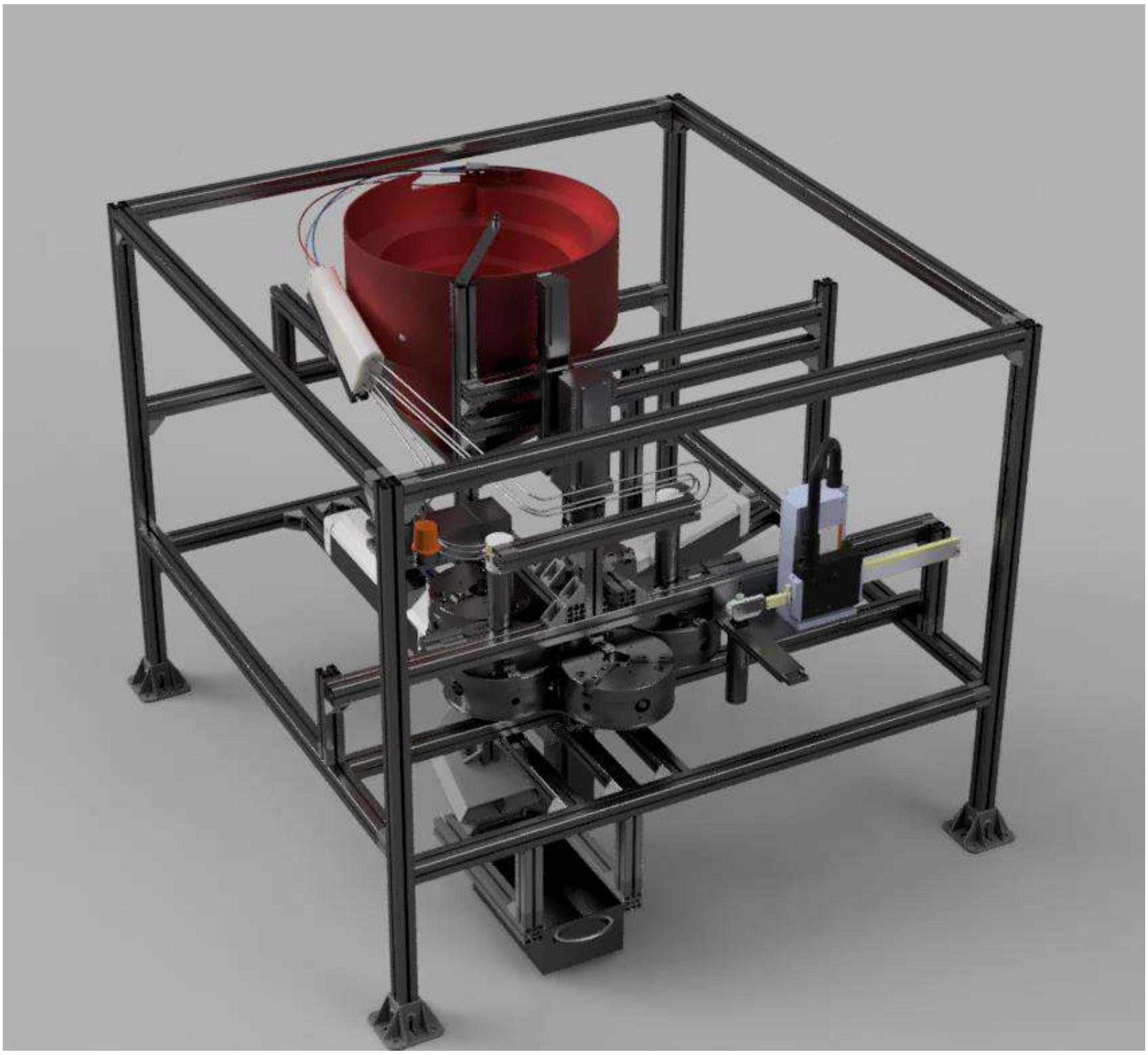
Machine Design Technical Report



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Summary

This report aims to document the main design process' that were involved in the development of automated friction welding machine. The final solution that was created during this project was a one-off manufacturing device that was required to assemble 1 million syringe filters that were used in the administration of a vital antidote against a severely infective pathogenic disease. Using an initial project brief provided by the client and subsequent meetings a list of product requirements was created and categorised into 'must' and 'wish' features. This allowed an initial 3 concepts to be developed that differed largely in their approach to fulfilling the clients needs. After evaluating and heavily iterating many aspects of each given concept a final solution was decided upon. This lead to the design of machine with a cost of £22,121 that successfully met the rigorous specifications required by the client.

Introduction

During this design project it was hoped that theoretical knowledge gained over the course of 4 design modules could be applied to a real-life situation where a machine was needed to aid with the vaccination against a deadly virus and in the process save millions of lives. A vital part of this vaccination process is reliant upon a syringe filter that is required to remove any trace of contaminated matter from the injected antidote that could lead to re-intoxication.

Thus, a machine was required to take two previously manufactured casing halves, referred to as casing A and casing B, and perform a friction welding operation while inserting a single filter paper between the two halves. Due to the deadly and contagious nature of the outbreak 1 million syringe filters were required to be produced as quickly as possible to prevent the pathogen from spreading further and causing additional fatalities. In order to reduce the time required to design and assemble this one-off machine it was desired that the machine be comprised of a large number of out sourced components.

In order to produce a successful solution market research was undertaken to identify the best possible solution. This proved to be difficult as such a machine that combined all the required tasks did not exit. Therefore, it was decided to break up the performance requirements into several fundamental tasks which, by relating these smaller tasks to those seen in modern manufacturing and production, allowed optimal solutions to be identified for each individual process.

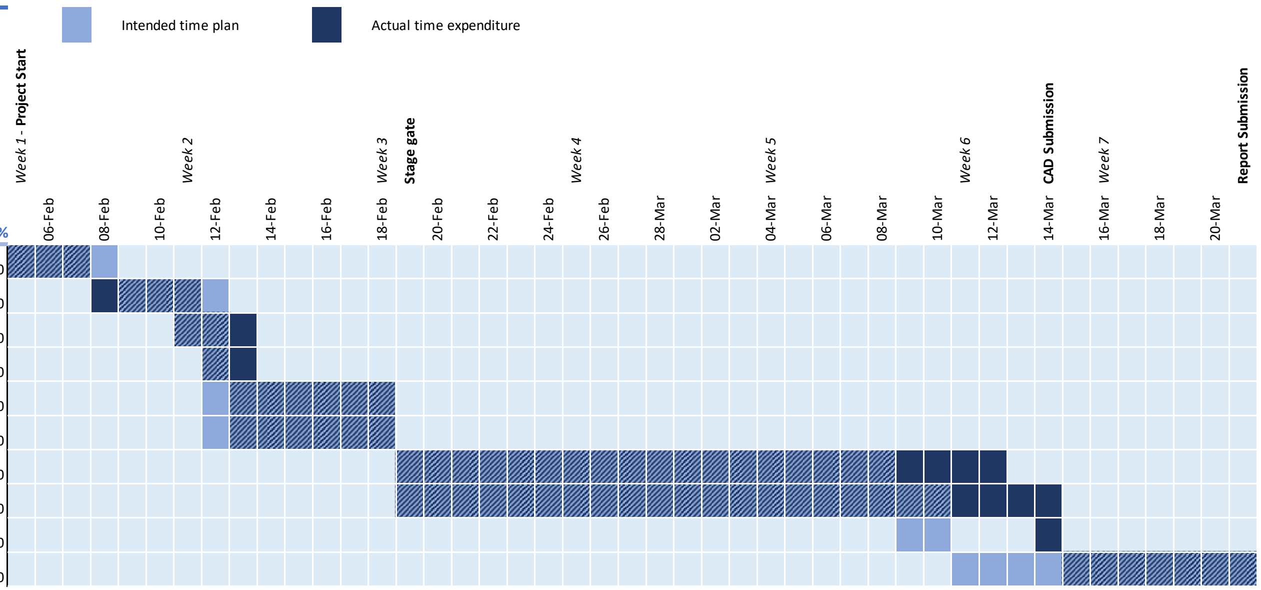
To create a focussed and driven solution from the outset of this project, as well as dividing the requirements into fundamental tasks, clear objectives and information was extracted from both the initial project brief and the subsequent Q&A sessions. This allowed a detailed product design specification (PDS) to be produced that, along with a Gantt chart that was produced, allowed a successful solution to be produced in an effective and time efficient way.

Gantt chart

In order to keep to the required time schedule and ensure all objectives were met a Gantt chart was produced. This was initially produced at the start of the design process however as we progressed through the project this was edited accordingly to adjust for any changes in time schedule or design plan.

