THE POPCORN EFFECT

Hydraulics clip de-tangling and delivery

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DROITWICH SPA HIGH SCHOOL AND SIXTH FORM CENTRE

BOSCH

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Executive Summary

Throughout the assembly of all hydraulics units at the Worcester Bosch factory, many wire clips are fitted. During storage, these clips often become tangled, and untangling creates an additional task within the assembly process increasing the process time.

This year saw a requirement for Worcester Bosch to reduce its production assembly cycle time from 41 seconds to 38 seconds and so our project challenge was to reduce non-value-added time in production when handling these clips.

The brief was particularly challenging but interesting: to find a way to de-tangle and present these clips to the operator. This meant a redesign of the process of delivering clips to the hydraulics line and reconsidering how they are stored for easier assembly and reduced assembly time.

This felt like a brief with a lot of potential depth to it, it required the consideration of many aspects, from the motions required to separate clips from each other and how to keep them separate, to how to store them and if that was even necessary.

As with many projects, the more we've done, the more it feels like we've only really managed to scratch the surface of the teams' ideas. And with more time and resources, some aspects of the project could have been complete in even greater death. In Appendix C - Personal reflection, we each have talked about elements of the project we feel could have been developed further.

This report contains our process from research and testing to design and development and all the way to the manufacturing of our final prototype.

Introduction

The Problem

Throughout the assembly of all hydraulics units at the Worcester Bosch factory, many wire clips are fitted. These clips are stored on each station on the assembly line in production bins and often become tangled. Where only 1 clip is to be picked and fitted to a product, this entanglement can create an additional task within the assembly process. The additional complexity in the task also ncreases the process time.

In 2025 the business is predicted to see an increase in demand on the final assembly lines, which will mean an increased demand from the hydraulics sub-assembly line. The current cycle time of the production cell is 41 seconds, but next year the line will need to run at 38 seconds. Any non-value-added time in production must be reduced or removed.

The Brief

Our brief was a design a solution to the problems Worcester BOSCH were having with the clips on the hydraulics line. The clips are delivered in bags of 1000 that are then emptied into boxes on the assembly line. Hence them being incredibly prone to getting tangled together. Additionally, soon BOSCH are going to reduce the cycle time from 41 seconds to 38 seconds, and that means that every second is precious and that anything we can do to decrease cycle time is useful.

The project proposed is a redesign of the process of delivering clips to the hydraulics assembly line at Worcester Bosch. The new process must consider the improved storage of the parts on the assembly line, so that clips have a reduced rate of entanglement, for easier assembly and reduced assembly time. Many clips of similar likeness are included on each assembly station and so the sorting of these clips could also be considered in the project scope.

The Solution

Due to the time limitation of this project and the sheer scope of the brief, we felt we needed to focus on a single element. We decided this element should be the de-tangling since that is what is causing the most problems on the assembly line. We didn't have time to look beyond this section, but we feel that we've identified a solution on how to de-tangle them, and how to present them to the operator. And that is what is documented below.

Initial Research

The first stage was to look for inspiration was by researching preexisting component sorting/aligning mechanisms used in manufacturing. Several different methods where found. Each with its own merits and limitations. The research wasn't about specifically the kind of parts we are working with but are general methods of sorting and separating. We did this to give ourselves a credible idea of what we can work with, whilst leaving our ideas open enough to apply to any of the different clips.

For some kinds of parts, it is possible to use a rotating arm to pick up the components in the right orientation and place them onto a rail. It was thought that something like this may be effective for our project because it presents parts directly into potential storage. It is also a remarkably simple idea because at its core it is just a single rotating arm. But because of this simplicity we felt that it could be too unreliable since there is little happening to orient the part and it is pure luck as to if the arm grabs one or not.[1]

EACH PART HAS A UNIQUE HEIGHT

Alternatively, it is possible to take advantage of a unique aspect of a part such as its height or a prominent physical feature in order to separate and align parts. This could mean that the processes of de-tangling a single type of clip and separating different clips could be made into a single mechanism. A limitation of this may be how dimensionally similar the different clips, making it difficult to find an aspect to use.[2]

The most promising method that we saw were vibratory feeder bowl systems. This was the first application of vibration we saw, and it provided inspiration for most following ideas used in the project. The bowl is shaped in such a way that parts move upwards in a spiral, and that ledges and specifically shaped sections knock off or realign the parts that are in the wrong orientation. Compressed air is also sometimes used to blow off some parts if they mis-oriented. A limitation of this kind of mechanism is how specialist they are, but we may be able to take the idea away find our own method.[3]

THE SPECIFICALLY SHAPED SECTIONS ONLY ALLOW THE PARTS IN THE CORRECT ORIENTATION TO PASS

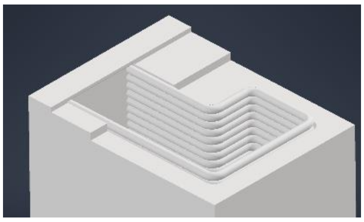
First thoughts on Various Ideas

Below is a summary of the initial ideas relating to de-tangling and storing. Any visualisations are using a simple clips shape that are unfaithful to the real clips, this was done to act as a simple way to visualize without worrying about specific clips.

Storage

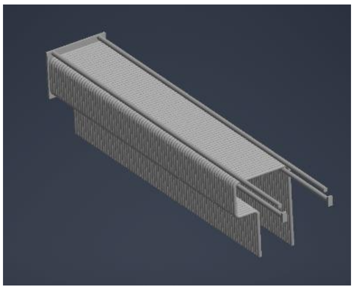
With the wide scope of the project and limited time, we felt it best to focus on the de-tangling element of the project. Nonetheless we wanted to consider storage as well, so we did start thinking of some ideas. Even though we didn't think we'd be able to prototype them.

Cartridge



We considered the concept of storing clips in groups of 100 or 200 in a long tube with the same profile as the clip. It would have been designed in such a way that a single clip could be taken at a time, and all the others would move forward. Ideally with an indicator of how many are left.

Rails



The second idea we had (as a variation of the cartridge) was to take clips and have them on a pair of rails placed at an orientation so that it is a perfect fit for one type of clip. They can then slide down as clips get taken from the end by the operator. The idea solved some of the problems with the cartridge, admittedly while introducing some new ones, but it was thought promising.

