prototypes operate at the same speed, only one set of numbers a presented which applies to both prototypes.

Cycle time:	3.5 seconds
Installs per minute:	~17

Table 5.1: Installation time

With a cycle time of 3.5 seconds the mechanism is able to install 17 springs per minute, which exceeds the goal of 4 springs per minute with a big margin.

5.2 Reliability

To test the reliability each prototype was used for 100 cycles without doing any adjustments in between and making a note if anything went wrong. Since there were no production parts available at the time of testing, all tests were performed with the same 3D printed plastic parts and a few springs that were used multiple times. These factors need to be noted since it may affect the results as dimensions and surface finish could be different compared to the production parts.

With a desired pace of 4 installations per minute, the installation of 100 springs would take 25 minutes. To put this into perspective, this gives 240 installs during 1 hour and 2160 installs during 9 hours (a normal workday). In table 5.2 the numbers for 1 hour and 9 hours are just extrapolated from the data gathered during the installation of 100 springs.

	3D printed Fail	3D printed Miss	Metal Fail	Metal Miss
100 installations	1	3	0	0
1 hour (extrapolated)	2.4	7.2	0	0
9 hours (extrapolated)	21.6	64.8	0	0

Table 5.2: Outcome of reliability test

A fail is defined as a situation where the system gets stuck and can not fix the problem without intervention by personnel. A miss is defined as a situation where the system fails to insert the spring at first, but manages to install a spring within two additional attempts without any intervention by personnel.

The failure that occurred was because the shutter leaned upward after mounting the spring, thus blocking the pusher assembly from rotating upwards. This was easy to fix by temporarily shutting off the air and pushing it back in place, but it would be an inconvenience for the operator.

All cases marked as miss were because the pusher failed to push the spring into place and pulled the spring back on the rod. That spring was then automatically discarded in the process of picking up a new spring, and the second spring was installed without any problems.

6

Discussion

So, what made the insertion of the spring so difficult with automation? The main problem was that the spring could not be handled like a solid part since it is flexible, but also how the grip needed to be changed during installation from first gripping and compressing the spring to finally pushing it into place.

Then, was it at all possible to automate it, and in that case, could it perform the task with adequate speed and reliability? Yes, it was certainly possible to automate it, and as can be seen in table 5.1 it could theoretically install about 17 springs per minute which is better then the goal of 4 installations per minute with a big margin. With the change of many parts into metal in the second prototype the reliability also became much better as seen in table 5.2, though a test in bigger scale and with components of production quality is needed to be able to definitely conclude whether the reliability is high enough or not but so far it looks very good.

The idea of using a rod to pick up and guide the spring while it was being compressed, combined with a good spring seat in the product, made the whole insertion process very stable and fairly easy to accomplish. Due to the angle of the rod the position of the moving part did not matter, so it was pushed into its correct location by the spring at the same time as it was being inserted. So as long as the location of the spring is accessible in a similar way it would be easy to adapt the concept to other products.

During testing of the first prototype one thing that was noted was that the shutter in some cases would get angled upwards after installing the spring, either hindering the rod to swivel away or making the shutter eject as the rod pushes it out of its way. This was not noted with the second prototype, but if it would become a problem a small edge on the fixed part stopping the shutter to rotate up could be a possible solution. Another solution would be to add an actuator with some attachment that prevents the shutter from rotating up.

One thing that is easy to forget when sitting and designing in the CAD software is how the parts are going to be manufactured in the end, especially when the initial prototype are manufactured with 3D printing which gives a much bigger design freedom in many ways but which also comes with its own limitations. As can be seen in figure 4.8 many of the parts that were initially 3D printed were completely redesigned before attempting to mill them out of metal in the CNC machine.

As for the reason to why the SCARA robot was not utilized even though it initially was proposed by the company it came down to one main thing, that for short movements and small manipulations of parts a set of pneumatic actuators can perform the task quicker and to a lower cost than a robot. Although the robot is available, not using it frees up the resource so it can be used for other tasks. Also, to overcome the limitation of only having four degrees of freedom on a SCARA robot some mechanism would still need to be created, so doing it as a separate mechanism did not make it more complicated anyway.