Machine Design Gantt Cart

Activity	Duration in Days: Intended	Actual	Percentage Complete/%
Product Design Specification	4	3	100
Concept designs	4	4	100
Morphological chart	2	3	100
Design Evaluation	1	2	100
3 x A3 full machine concept sketches	7	6	100
Pairwise Comparison	7	6	100
Design Development	18	22	100
CAD production	20	24	100
Engineeing Drawrings	2	1	100
Report	11	7	100



Product Design Specification

In order to provide a clear overview of the requirements specified by the client and product design specification (PDS) was produced. This was made usisng information gathered from the initial project brief provided by the client and subsequent question and answer sessions. This allowewd a thorough PDS to be produced that covered all the main fundamental requirement's that were specified by the client as well as features that we felt necessary to produce the best possible solution. This information was then formated into the table below according to Garvin's 8 principle quality dimensions with each feature either being categarised into a wish or a must

No.	Date	Source	Requirement	Target	Must / Wish
Performance					
1		Initial Project Brief	Production Length	1,000,000 Units	Must
3		Initial Project Brief	Store Casing A	Up to 200 Units	Must
4		Initial Project Brief	Store Casing B	Up to 200 Units	Must
5		Initial Project Brief	Retrieve Casing A from Buffer	Automatically completed by Machine	Must
6		Initial Project Brief	Retrieve Casing B from Buffer	Automatically completed by Machine	Must
7		Initial Project Brief	Insert Filter Paper	Automatically completed by Machine	Must
8		Initial Project Brief	Friction Welding	250e-6m	Must
9		Initial Project Brief	Inspection Process	If Weld Faulty Eject into scrap buffer else Eject into Output Buffer	Must
10		Initial Project Brief	Alarm		Must
11		Q and A	Floor Area	Maximum 5m^2	Must
12		Q and A	Height	Maximum 2m	Must
13		Q and A	Budget	£30,000	Must
14		Q and A	Black Box	Contain Black Box of Dimensions of 200mm x 100mm x 50mm	Must
15		Q and A	Air Supply	6bar	Must
16		Q and A	Power Supply	Single or Three Phase	Must
Reliability					
17		Q and A	Friction Welding Reliability	Failure 1 in 1000	Must
Conformance					
18		Q and A	BSI Manufacturing standards	Conform to given British Standards	Must
19		Q and A	Medical Standards		Must
Durability					
20		Q and A	Good Service Life	10 Year Service Life	Wish
Serviceability					
21		Group Meeting	Key Component Accessibility	Easily Accessible for Maintenance	Wish
Aesthetics					
22		Group Meeting	Machine Housing	All Encompassing Design	Wish
Manufacture & Assembly					
23		Group Meeting		Use Minimal Components	Wish