No Storage?

As the project proceeded, we considered a different idea. One that came from the question "what if you didn't need to actually store the clips?" We started wondering if they could just land on a surface directly on the hydraulics assembly line and be picked up by the operator when needed. The principal being they would stay de-tangled because they're not getting moved until they are attached to the component. For a limited number of clips (at any one time) we felt it could work but further work would be needed to fully determine if that is true, and to optimise this solution.

De-Tangling

Sieve

Consideration was given to a sieve-like bowl with holes slightly bigger than the clips so those that are not entangled with other clips can fall through. The clips could have been moved by hand by the operator or shaken mechanically. They would then drop into or onto storage. After some consideration it was decided that it probably wouldn't be that effective, and most likely too slow to meet the 38 second cycle.

Plate Vibration

We also considered use of a vibrating plate that was shaped to slowly move clips towards storage. Looking at the vibratory bowl feeders it can be seen that the vibrations cause the parts to move in a very controlled manner, meaning it might be effective to experiment with. However, further testing led to the idea being ruled out because of insufficient speed and sometimes separation of clips was ineffective and would have caused a delay in the assembly process.

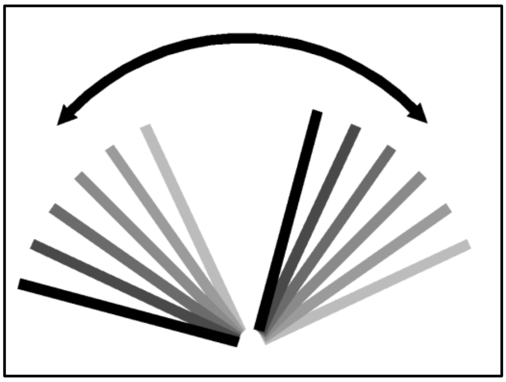
Angled Panels

Tests were done using two sheets of MDF at an angle to each other and with a small gap between them allowing clips to be dropped onto them. The clips would be funnelled into the centre, and we found that with an appropriately sized hole, you'd usually only get one or two dropping through at a time since the hole would be too small for only one. However, this idea was impractical without intervention as the bunches of clips would get caught and the entire system would stop working. This showed that it was an unsuitable concept to use for the final design.

Arm

Despite being considered as part of initial research, this was ruled out before doing more testing. Briefly we considered using some kind of arm to push into the bin of clips and extract a number of them in the process. However, it was found that the resistance of the clips as the arm lifted was too much to be practical though and this idea was not pursued further.

Oscillation



Oscillation was an alternate version of the angled panels idea mentioned above. It was found that if the panels were oscillated around the hole the clips were falling through instead of bunches getting stuck, the oscillation of the panels against the clips would cause them to separate effectively. This idea would have been perfect if not for the potential cost, it was considered that a large object oscillating constantly would have used too much energy to be cost effective, and the wear of parts would have been a major concern, so this concept was ruled out.

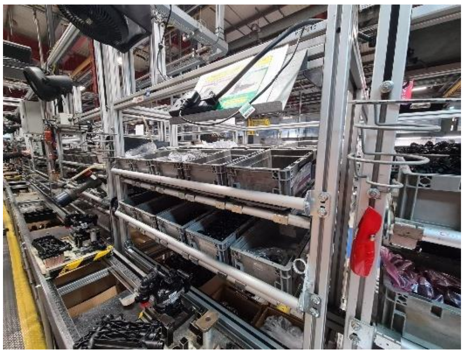
The "Popcorn" effect

This idea started as experimenting with an acoustic cone-type speaker controlled by a signal generator. It was observed that the motion of the speaker could accelerate and throw clips upwards, and that if a group of partially tangled clips were placed over the speaker at the same time, only individual clips would escape from the group. Meaning only one clip was jumping up at a time. While it was running the sound made by the clips against the speaker cone was a kind of popping sound similar to that produced when cooking popcorn, hence the name 'the popcorn effect'.

Further Developments and Testing

Visit to Worcester BOSCH

Around the time of beginning testing, the team went to visit the factory at the Worcester site of Worcester BOSCH. Seeing the factory floor, particularly the Hydraulics line, was incredibly beneficial in allowing us to consider our ideas in more depth. This is because we could see how the clips are currently presented to the operator, therefore seeing the current problems being faced in the assembly process. Additionally, it meant we could begin to gauge the space available for our mechanism.



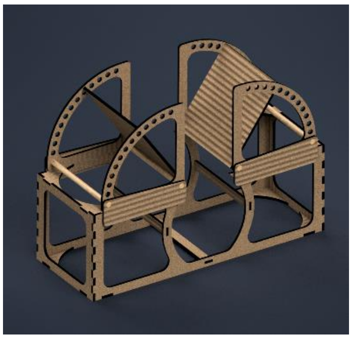

Testing

This section details the testing we did to determine the most likely ideas to work.

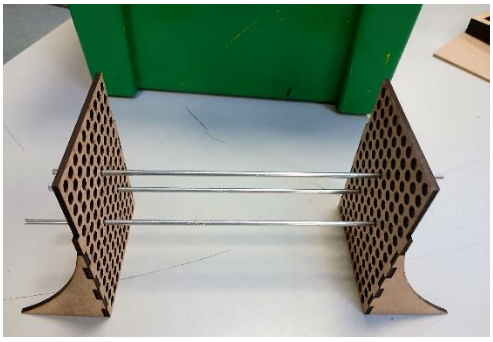
At this point the testing is purely qualitative: all observations made were to enable the optimization of ideas used as we move towards the final prototype.

All the testing was fascinating because often the clips would behave in different ways to what we expected. However, a lot of useful information was learned, and it really helped the team push towards what would eventually become the final prototype.

Angled Panels / Oscillation



For this, it was decided it would be a good idea to create a testing rig to optimise the gap between the panels and consider the motion that would work best. The rig was 3D modelled to ensure it would fit together and then laser cut out of 3mm MDF. Breakages of the rid did unfortunately occur which slowed our progress to some degree during testing but while it was working it was found that the oscillation made the de-tangling much more effective and that it was possible to simply to drop onto a wire held below which could act as a form or storage or to guide it into storage.