6.1 Further development possibilities

Before installing this solution in production a bigger test, with the actual injection molded components, the final spring design and automated supply of components need to be performed to make sure that no unforeseen problems arises. Minor changes in the design may also be needed depending on how the components of the shutter are going to be supplied to the mechanism.

On thing that also needs to be added to increase reliability is some way to detect if the spring is actually installed correctly or not, if the spring is not installed it should try a couple of more times and if that is not successful it should halt and alert an operator. The assembly should never leave the mechanism without verifying that the spring is installed.

To limit wear of the machine and reduce noise, the speed of the actuators in could be limited with adjustable restrictors on the returning air. This makes the speed adjustable for each direction separately and does not limit the available force when needed to reach the endpoint. These restrictors need to be adjusted depending on the processes around the machine and the desired cycle time so that those needs are still fulfilled while not operating the machine at higher speed than necessary.

7

Conclusion

In this thesis we looked at the task of installing a spring in a product, found some difficulties but also ways to overcome them. The final solution to the problem is not the only way to solve it, but the idea of using a rod to pick up the spring and guiding into position stood out as a simple and reliable solution compared to the other ideas that came up during concept generation. As can be seen in the results of the testing, the achieved installation rate was over four times higher than the requirement and the machine also proved to be very reliable during testing.

The ability to automate this task is of great importance when it comes to where a company can place its manufacturing and assembly, which makes it possible to keep it locally, which ensures both working conditions and limits transport. Although today's market is in many cases global, trying to keep production as local as possible is something we should strive for with the goal of sustainability.

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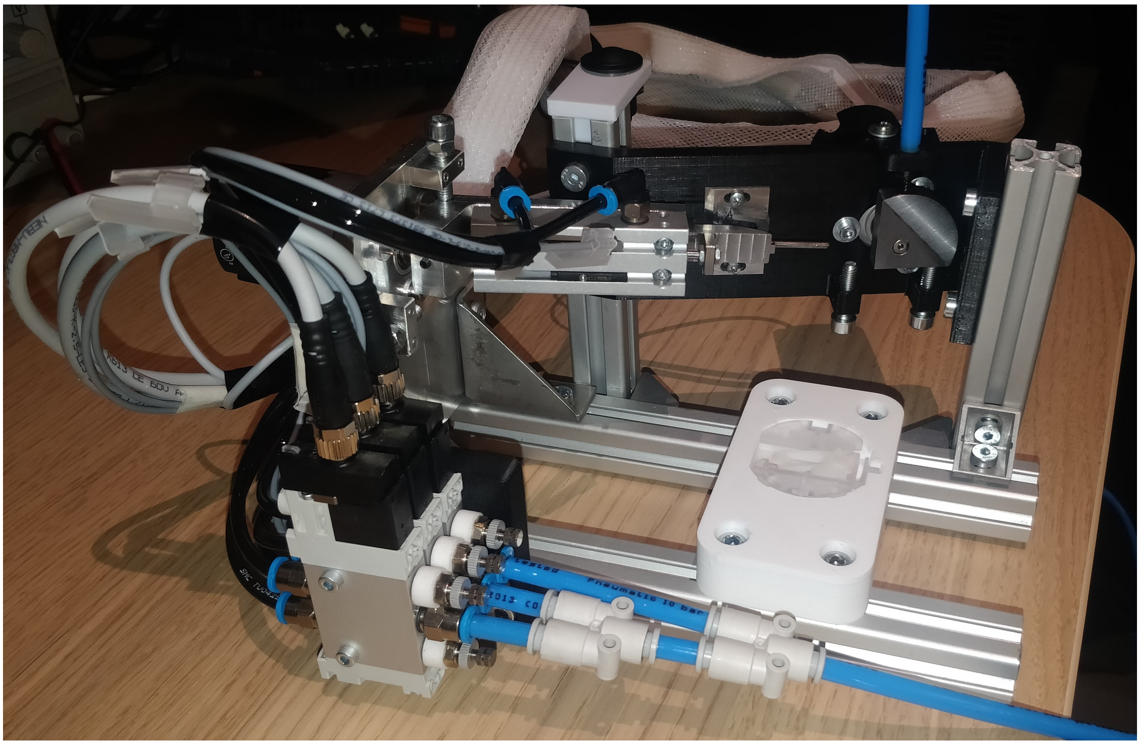
A