Morphological Chart

Function **Concepts**

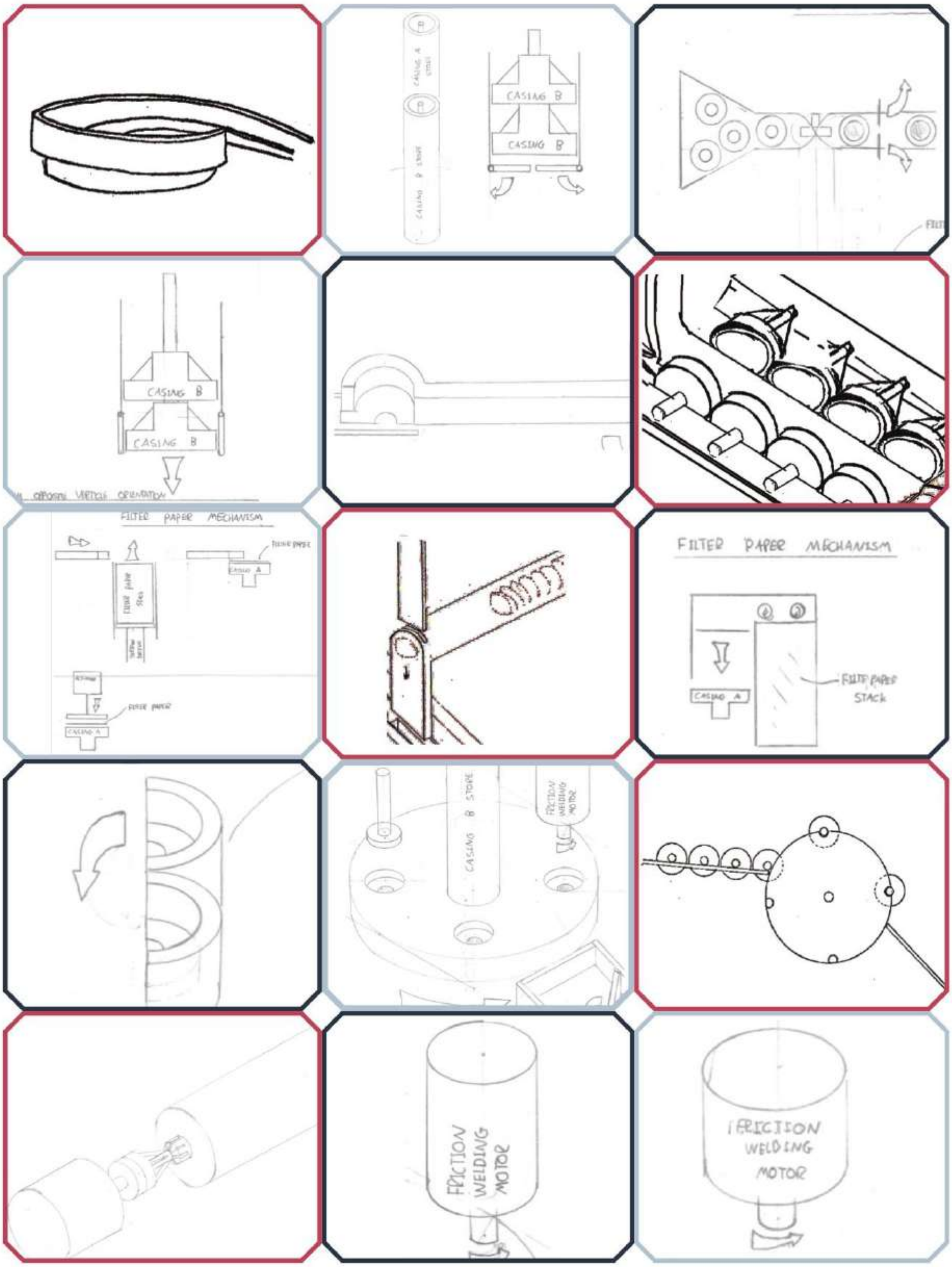
Inital Storage

Retreval

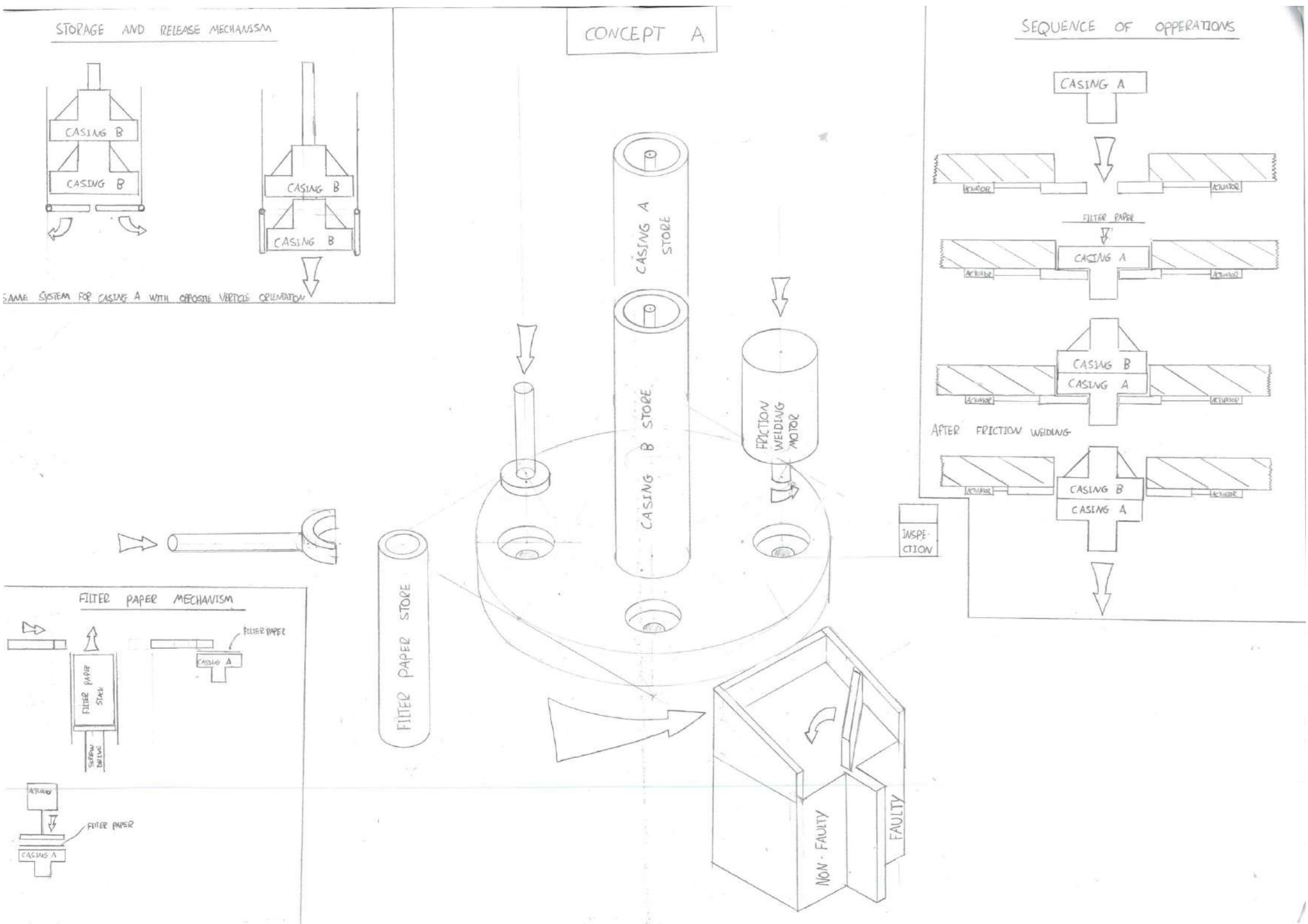
Filter Paper Placment

Alignment

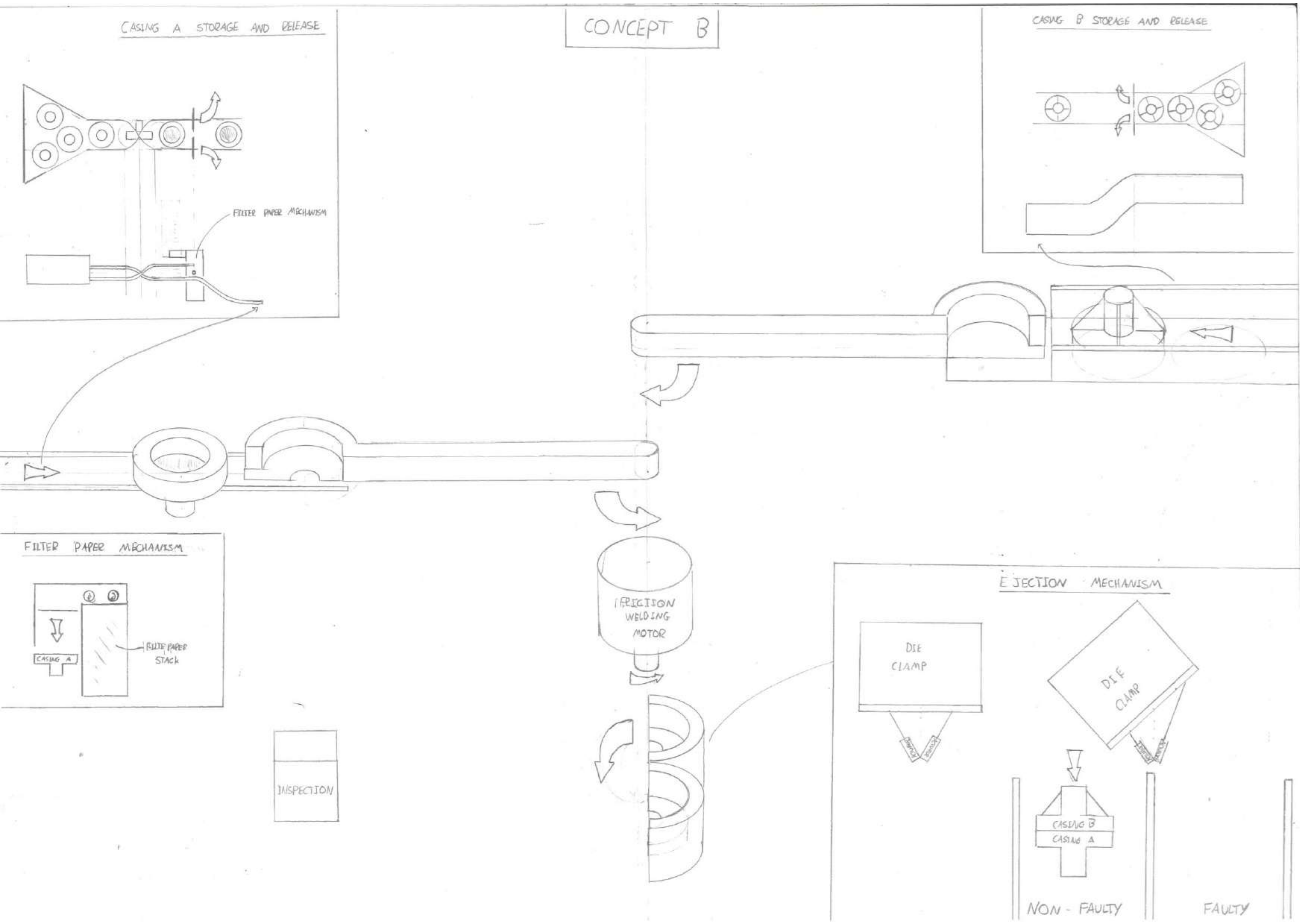
Weld



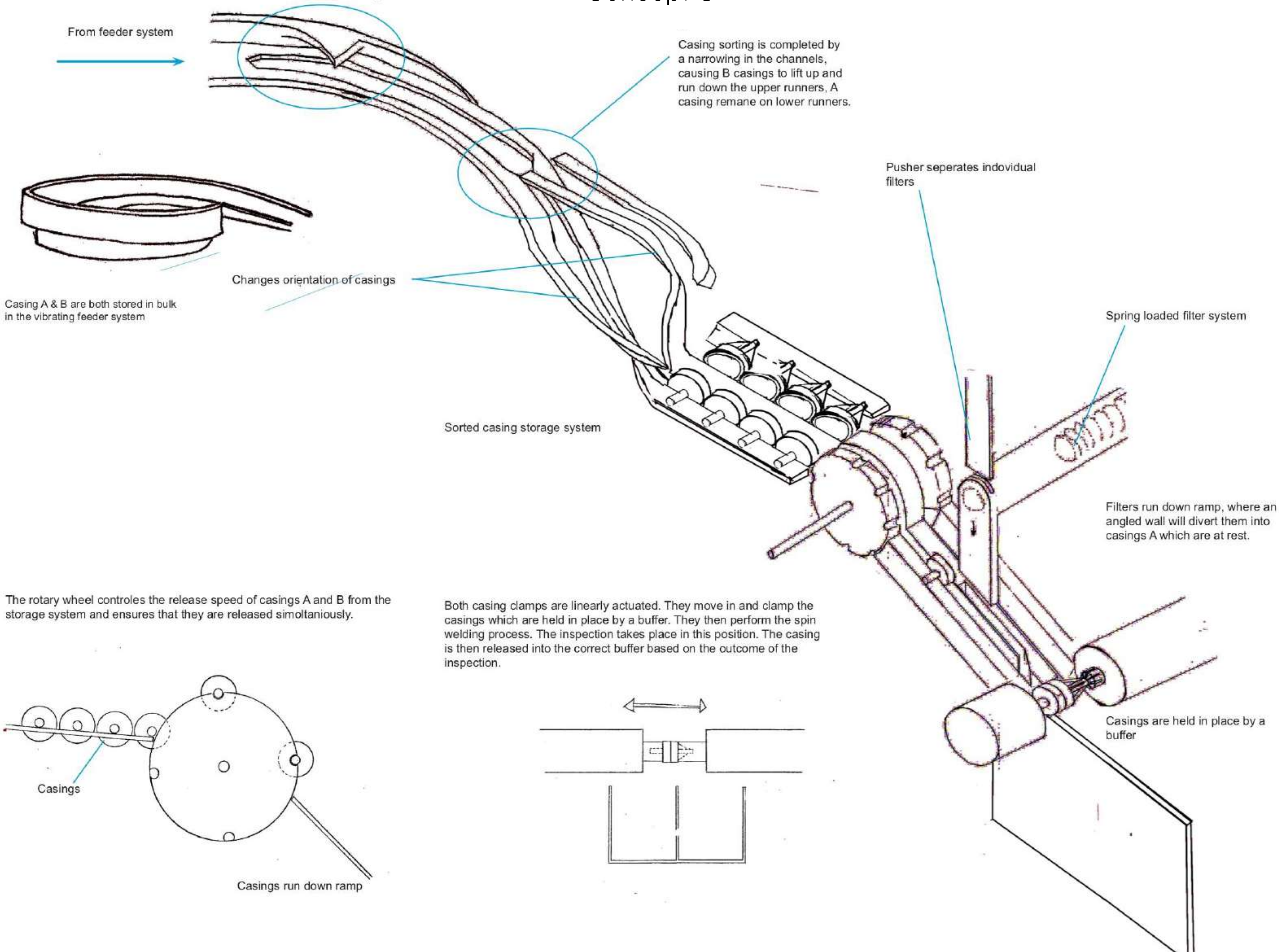
Concept A = **Concept B =** **Concept C =**