AN ELEMENT OF THE RIG USED TO TEST DIFFERENT WIRE SETUPS BELOW THE PANELS

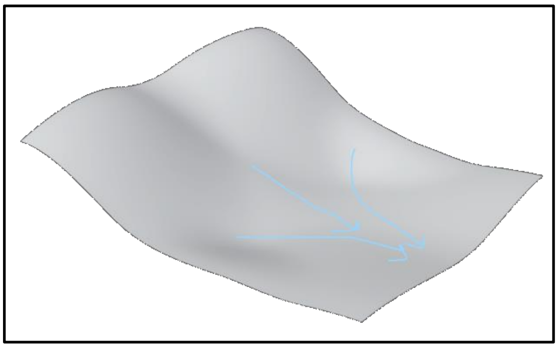
It was noted that as the clips fell, not all landed on the wire meaning there would have to be some kind of cycle of clips allowing those that don't get caught get fed back into the process. For this reason, it seems unlikely that this would work on the assembly line due to its size. Future consideration could be given if the device could be placed in the logistics department instead of the factory floor and then the de-tangled clips moved onto the assembly line afterwards.

Popcorn

The first step for testing this was to make an enclosure around the speaker. This was done using a paper cylinder simply held around it. We tried varying the height and the radius of the cylinder and although it was not possible to find a specific combination that was perfect, it gave the team confidence that this was a really promising idea. It also confirmed our experiments before that if there were many clips in the enclosure, only single untangled clips would jump out at a time. Meaning that they wouldn't tangle, and the 'popcorn' principle was working as intended.

In terms of presenting clips to the to the operator we knew from these experiments that since the clips get thrown out of the top of the enclosure at random uncontrolled angles, a way was needed catch and collect them. It was thought that use of a cone beneath the speaker would be effective at catching the clips, but due to limited time, it was decided to focus on de-tangling as a first priority and revisit this aspect of the design later if time permitted.

Plate Vibration



It was found that if we took a piece of paper and bent it in such a way that it wasn't creased, but ensured a gentle slope in one direction, the clips would slowly move down the slope while separating from each other. But all would be funnelled in one direction.

It was observed that this would offer an excellent method for presenting suitably separated clips to the operator since the clips all move in a very controlled manner and are all moving towards one place. If placed on the line, operators would be presented with a slow, continuous feed of clips. Alternatively, due to how controlled the motion of the clips is clips could be quite easily placed into storage in the logistics department and then moved to the assembly line. However, there were concerns that the process was too slow and with the high failure rate. Leading to clumps of un-separated clips reaching the output of the mechanism.

Decision Matrix

Idea	Effectivness	Cost	Size	Speed	Maintance	Total
Reciprocal Vibration	3	2	3	1	3	15
Occilatory Vibration	4	1	3	5	1	18
Popcorn Effect	5	3	4	4	3	24
Sieve	2	4	1	2	5	16
Angled Panels	1	5	5	3	4	19

Decision matrix techniques were used to select the idea for the team's final prototype. The categories were derived as a summary of the specification given to us by Worcester BOSCH. In each category, we ranked each idea on a scale of 1 to 5. (5 being best and 1 being worst) and totalled the scores to determine the best decision. A weight was applied towards effectiveness since that is the most important aspect of the design. A low ranking wasn't necessarily taken to mean that an idea is bad in that category, simply that the others are better.

This is how the team defined the categories:

- **Effectiveness**
  → This is reasonably self-explanatory. How good that idea is at separating and controlling clips. This is partly about how often failures occur. and partly how separate the clips are presented.
- **Cost**
  → The Cost category combines both manufacturing cost and running costs. With a slight focus on running costs since they should have a much bigger impact over time. This *does* include maintenance costs.
- **Size**
  → It was considered better for the design to be more compact since the space on the hydraulics assembly line is only so big.
- **Speed and Cycle time**
  → A key part of the specification is the cycle time reduction from 41 to 38 seconds. Some ideas were too slow to work within the shorter cycle time. It was thought better for more clips than needed to be output than too few.
- **Maintenance**
    - This is a combination of how often maintenance is needed and how easy maintenance would be.

As can been seen in the image above, the idea that came out on top was the "Popcorn" effect. So, the following part of the report will focus only on that, and how the team developed it.

Final Testing and key takeaways

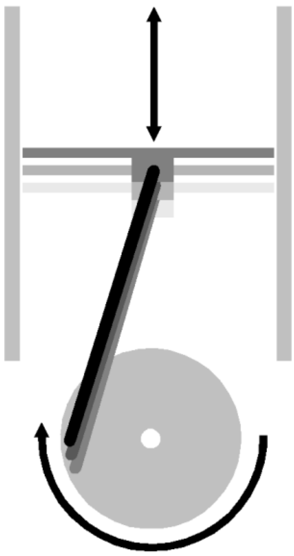
Tests

To test the so called "popcorn" effect thoroughly the team decided to create a container that was more rigid than the paper version, and more representative of the final design. The container was made of layers of laser cut 6mm-MDF so that the height could be adjusted. We didn't allow for a variable radius; it was simply made to the side of the speaker cone to maximize use of the speaker without making it too big. NB at this point that although for the tests carried out and even the final prototype design, the team has made use of a speaker and signal generator. This would not be the case for the production line version. Most likely a production version would use a rotary to reciprocal mechanism as shown below, See final developments in the next section.

For the development prototype the team made a container out of semicircular pieces (semicircular instead of a full circle to save on material) that could be layered to assemble to different height with 4 pieces of metal bar through pre-positioned holes to hold everything together.

Different combinations of factors were tested to help to determine which setup have the best results. Different heights were tested by varying the number of layers (Either 10 or 15), and clip loading level effects were measured by varying the number of clips that started in the container (10,15,20 or 25) and the frequency was varied qualitatively.

To do this the team set up a clamp to hold a phone enabling a video to be recorded of each setup. Each video had text visible with the setup of that video. We took from these videos the time between the speaker turning on to the container being fully empty and confirmed that the more clips you added, the longer it takes. This may appear quite obvious: if there are more clips to remove from the contain, they will take longer to all leave. But it was an exponential relationship, meaning that on average with more clips in the container, the *rate* of clips jumping out is lower. It will take longer for the next clip to jump out compared to when there are less clips. This is quite a useful observation because it means we can potentially control the rate of clips coming out.