Appendix

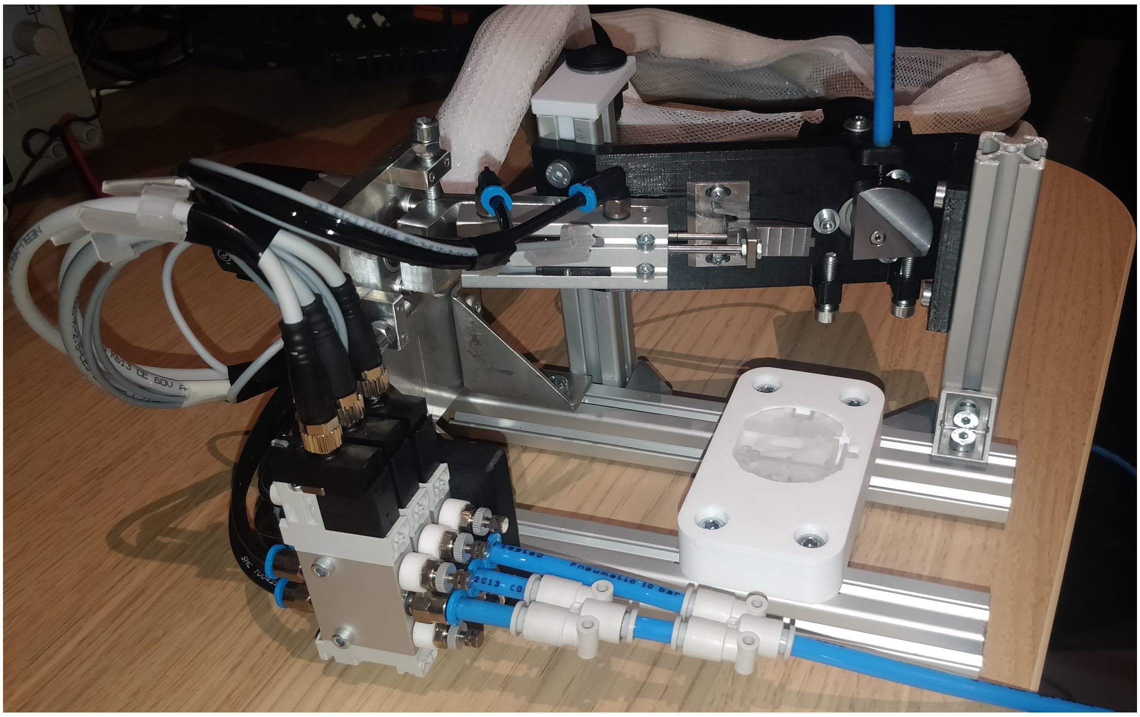
Here the complete cycle of installing a spring in the product is described.

The initial state is where the pusher assembly is up and the pusher is retracted, in this state the product without spring can be placed in its white plastic holder.