CONCEPT A
STORAGE AND RELEASE MECHANISSM
CASING B
CASING B
CASING B
CASING B
SAME SYSTEM FOR CASING A WITH OPPOSITE VERTICLE ORIENTATION
CASING A STORE
CASING B STORE
FRICTION WELDING MOTOR
FILTER PAPER STORE
INSPECTION
NON-FAULTY
FAULTY
FILTER PAPER MECHANISM
FILTER PAPER
CASING A
FILTER PAPER STACK
SCREW DRIVE
ACTUATOR
FILTER PAPER
CASING A
SEQUENCE OF OPPERATIONS
CASING A
ACTUATOR
ACTUATOR
FILTER PAPER
CASING A
ACTUATOR
ACTUATOR
CASING B
CASING A
ACTUATOR
ACTUATOR
AFTER FRICTION WELDING
CASING B
CASING A
ACTUATOR
ACTUATOR


CONCEPT B
CASING A STORAGE AND RELEASE
FILTER PAPER MECHANISM
CASING B STORAGE AND RELEASE
FILTER PAPER MECHANISM
FILTE PAPER STACK
CASING A
FRICTION WELDING MOTOR
INSPECTION
EJECTION MECHANISM
DIE CLAMP
DIE CLAMP
CASING B
CASING A
NON - FAULTY
FAULTY

Concept C


From feeder system
Casing sorting is completed by a narrowing in the channels, causing B casings to lift up and run down the upper runners, A casing remane on lower runners.
Pusher seperates indovidual filters
Changes orientation of casings
Casing A & B are both stored in bulk in the vibrating feeder system
Spring loaded filter system
Sorted casing storage system
Filters run down ramp, where an angled wall will divert them into casings A which are at rest.
The rotary wheel controles the release speed of casings A and B from the storage system and ensures that they are released simoltaniously.
Both casing clamps are linearly actuated. They move in and clamp the casings which are held in place by a buffer. They then perform the spin welding process. The inspection takes place in this position. The casing is then released into the correct buffer based on the outcome of the inspection.
Casings are held in place by a buffer
Casings
Casings run down ramp

Controlled Convergence

Specification Criteria	Weight	Concepts A	Concepts B	Concepts C	Rational
Produce 1,000,000 units	2	DATUM CONCEPT	0	-1	A & B are equal as both would likely have no problem producing all units. C scores negatively as the filter paper mechanism may not be fully workable.
Store 200 units of casing A & B	2		+1	+2	A scores negatively as uses one dimensional storage. B uses two dimensional storage so scores higher. C scores highest due to three dimensional storage system.
Automatically retrieve casings	2		-2	-1	A uses release arms and a rotary disc, a simple and efficient design. B uses a rotary arm which could potentially drop the casings. C uses runners which would work but are more complex than A.
Complete Friction weld process	2		0	0	All designs will successfully perform the friction welding process.
Sort due to outcome of inspection	2		-1	-1	A is the simplest design as it requires a single motor. B & C would both require more complex, dual degrees of motion systems.
Audible and visual alarms	2		0	0	None of the concepts mention this specification, alarms could be simply added to all three
Within a 5m^2 area	2		0	-2	The rotating nature of A & B makes them compact designs. The Bowl feeder and runners in C would take up a larger area than A and B.
Maximum height of 2m	2		+2	+1	The vertical stacks of design A would exceed this limit. Design C works on a gravity feed, so will be fairly tall. B is an almost horizontal system so scores highest.
Below budget of £30,000	2		N/A	N/A	Difficult to determine at concept stage.
Conform to BSI standards	2		N/A	N/A	Difficult to determine at concept stage.
Component accessibility	1		0	-1	The rotatory setup of A & B allow each subsystem to be highly modular. C is more linear and hence less accessible,
Simplistic design, using minimal components	1		-2	-1	Disc with multiple stations in A is very simple. C has stationary casing orientation, reduces need for motors or actuators. B has neither simplifying features.
Total		0	-2	-6	**Concept Selected: A**

Concept Generation and Controlled Convergence

Concept sketches

Three different concepts were generated for each function of the system. These were than organised into three full concepts based on which individual concepts would work together most effectively. Three full concepts were generated and analysed using controlled convergence.

Controlled Convergence Analysis

The controlled convergence showed that Concept A is the most suitable for the required task. Despite this, the convergence also demonstrated that there are parts of Concepts B & C that are superior to that of concept A. Primarily, the storage method of Concept C which is a far more efficient use of space and doesn't require the casings to be manually organised. Essential requirements were ranked 2, additional requirements were ranked 1.

Design Changes

The final concept was an iterated version of Concept A with some additions and modifications. The Initial storage and sorting method from concept C was also used due to qualities highlighted in the controlled convergence. The Paper placement method used in the final design was a later iteration of Design A that used air suction instead of physical pushing. The casing release mechanism was also developed to insure a more controlled release of individual casings. The Actuators used for clamping Casing A in Concept A were replaced with chucks as the rotary nature of the disk made running the actuator lines overly complex.

Calculations and choice of components

Having considered all the concepts and arrived at a final solution it was now necessary to choose components that would satisfy the design requirements while integrating correctly with the chosen design. This involved conducting calculations on performance characteristics and searching through manufacturer catalogues to find the desired component.

Friction Welding Motor

From the Initial project brief it was specified by the client that there were two desired ways in which the friction welding could be performed. This involved either a direct drive mechanism or an inertia method implementing the use of a flywheel. After conducting some basic calculations and analysis it was found that the inertia method would require a significantly more powerful motor rotating at a much higher RPM and seemed to be an unnecessarily more complex solution. Thus, it was decided to proceed with the direct drive method. In the data sheet provided by the client this particular weld method would require a tangential weld speed of $5ms^{-1}$. Using an average outer radius of 22.5mm for both casing A and casing B, and a recommended welding pressure of 0.5Mpa, this allowed the normal reaction force for the operation to be calculated at 353N and the work done by friction to be 778J. Thus by using equations shown in appendix B it was calculated that the selected motor would be required to produce 3.51Nm of torque and be capable of rotating up to 2000 RPM. To accommodate these requirements an EMME-AS-100-MK-HS-AMXB was chosen. This particular motor also included a break and an absolute safety multi turn encoder ensuring the process was undertaken accurately.

Rotary Disk Motor

Once a final design for the main rotary disk assembly had been completed it was required to select a motor to control its rotatory motion. Using equations shown in appendix A the total inertia of the rotary system was calculated to be 7.6871 Kgm^{-2}. Assuming the velocity profile shown in figure 11 and a total weld duration of 1s, as specified by the client, this allowed the required torque for the motor to be calculated as 4.159Nm. This torque requirement was found to be within that of the EMME-AS-100-MK-HS-AMXB motor produced by Festo that was chosen for the friction welding motor. Thus, in order to aid the design for assembly by increasing modularity, this particular motor was also chosen for this operation. The absolute safety multi turn encoder and break present also ensures the precise movement of the main disk that is required.

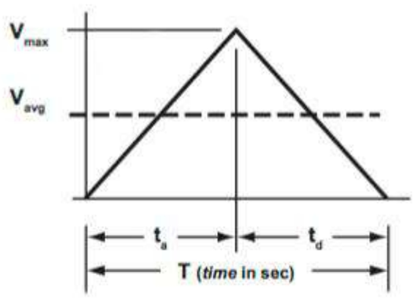


Figure 1: Servo Motor Velocity Profile

Main Chucks

By Referring to the friction welding calculations the required clamping force for the operation was found to be 140.4N. For the specified design it was also required that a through hole of at least 50mm was present allowing the completed filters to fall through once the process had been completed. Therefore, a schunk ROTA-S plus 2.0 250-62 Z235-SFG was selected. This provided an excessive clamping force of 160KN with a through hole 63mm in diameter, meeting both requirements.

Chuck Tightening Motor

The chucks chosen for the final design were intended to be operated manually and thus it was difficult to quantitatively select a given motor. However, by researching about the rack and pinion mechanism used in the selected chucks and experimenting with the chucks found on the lathes in the University of Bath Student Workshop, a Festo EMME-AS-40-S-LV-AMB was selected. This produced a nominal torque of 0.21Nm at 9000 RPM which was deemed to be sufficient for this particular use. The Absolute Encoder also made it possible to accurately specify the number of rotations to tighten and loosen the chuck accordingly.

Chuck Tightening Actuator

In order for rotary disk assembly to rotate free it was required that the chuck tightening motor be able to have a minimal travel of 20mm. A Norgen M/146116/M/100 rod less cylinder was therefore selected as it possessed 100mm of the travel, the minimum for this type of actuator. In retrospect, it may have been more sensible to seek a different solution for this component as this particular range has much higher specifications than required.