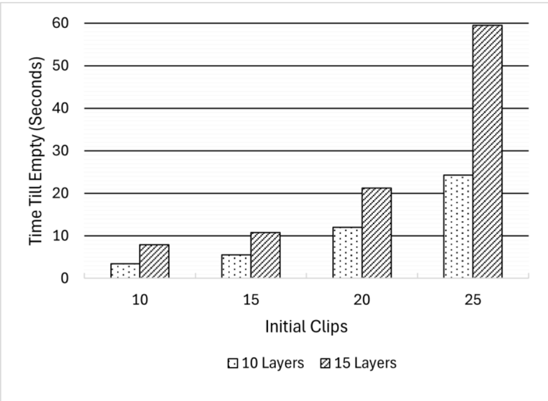
THIS IS LIKELY A BETTER MECHANISM

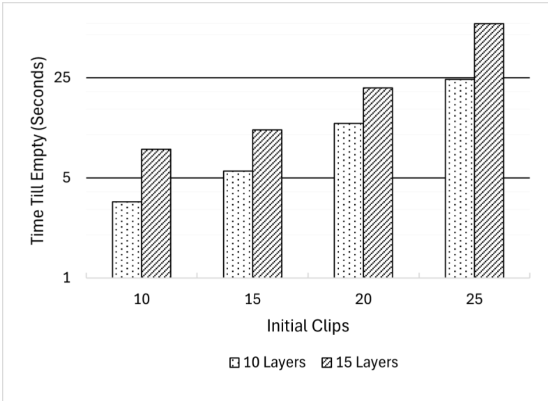
The most effective frequency for separating clips was 60Hz. It appears that the reason for this may be that the speaker cone is moving fast enough to put energy into the clips, but it also doesn't create a pattern where the speaker comes up and almost catches the falling clips and absorbs their kinetic energy. Instead, it interrupts their fall at the right time to make them jump up again. Alternatively, 60Hz could be the resonant frequency of the speaker since at a speakers resonant frequency it will displace more air and so in this case would be putting more energy into the clips.

Risk Assessment

Hazard	Risk	Mitigation
Clips moving with speed	Fast moving clips could damage eyes if they are hit	Ensure people don't stand too close to the mechanism when running. i.e. Do not look down on the mechanism. Do not crouch next to the mechanism.

Summary Of Takeaways





1 - Height of Container

In the graph, it can be seen that when only 10 layers are used the rate of clips is *more* constant than with 15 layers. This makes the process more controllable. It also provides an opportunity to minimize the size of the design. Minimal size makes it easier to fit onto the assembly line and more controllable makes it generally easier to work with.

2 - Frequency

As discussed earlier, the most effective frequency was 60Hz, it seems to give plenty of energy to the clips, which aids separating and maintains effectiveness even if a larger number of clips is loaded into the equipment.

3 - Number and Maximum Number of Clips

After 25 clips, it was found that it would take a *very* long time for any clips to jump out. This may be a limitation of the speaker and its power, meaning we can't make the entire structure big enough to allow for more. But this means a way will be needed to control the rate of feed of clips into the container. Unfortunately, due to time constraints we weren't able to look into this, but we think that it might be possible for the operator to grab a handful when they're running low.

4 - Enclosure

Both for safety and functionality, a means of catching the clips as they jump out is required and must be designed in such a way that clips will be contained regardless of their speed. This will need to be a structure that surrounds it on all sides.

Final Prototype

Cardboard

To design and make the final Prototype the team started by making a simple cardboard model held together by masking tape. This was used this to gauge the size of the enclosure and to allow us to better consider the manufacturing of the final design.

We discovered that the size of it meant that we'd need a cone on the top to allow the operator to drop clips in easily.

CAD and planning manufacturing

It was decided that the easiest way to manufacture our final prototype was to use a combination of Laser cutting and 3D printing. The stand, holding the enclosure and the speaker in place, would be laser cut out of 3mm MDF and then glued together. The enclosure would be made of clear 3mm acrylic panels, which would be then hold together by 3D printed corner pieces.

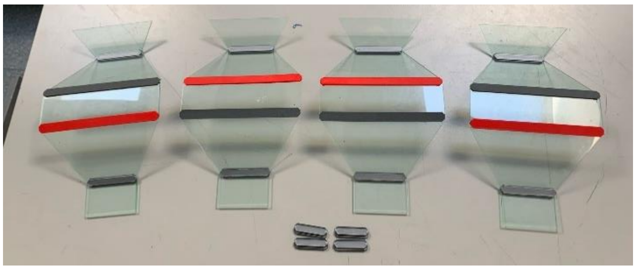
The Stand

The design of the stand was quite a simple one, but at the time we thought it was a highly effective way to allow the parts to all be held together using flat pieces that could just be glued into place. Additionally, it doesn't matter that individual sheets of 3mm MDF aren't that strong, since we're combining them into a single stronger 3D structure.

Enclosure

We needed a handful of different variations of the corner piece to hold the enclosure together, so the team developed a parameterized CAD file. This makes it possible to enter a list of angles and lengths required, and the parts are generated procedurally. This gives STL files which can then be sent to a 3D printer.

Part Number	ANGLE	LENGTH	THICKNESS	ACRYLICDEEP	Chamfer3	Chamfer4
Join-01	144.74 deg	185 mm	3.2 mm	5 mm	Suppress	Suppress
Join-02	109.47 deg	105 mm	3.2 mm	5 mm	Suppress	Suppress
Join-03	90 deg	50 mm	3.2 mm	5 mm	Suppress	Suppress
Join-04	109.47 deg	58.312 mm	3.2 mm	5 mm	Suppress	Suppress
Join-05	109.47 deg	80 mm	3.2 mm	5 mm	Suppress	Compute
Join-06	144.74 deg	80 mm	3.2 mm	5 mm	Compute	Suppress



The acrylic parts are based on the faces of an octahedron. Each face is an equilateral triangle but because the top and the bottom points of the octahedron have been cut off, the faces become trapeziums. Then there are the 4 rectangles at the bottom to stop stray clips from flying outwards, and 4 more trapeziums at the top to act as a funnel for clips getting added.