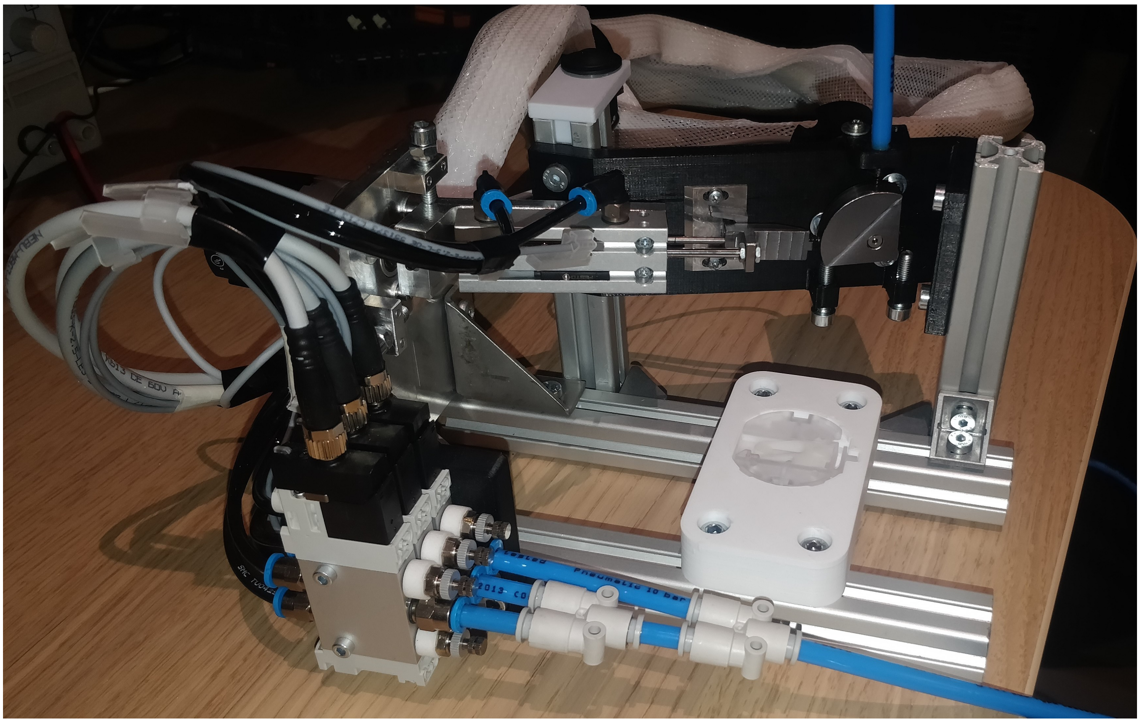
Initial state

In the second state the pusher is extended to be prepared to pick up a spring.