Spindle Axis

In order to achieve the vertical motion of the main friction welding motor specified by the design a linear actuator was chosen. As previously specified in the friction motor selection a reaction force of 353N was required for the process. A relatively small vertical travel of only 25mm was also required. Thus, an EGC-70-100-BS-10P was chosen. This provided ample stroke length at 100mm with a maximum feed force of 400N also capable of performing the friction welding process and lifting the motor after the operation had been completed. By referring to the catalogue for this component a Festo EMME-AS-60-S-LV-AMB was chosen to power the spindle axis with an EAMM-A-S38-60P-G2 coupling and housing to mate the two units.

Casing Timing Control Actuator

The Temporary casing storage in which this mechanism operates was only designed to hold 5 casings at any one time and thus minimal force was required to separate the casings from each other. Thus, the only main constraint for this component was the 50mm stroke required to clear the casing storage. Therefore, a Norgen RM/92020/M/60 was selected which provided a 60mm stroke with a M5 port size allowing the timing custom release forks to be easily mounted.

Lift and Place Mechanism

The system designed to place the filter paper in casing A required a 207mm horizontal travel and 30 mm vertical travel to avoid contact with the main rotary disk. Therefore, a WEISS

HP140T was chosen. This provided 65mm of vertical stroke and 400mm of horizontal stroke while providing an ideal mounting point for the Piab flexible suction cup holder.

4 finger Gripper.

Again, using calculations made during the friction welding analysis a lamping torque of 3.51Nm calculated. Using the Outer radius for both casings of 25mm this meant a clamping force of 140.4N was required. Thus, this led us to select the Schunk PZV-100 4 finger gripper. This component provided an ample clamping force of 1800N and allowed the attachment

of a Schunk OPS-100 impact sensor allowing timing and force applied during the welding operation to be monitored.

Bearings

The bottom bearing used was an SKF 320/32 X tapered roller ball bearing. This was chosen as it was particularly good at supporting the large axial load produced by the rotary disk assembly. The top bearing used was an SKF W 61809 deep groove ball bearing. This was not required to support any substantial loads or torque and thus is a standard bearing.

Costing

The costing for this machine was split into 3 separate sections. Parts produced by the University of Bath including raw material and labour costs, externally sourced parts and assembly costs. Detailed spread sheets of these costing regimes can be seen in appendix A.

Category	**Cost (£)**
University of Bath Manufactured Components	1,685
Externally Sourced Components	20,236
Assembly	2,000
Total	22,121

Method of Operation

Step 1: Casing Initial storage and Orientation

The vibrating bowl feeder acts as the primary storage unit for both casings A and B, it is filled manually by the machine operator. With a Volume of 0.04m^{-2}, it is capable of holding 200 of each casing at once. The orientating guides at the top of the bowl feeder insure that only casings that are sitting on the wide base will be able to pass through onto the rails. The guide bar will push any alternatively orientated casings back into the bowl. The chamfer on the

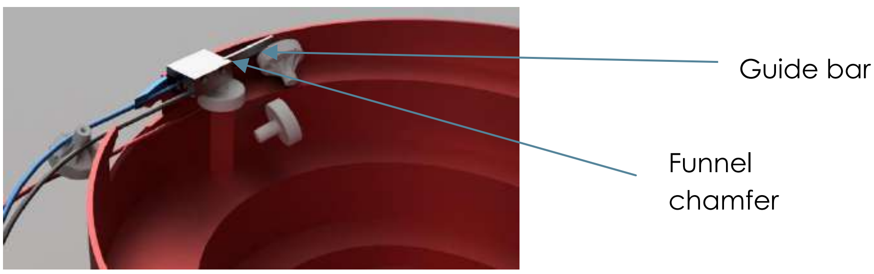


Figure 2: Bowl feeder and orientation guides

Step 2: Casing Separation

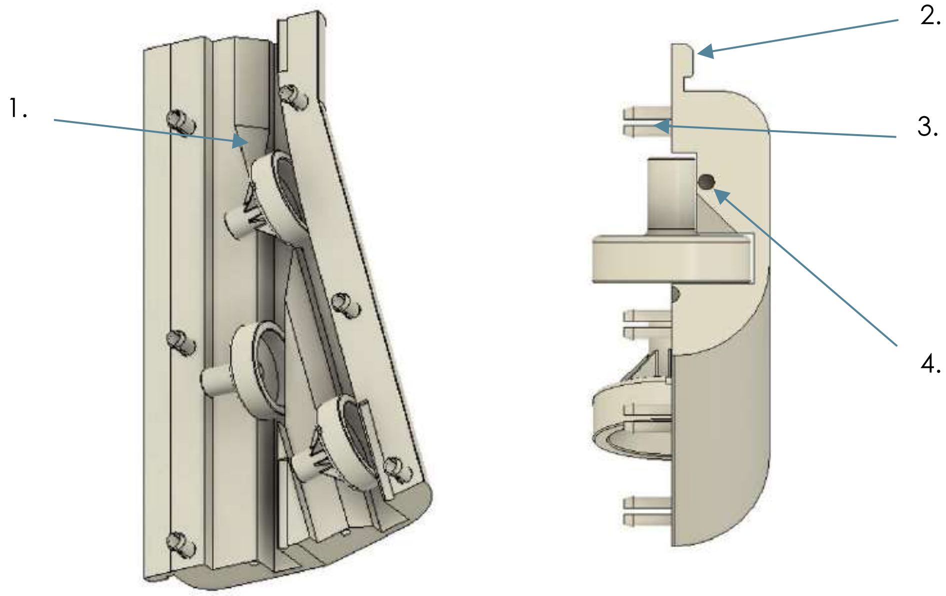


Figure 3: Casing separation system

The casings are separated by a custom separation unit. Both Casings A and B are guided into the top of the unit by the rails. The casing shaped gutter then narrows at point 1. This angled face comes in contact with the fins on casing B causing it to divert into the other track. Both casings A and B then are gravity fed down separate rails into the temporary vertical casing storage unit.

2. Component is compatible with Minitec beams, so can slide directly into frame.
3. Clips easily connect male and female halves.
4. Holes for runner rails

Step 3: Casing A Release

As shown in Figure 3, Once the casings are stacked in the vertical storage unit, they rest on two casing release forks. These move linearly in and out of the storage unit in a horizontal direction. This motion is controlled by two pneumatic actuators. The lower actuator will pull out of the tube, allowing a casing to fall, while the upper fork holds the remaining casings. The lower fork will then return to its original position in the tube. The upper actuator will then pull the fork out of the tube, allowing the casing stack to drop.

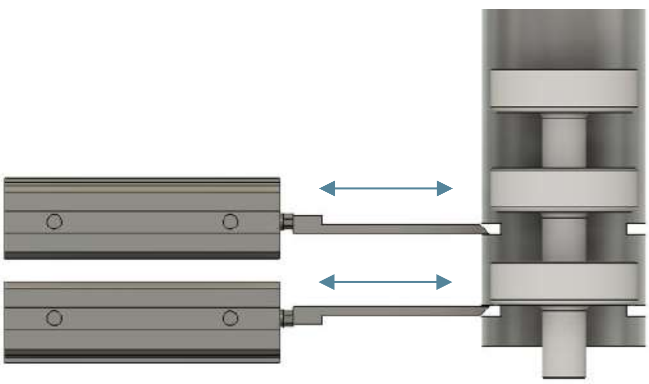


Figure 4: Casing A release assembly with forks in withdrawn position

Step 4: Chuck Disc Rotation (72 degrees)

Once a Casing A has been dropped into one of the five chucks, the system is rotated to the next station, which is a 72° from its original position. This is controlled by a servo motor which is attached to the central shaft by a coupling. To prevent any reverse motion, a ratchet mechanism holds the disk in place at each operation point.

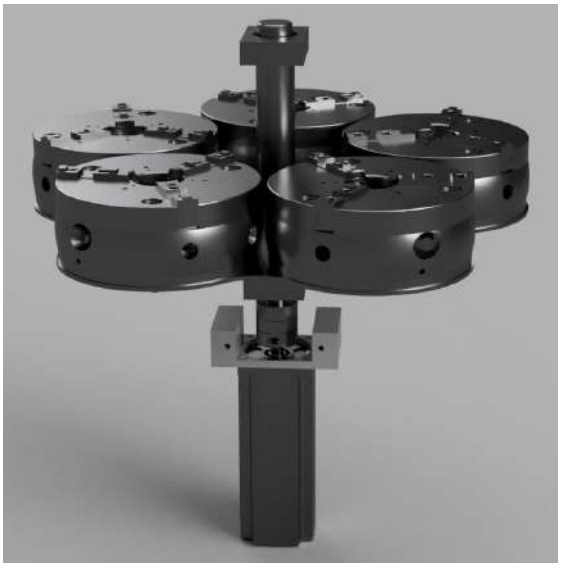


Figure 5a: Rotary disk Assembly

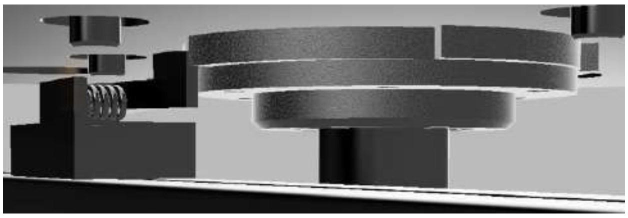


Figure 5b: Ratchet Mechanism

Step 5: Tighten Chuck

As casing A has been dropped into position, the chuck jaws need tightening. This operation is performed by a small servo motor mounted on a linear pneumatic actuator. On the end of the motor, is mounted a hex-head socket custom made to fit the chuck. The linear actuation allows the motor to move forward, tighten the lathe, and withdraw so that the central assembly can rotate to the next position.