Evaluation

Below is our evaluation of the final prototype on the points given in BOSCH's specification.

Quality

When the clips fall out of the bottom of the mechanism, they seem to always be de-tangled. This means that the operator is able to pick up individual clips creating a more reliable process. Overall, we feel that this is a very good point in the prototype.

Cycle Time

Because the clips are leaving the device de-tangled, we have successfully removed the non-value-added assembly time being given to de-tangling. However, some of the non-value-added time gets reintroduced by the need to refill he device periodically, nonetheless this is a quick task since no de-tangling needs to occur before clips gets added to the device. For this reason, although we can't be sure without testing on the assembly line, we believe we could fulfil the 38 second cycle time.

Efficiency

While the device is running some clips do get stuck due to the attraction to the speakers magnet. However, for two reasons, this is not an issue. Firstly, in reality, a speaker would not be used to excite the clips. Instead it would be a rotary to reciprocal mechanism. Is low energy use since it is running a rotary motor at a constant speed. And standard components could be used. Secondly even when the clips get stick, others will collide with them and force them onwards. However, since we are getting a higher than allowed failure rate, we have not managed to fully meet the specification point. If we were able to continue development, this would be a major point to look into.

Safety

In order make the device safe, an E-stop would have to be installed, which would be fairly trivial since it could be an off-the-shelf component. Due to time constraints we were unable to do this for our prototype. But since it would be so easy to install, we believe that safety would not be an issue with a production version.

Ergonomics

Placing the clips into the device is very ergonomic. However grabbing the clips out of the bottom is not. The distance between the outer and inner frame it not a problem[4-Pg.162] but because of the inner frame, the operator would have to reach round to grab some of the clips. This may add non-value-added time and is bad ergonomically. For this reason we have only somewhat fulfilled this specification point. This would be a good area to improve on, particularly with the advice of a specialist.

Live Time expectancy

On this point, the prototype doesn't reflect the requirement in the specification. However, the team believes that it would be possible to fulfil it by machining the joints out of metal and possibly by using a different mechanism to excite the clips.

Materials / Components

Since the shape of the enclosure is bespoke, not all components would be standard. But standard components could be used to excite the clips and standard stock forms can also be used to create the non-standard components.

Maintenance requirements

Since there is only one moving component (minus the clips), maintenance should be fairly minimal. There internal components can be accessed by removing one of the sides of the enclosure. So when maintenance is required, it can be carried out. Repairs and replacements of the other parts would be more difficult but should still be fairly trivial since it can be deconstructed.

Layout

It is believed that the current prototype wouldn't fit on the assembly line. But for a production version dimensions could be able to be adjusted to fit, alongside the boxes of clips. This would be something to look into more detail though. Since it would require a redesign of how the components are arranged on the hydraulics assembly line.

Variant Changeovers

The team believes that the general idea can work for any of the clips. We know that it works with two of them and we believe that any of the others could be added to the device and they'd get de-tangled. The only change that may have to be made is the heigh of cylinder inside the enclosure. This would likely have to be optimized for every clip. In such a way that the device wouldn't need to be replaced for variant changeovers.

Appendixes

Appendix A - Specification Document

Industrial Cadets- Gold
Revision 01

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TECHNICAL SPECIFICATION

HYDRAULICS CLIP STORAGE AND DELIVERY

PROJECT INDUSTRIAL CADETS **REVISION** 01 **DATE** 04/12/2024

Contact Information

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1. Introduction

Technical Specification provided to students of Industrial Cadets- Gold.

2. Background

Throughout the assembly of all hydraulics units at the Worcester Bosch factory, many wire clips are fitted. These clips are stored on each station on the assembly line in production bins and often become tangled. Where only 1 clip is to be picked and fitted to a product, this entanglement can create an additional task within the assembly process. The additional complexity in the task also increases the process time.

In 2025 the business is predicted to see an increase in demand on the final assembly lines, which will mean an increased demand from the hydraulics sub-assembly line. The current cycle time of the production cell is 41 seconds, but next year the line will need to run at 38 seconds. Any non-value-added time in production must be reduced or removed.

The project proposed is a redesign of the process of delivering clips to the hydraulics assembly line at Worcester Bosch. The new process must consider the improved storage of the parts on the assembly line, so that clips have a reduced rate of entanglement, for easier assembly and reduced assembly time. Many clips of similar likeness are included on each assembly station and so the sorting of these clips could also be considered in the project scope.

3. Specifications

3.1. Process

Wire clips are decanted from supplied bags into production bins and placed on the hydraulics sub-assembly line.



Variants of wire clips fitted into hydraulics assemblies:

3.2. Quality

At the point of use by the associate, the wire clips are often tangled. Typically, only 1 clip is required at a time and therefore, the additional task of de-tangling the clips adds to the non-value-added assembly time. The improved process design must reduce or remove this risk, by ensuring a more reliable process.

3.3. Cycle Time

Each 'shake' arm movement applied to the process incurs a time cost of 0.36 seconds. The business aims to reduce the cycle time of the assembly line from 41 seconds to 38 seconds which leaves very little time for non-value-added processes.

3.4. Efficiency

The system should be tested for machine reliability with a capability study. A minimum pass rate of 85% is expected.

3.5. Safety

Safety features must be considered in the workstation design, this includes guarding around trapping points, enclosures around bright lighting, and emergency stop buttons if appropriate. All designs should be free from sharp corners or edges.

3.6. Construction

Construction of any equipment or devices to be completed off site from Worcester Bosch, with a plan for installation on-site.

3.6.1. Ergonomics

All equipment must meet Bosch ergonomics standards, please see attachments. Delivery of wire clips must be within working reach dimensions.

3.6.2. Life Time Expectancy

The system components and equipment must have a life-time-expectancy of 5 or more years. The number of standard components are to be maximised where possible to minimise the cost and difficulty to replace parts in the case of damage/wear.

3.6.3. Materials and Components

Materials and components must be standardised where possible.

3.6.4. Maintenance Requirements

TPM (Total Productive Maintenance) guidance should be provided with troubleshooting support for the process design.