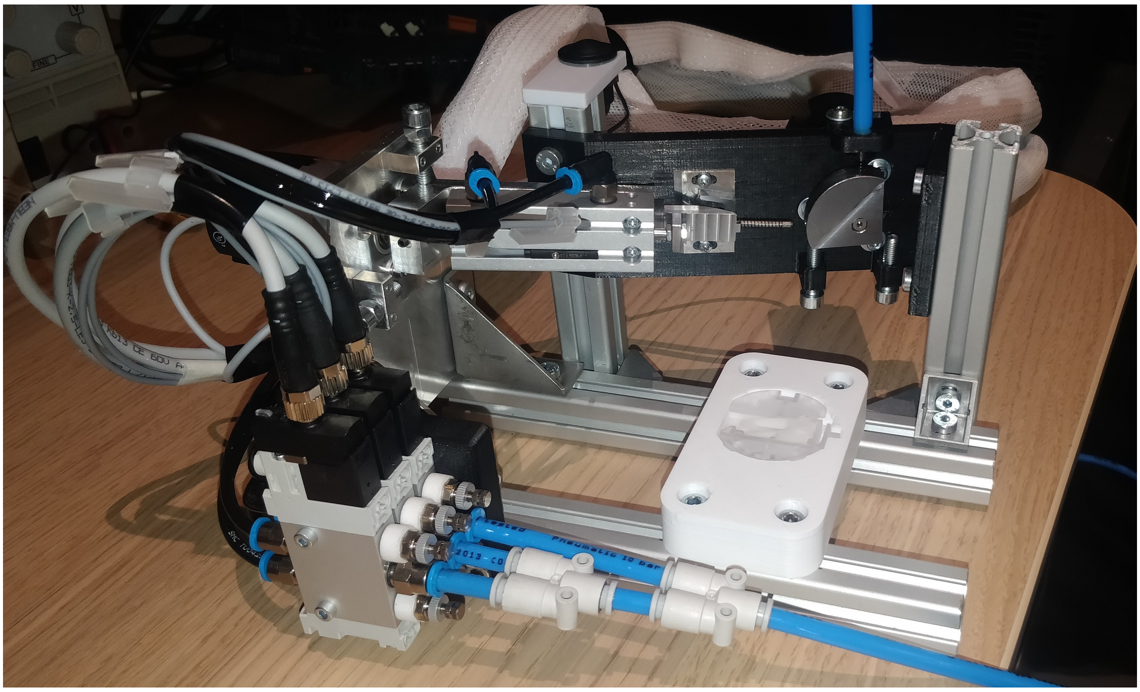
Second state

In the third state the quarter-circle wheel rotates down with a spring from the vertical blue tube so that it is now horizontal.



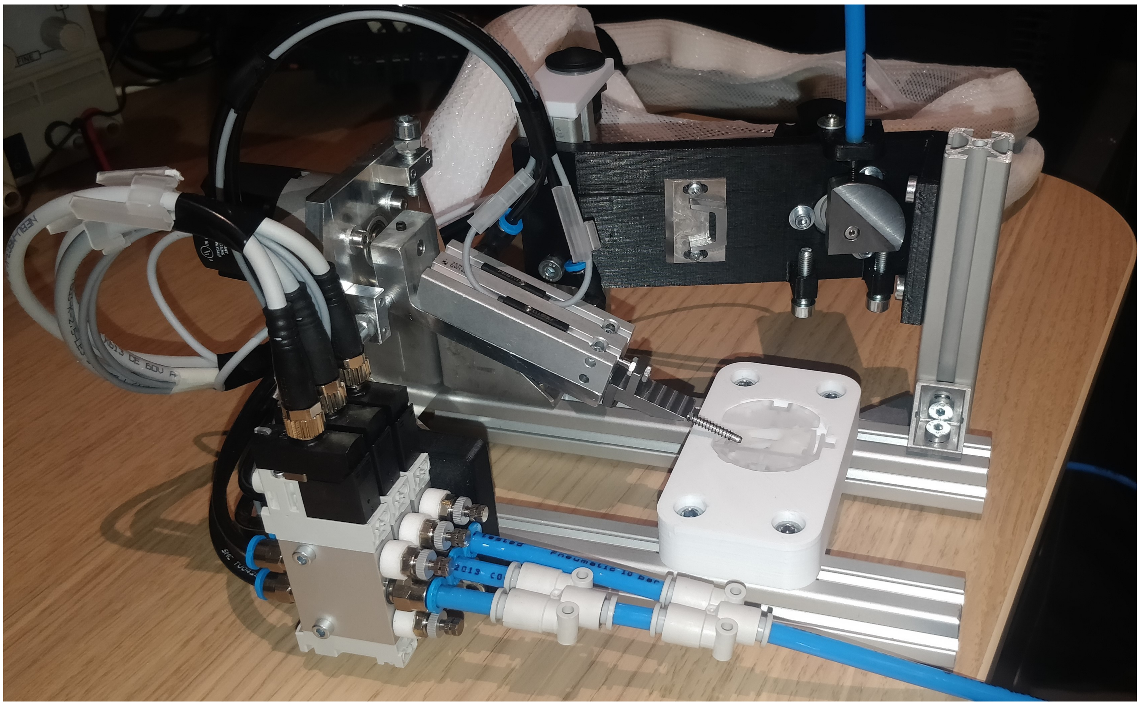
Third state

In the fourth state the pusher is retracted, pulling the spring back with it.