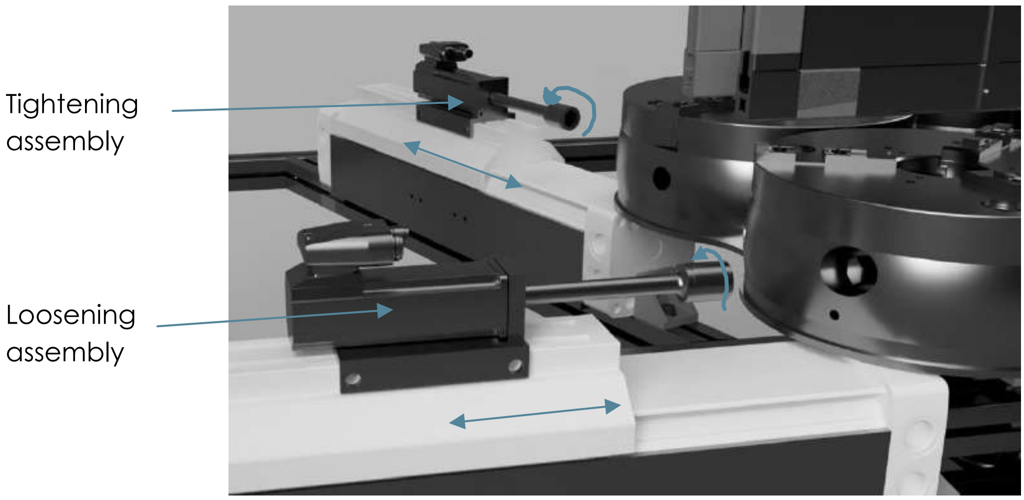


Figure 6: Chuck Tightening Mechanism

Step 6: Chuck Disc Rotation

Step 7: Filter paper Placement

Once the disc has completed another 72 degree rotation, the dual axis linear actuator collects a filter from the spring loaded storage mechanism, this ensures that the top filter is always at the same height. The filter paper mechanism has capacity for 200 filters. A filter is picked up using a suction cup, the pressure can be tuned so only one filter is collected. The dual axis actuator then monoverse the filter, up and over the chuck and down into casing A. The air suction is then stopped, and the filter is dropped into place.

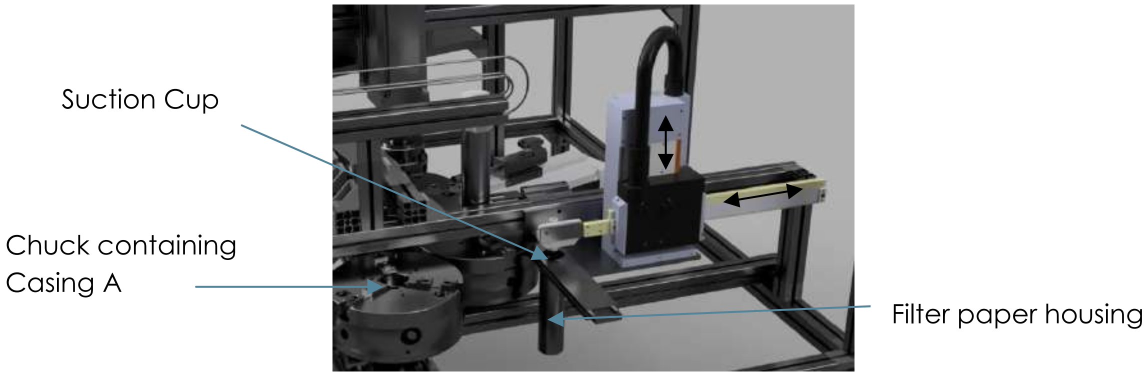


Figure 7: Filter paper placement assembly

Step 8: Chuck Disc Rotation

Step 9: Casing B Release

The casing B release mechanism is the same as the casing A release mechanism, except the casings are orientated differently.

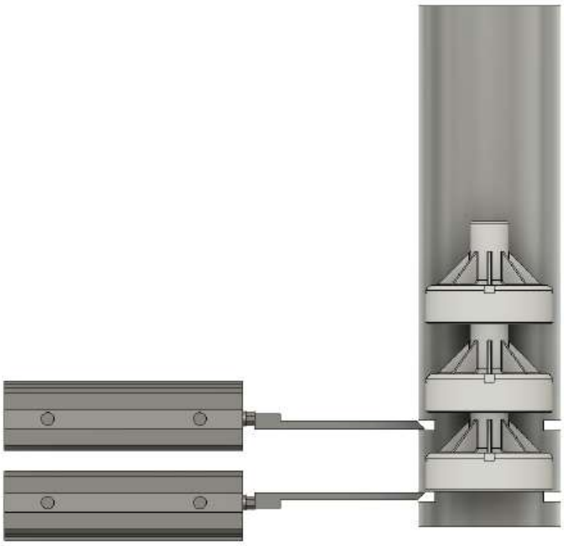


Figure 8a: Casing B release assembly with forks in withdrawn position

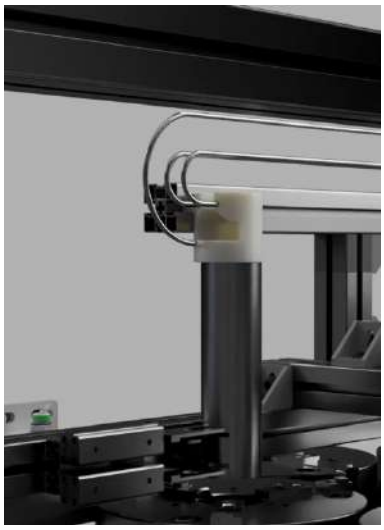


Figure 8b: Release assembly with runners and conversion unit

Step 10: Chuck Disc Rotation

Step 11: Perform Friction Weld

The friction weld is performed at the forth position of the rotary disc. By this point, casing a is clamped in the chuck. The filter paper is in position and casing B is sitting on top of casing A. The friction welding assembly has both vertical linear motion and horizontal rotary motion to perform the friction welding process. The linear motion is controlled by a spindle axis(3). This is mounted to the frame via a mounting plate and owered by a motor 1. The friction welding process is completed using motor 2. Once the chuck is in position, the subassembly is lowered. The 4 custom clamps (5) are tightened using a pneumatic system which connects to the body of the four finger gripper(4). The sub-assembly is then lifted, spun up to speed, and lowered onto casing A to perform the friction weld. The clamps are then released, and whole system raised.

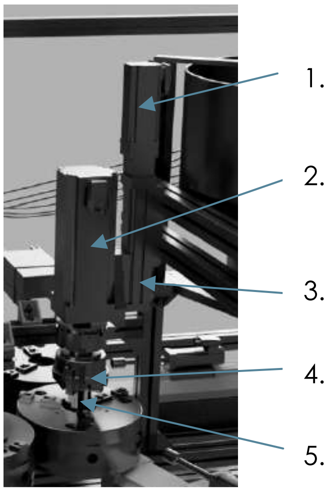


Figure 9: Friction welding system

Step 12: Chuck Disc Rotation

Step 13: Perform Inspection and Filter release

The final position of the rotational disc is the inspection point. The black box is situated directly above the centre of the chuck to allow for direct line of sight. The outcome of the inspection triggers the filter sorting mechanism to move to one of two positions, this will cause the filter to follow one of two output paths after ejection from the chuck. The chuck is then loosened fully, which allows the filter to drop out the bottom of the rotary plate. This is performed similarly to step 5 but in reverse.