3.7. Layout

The improved process will run in-line and therefore must be a suitable size to fit within an assembly line. Specific racking/layout dimensions available on request.

3.8. Tooling, Jigs and Fixtures

Any system fixtures or devices should be suitable for multiple variant changeovers.

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4. Attachments

Ergonomics Blue Data Cards

Appendix B - Clip Data

REPT 1

Total Time (s)		# Layers 10	# Layers 15
# Initial Clips	10	5.37	7.73
	15	4.94	12.01
	20	14.94	12.84
	25	14.45	71.68

REPT 2

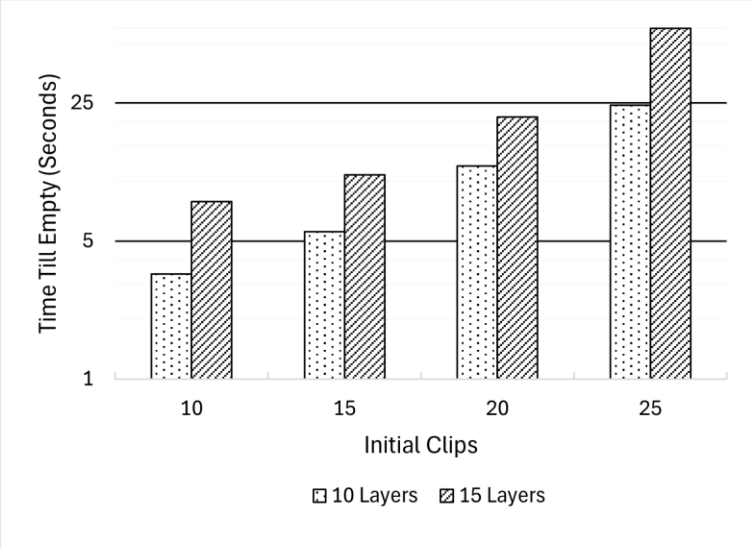
Total Time (s)		# Layers 10	# Layers 15
# Initial Clips	10	1.66	9.12
	15	5.13	11.63
	20	8.53	28.14
	25	20.00	50.26

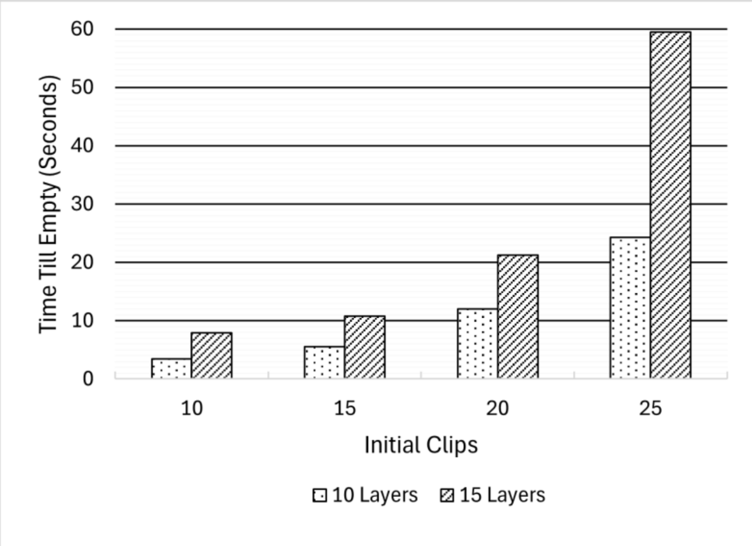
REPT 3

Total Time (s)		# Layers 10	# Layers 15
# Initial Clips	10	3.19	6.89
	15	6.62	8.81
	20	12.57	22.64
	25	38.28	56.44

Mean

Total Time (s)		# Layers 10 Layers	# Layers 15 Layers
# Initial Clips	10	3.41	7.91
	15	5.56	10.82
	20	12.01	21.21
	25	24.24	59.46





Appendix C - Personal Reflection

Amy

Working on this project has been a great experience, if a challenging one. Some of my personal highlights include experimenting different ways to de-tangle the clips, it was amazing to be able to come up with ideas and see if they would work or not, though in the end it seemed a relatively simple solution worked best. One of my other favourite parts of this project was working on the model as the satisfaction of seeing what we've come up with being put together is one of the best feelings. If we had more time and resources, I would like to revisit the structure surrounding the speaker as I feel it could be more efficient/ less bulky.

Owen

This project has been an excellent experience, and one that has been fun whilst teaching me a lot. It's been fascinating to experiment with the behaviour of the clips and ways to control them. I have been doing the vast majority of the report for this project, and it's been a really good experience learning how best to document the project. If we'd had more time, I would have loved to experiment with ways to feed clips into the system and to better capture them after they leave. Overall, I'm pleased with what we managed to come up with in the time frame and am really grateful to have had the experience.

William

I have enjoyed working on this project. For the main and final design, I did most of the cad work. I feel that this has helped me improve my 3D CAD skills greatly. I feel the most rewarding part of the project for me was seeing that the dimensions that had been put into and worked out on the CAD software added up when a physical model was made, even if some slight adjustments need to be made in some places. If we had more time and Resources for the project, I would further improve my CAD skills and create more highly detailed models for the parts and I would like to have further developed the way that the clips are vibrated.

Appendix D - Glossary

Operator	The workers assembling parts on the on the assembly lines at Worcester BOSCH.
Hydraulics assembly line	The water pump assembly line at Worcester BOSCH.
Feeder bowl systems	See (https://www.youtube.com/watch?v=vmUP19oqtbY)
MDF	Medium Density Fibreboard, a type of manufactured board, particularly good for laser cutting.
STL	Stereolithography, a popular file format for saving models for 3D printing.
CAD	Computer aided design.
Parameterized parts	In the context of CAD, it is a process used for automating creation of similar parts.
“Popcorn Effect”	The name we've given to the way clips move when we manipulate them with a speaker. Named because it is a similar sound to popcorn being cooked.
Ergonomics	The study of how people interact with their working environment, is used to make workspaces more comfortable and safer for people.
Octahedron	A regular polyhedron with 8 faces.