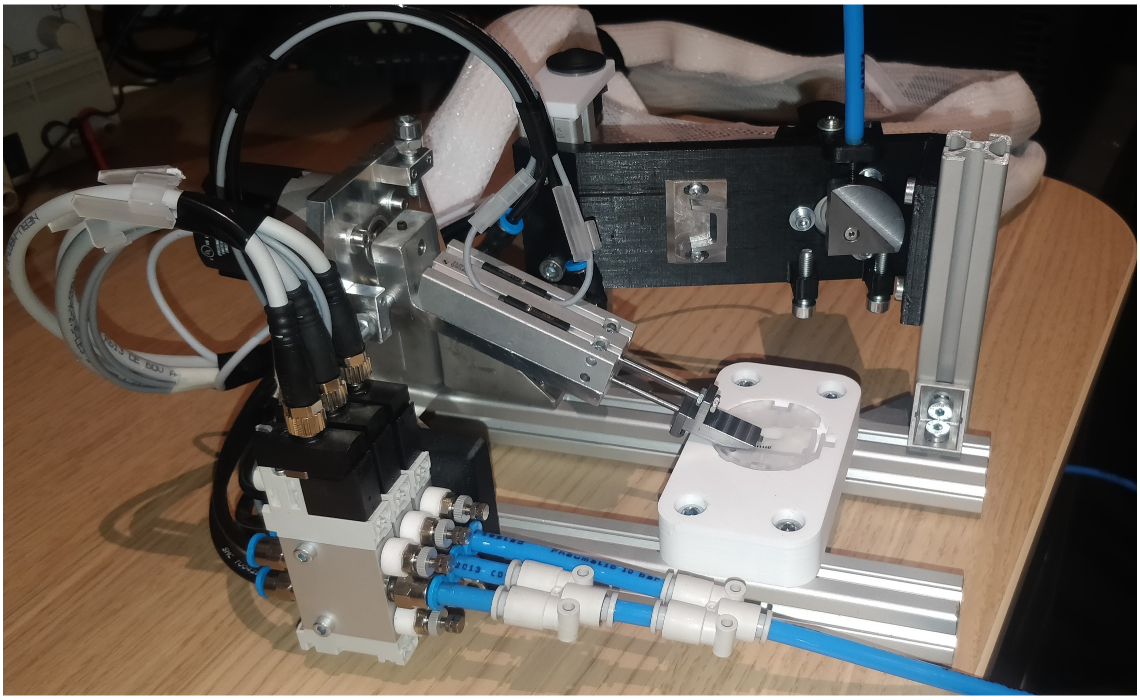
Fourth state

In the fifth state the quarter-circle wheel is rotated back up and the pusher assembly is rotated down.