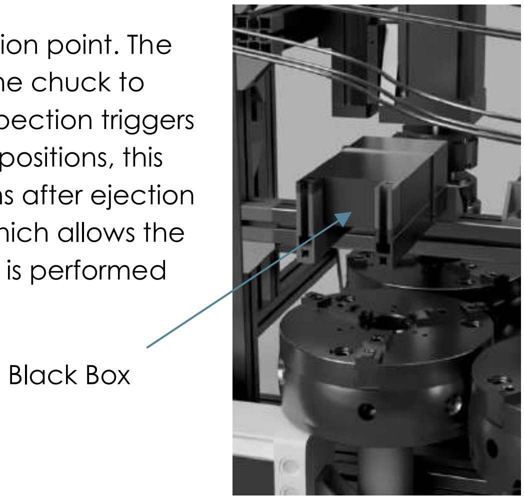


Figure 10: Black Box inspection system

Step 15: Remove Casings from Draw

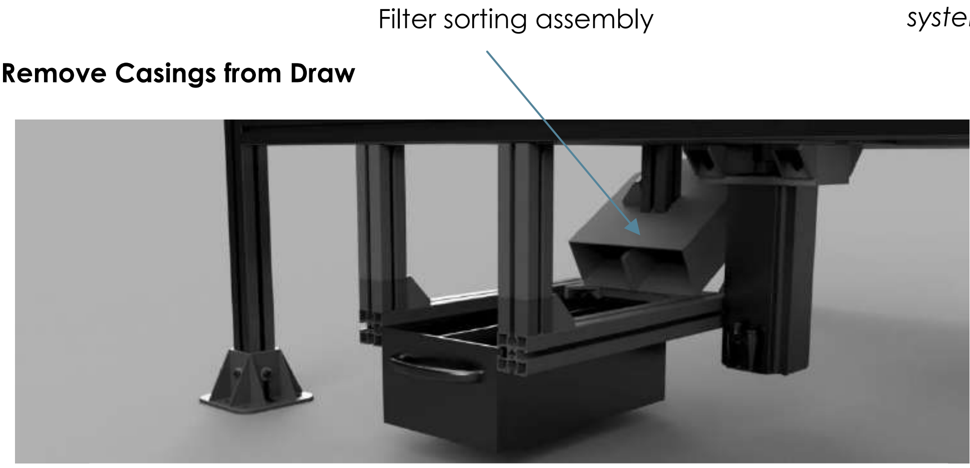


Figure 11: Finished filter output shoots and storage draw

Design for Assembly

Figure13 shows one half of the casing sorting unit. Point 1 shows the male connector that allows the unit to be connected directly to the Minitec frame. This technique was also used in a variety of other components. this will reduce assembly time and complexity. Point 2 shows the male clip for the separating unit, these will be produced easily with a 3D printer and also simplify the assembly process.

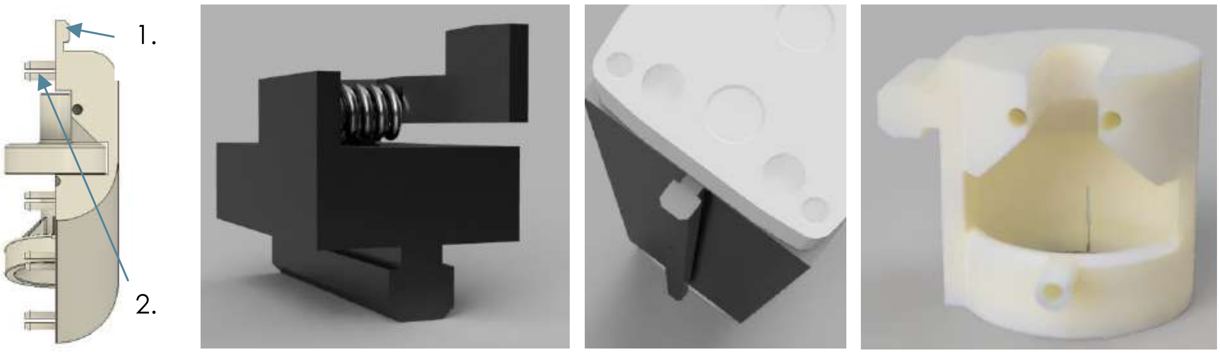


Figure 13: Components demonstrating Minitec Compatibility

The Main rotary motor and friction weld motor are the same, this increases the modularity of the machine and hence simplifies the assembly process.

Design for Manufacture

All UoB parts have been designed to be simply machined with simple shapes and easy to access features.

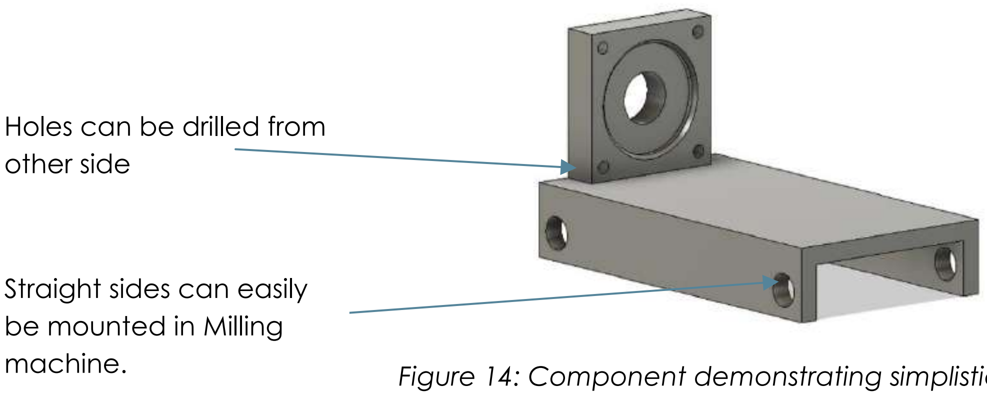
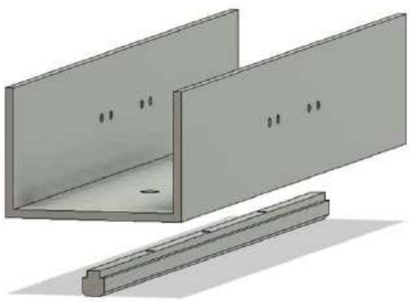


Figure 14: Component demonstrating simplistic manufacturing

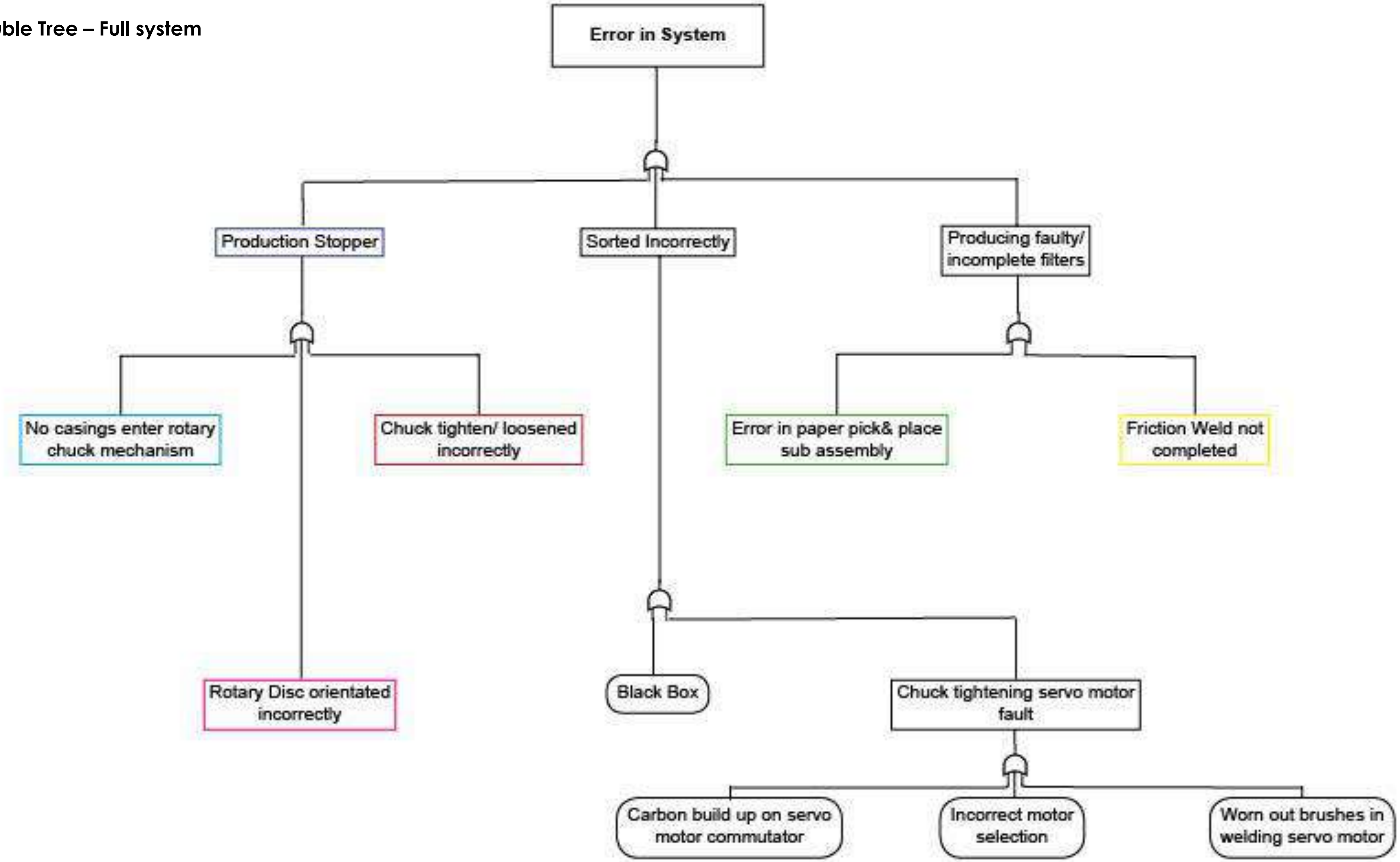


The chuck tightening linear actuator mount has been produced from two separate parts, which will allow the use of u channel for the main housing and minimal machining for the Minitec slide mount. If this had been produced from a single part, this part would have had to be machined from a single block of material. This design has reduced both machining time and material cost.