Appendix E – References

1) https://www.youtube.com/watch?v=EqIXVfo7BpA
2) https://www.youtube.com/watch?v=BvSruAYZTp4
3) https://www.youtube.com/watch?v=vmUP19oqtbY
4) ADULTDATA – Laura Peebles and Beverly Norris

Appendix F – Technical Drawings & CAD files

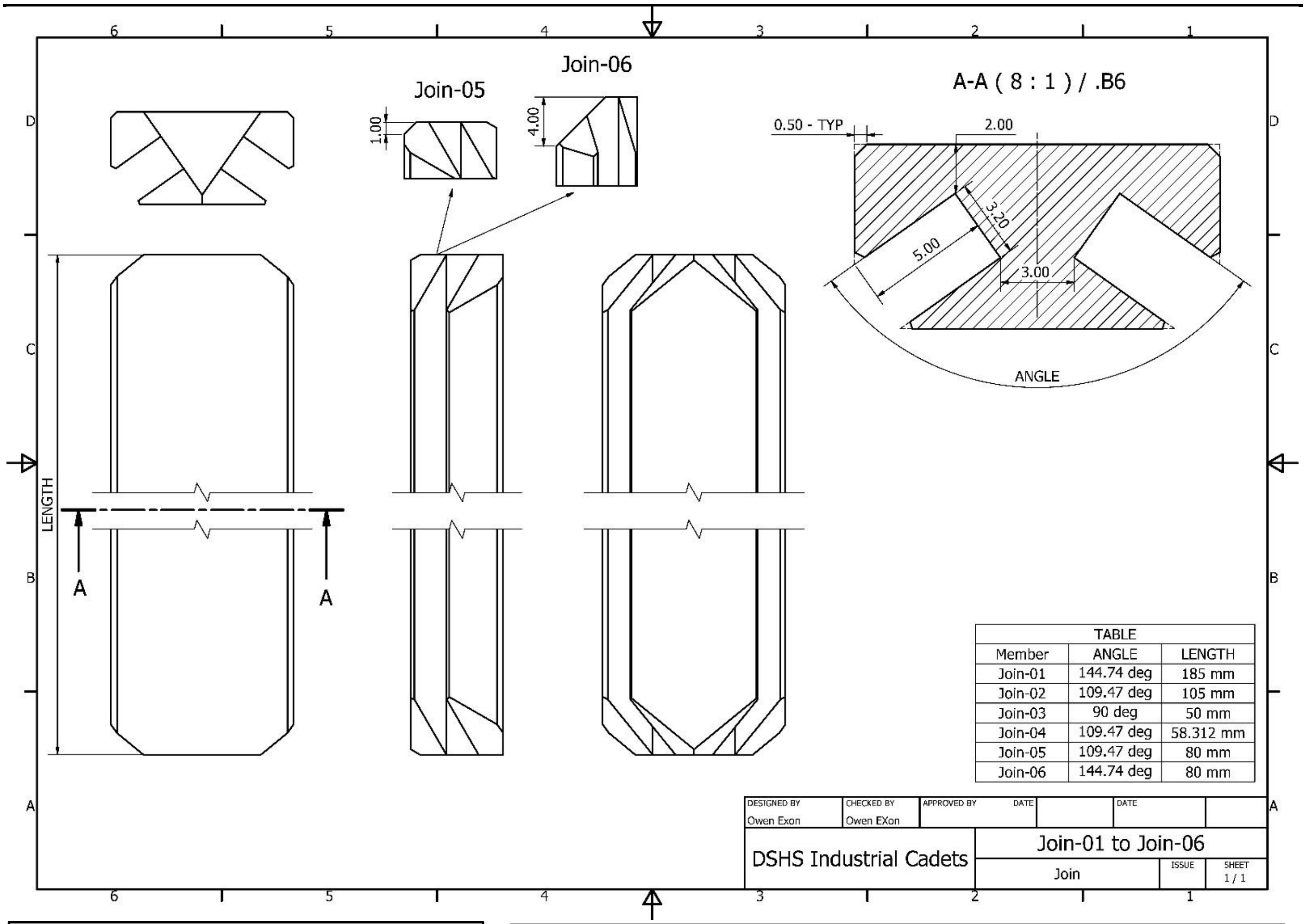
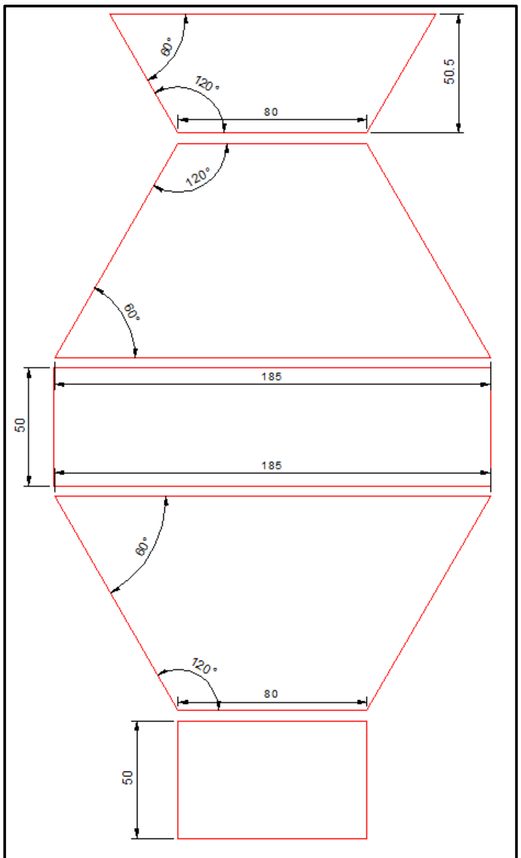
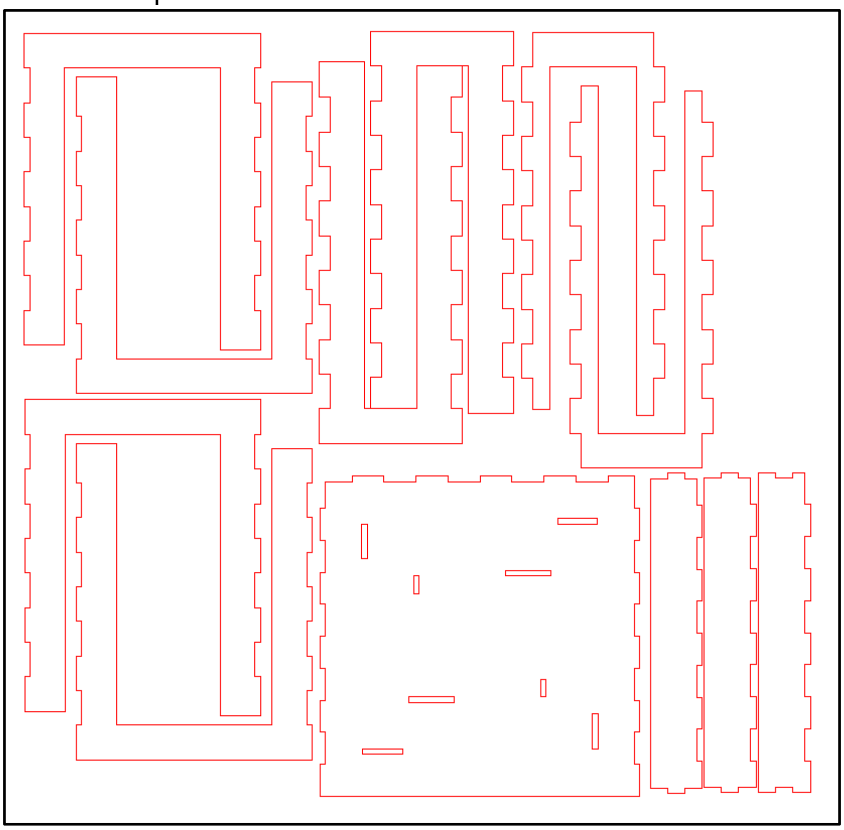