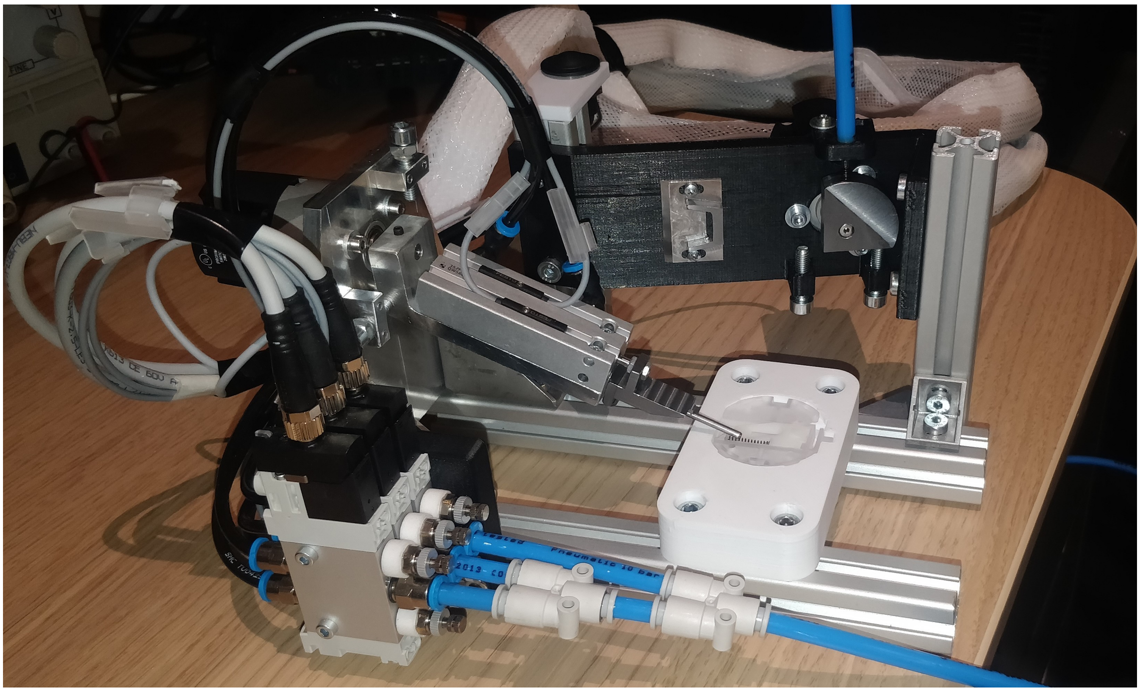
Fifth state

In the sixth state the pusher is extended and pushes the spring into its position.



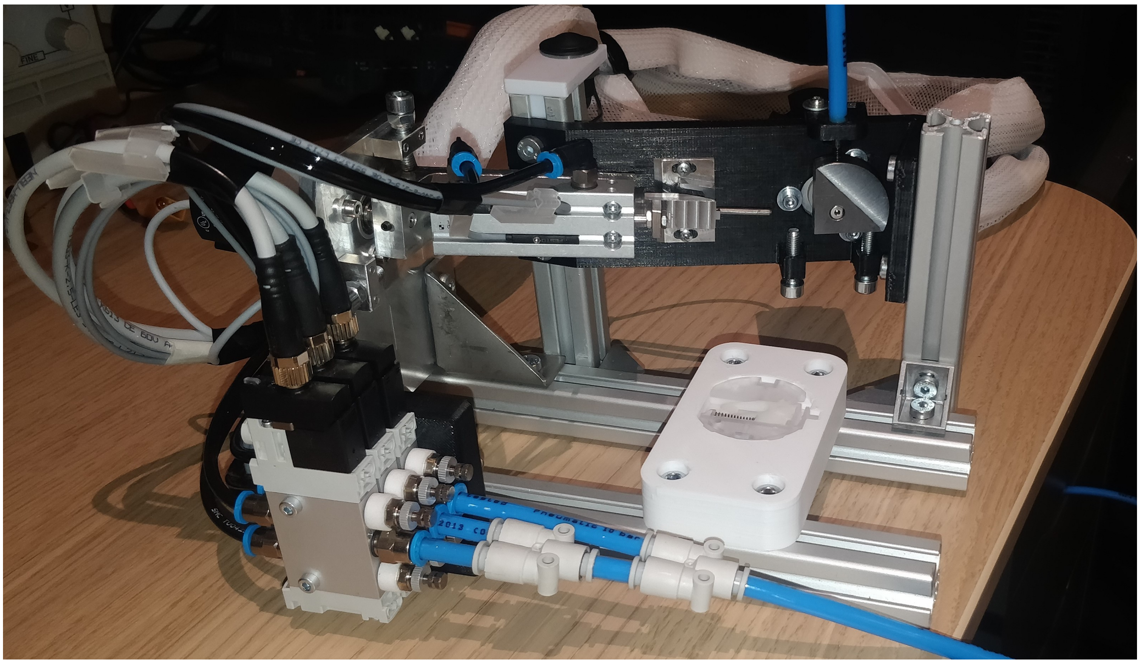
Sixth state

In the seventh state the pusher is again retracted and the spring is now installed.



Seventh state

In the final state the pusher assembly is rotated up again, so that it is out of the way for removing the product, now with spring, from the holder. Then we are back at the initial state.



Final state