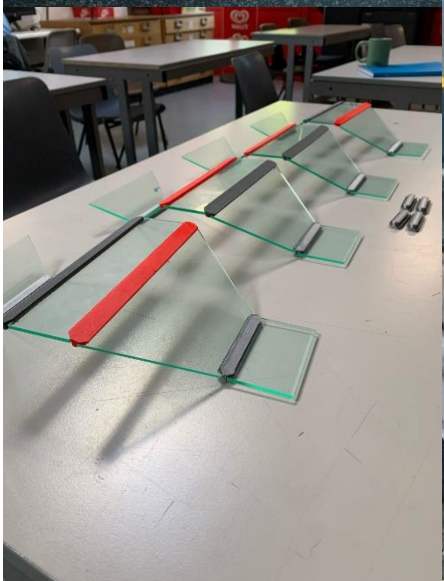
TABLE		
Member	ANGLE	LENGTH
Join-01	144.74 deg	185 mm
Join-02	109.47 deg	105 mm
Join-03	90 deg	50 mm
Join-04	109.47 deg	58.312 mm
Join-05	109.47 deg	80 mm
Join-06	144.74 deg	80 mm

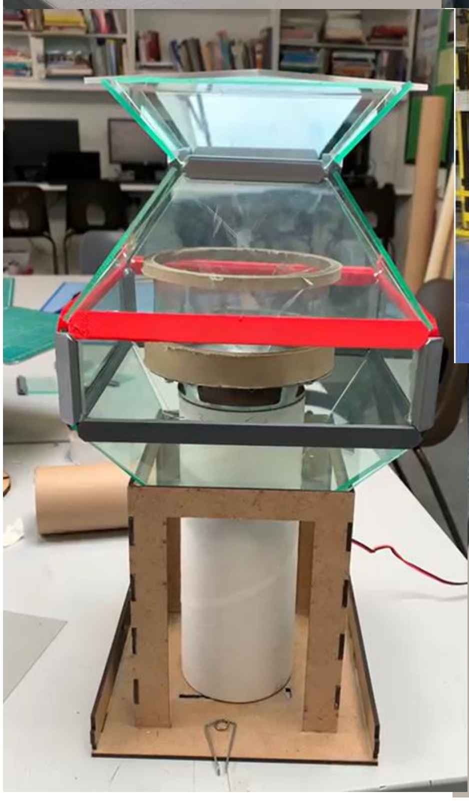


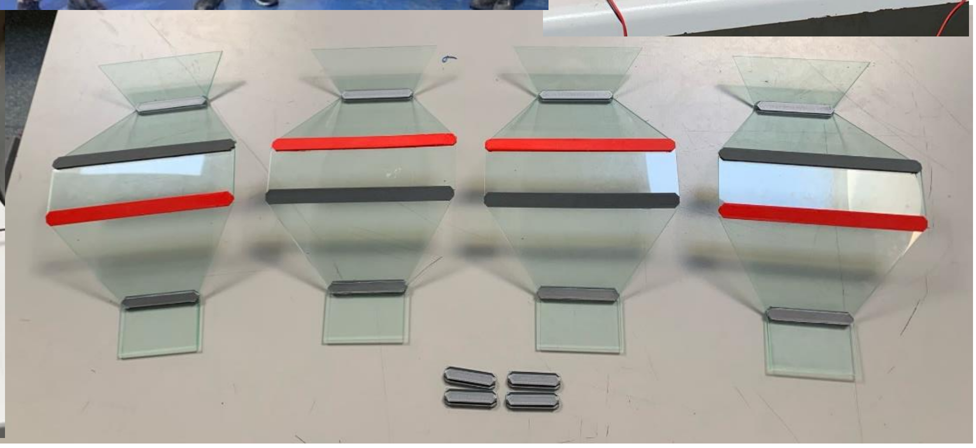
Four of each



Appendix G – Gallery







Acknowledgements

We owe particular thanks to these people for helping us during the course of this project.

Sally Lessing

Sally was our mentor at Worcester BOSCH and helped provide insights throughout the project and arranged our visit to the factory early on which really helped with development.

Mr Edward Rollit

Mr Rollit helped manage the group and kept us in contact with Sally and gave good advice throughout the project.

Freya Kelly

Unfortunately, Freya had to leave part way through the project as she had too many other commitments, but she worked with us through the first half of the project.

The DT department staff

The entire DT department always welcomed us to use their equipment and workshops to work whenever we needed and always gave good advice.