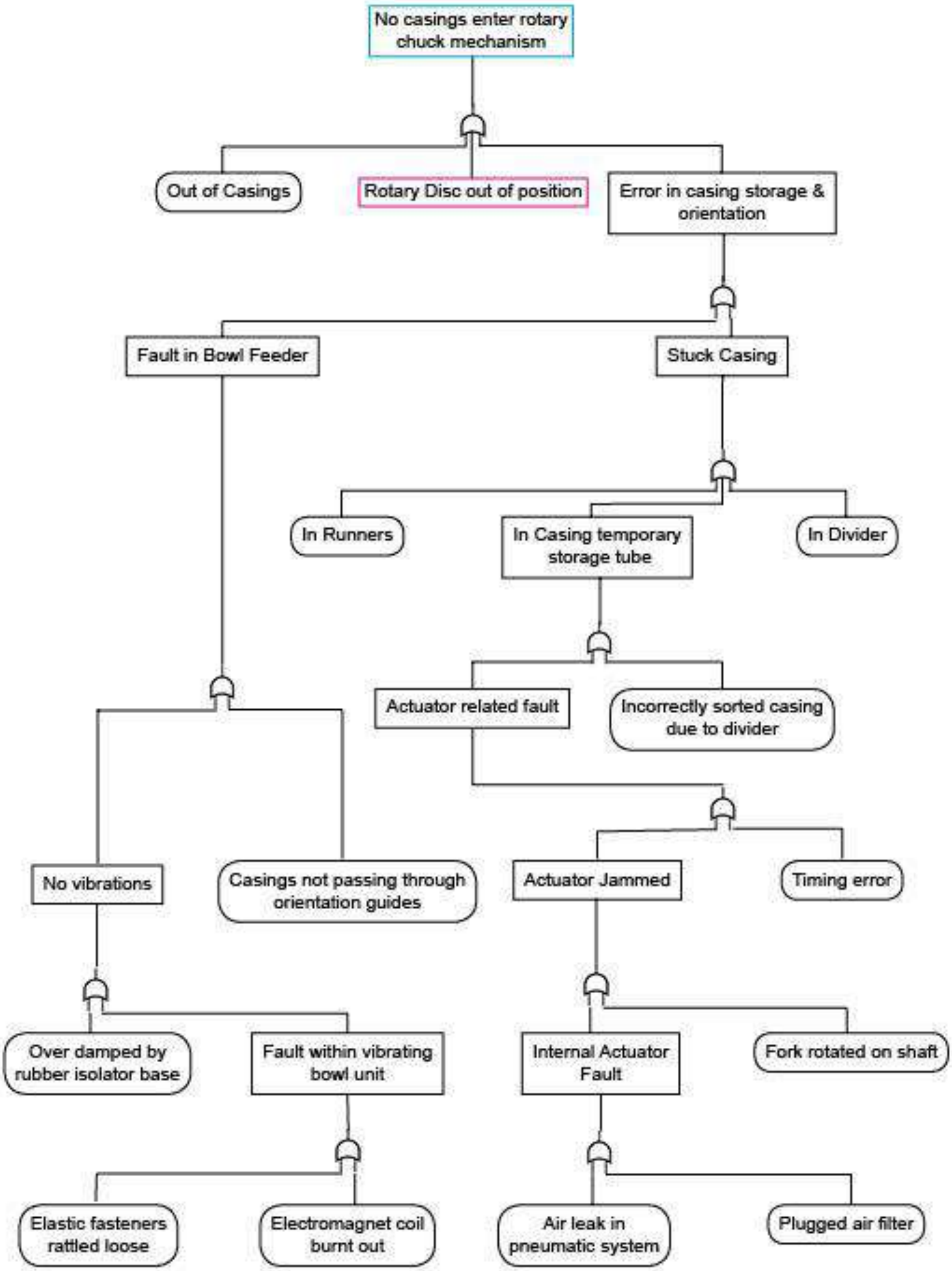
Figure 15: Component demonstrating intelligent design to reduce machining

Retrospective Design for Reliability Assessment

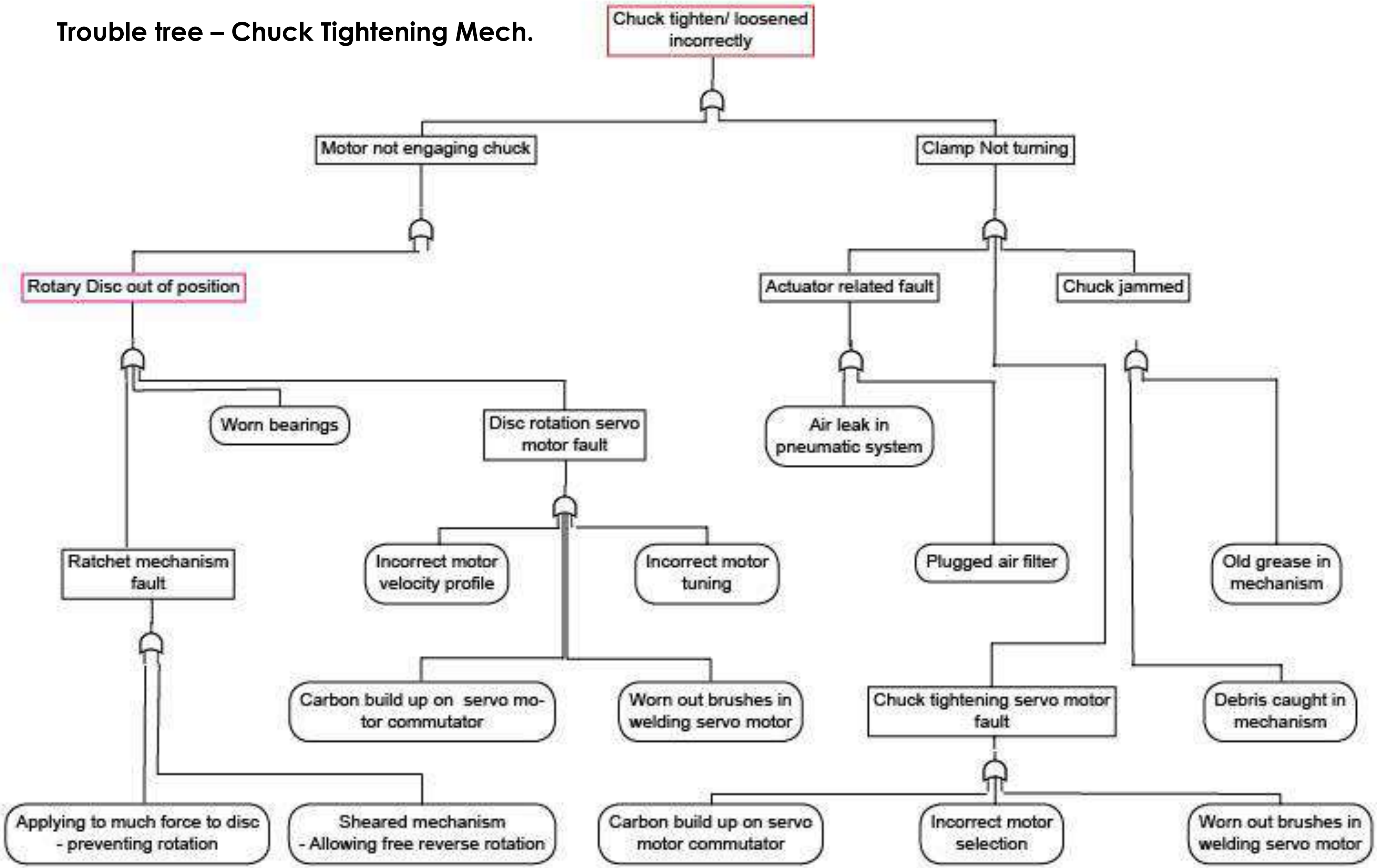
Trouble Tree – Full system



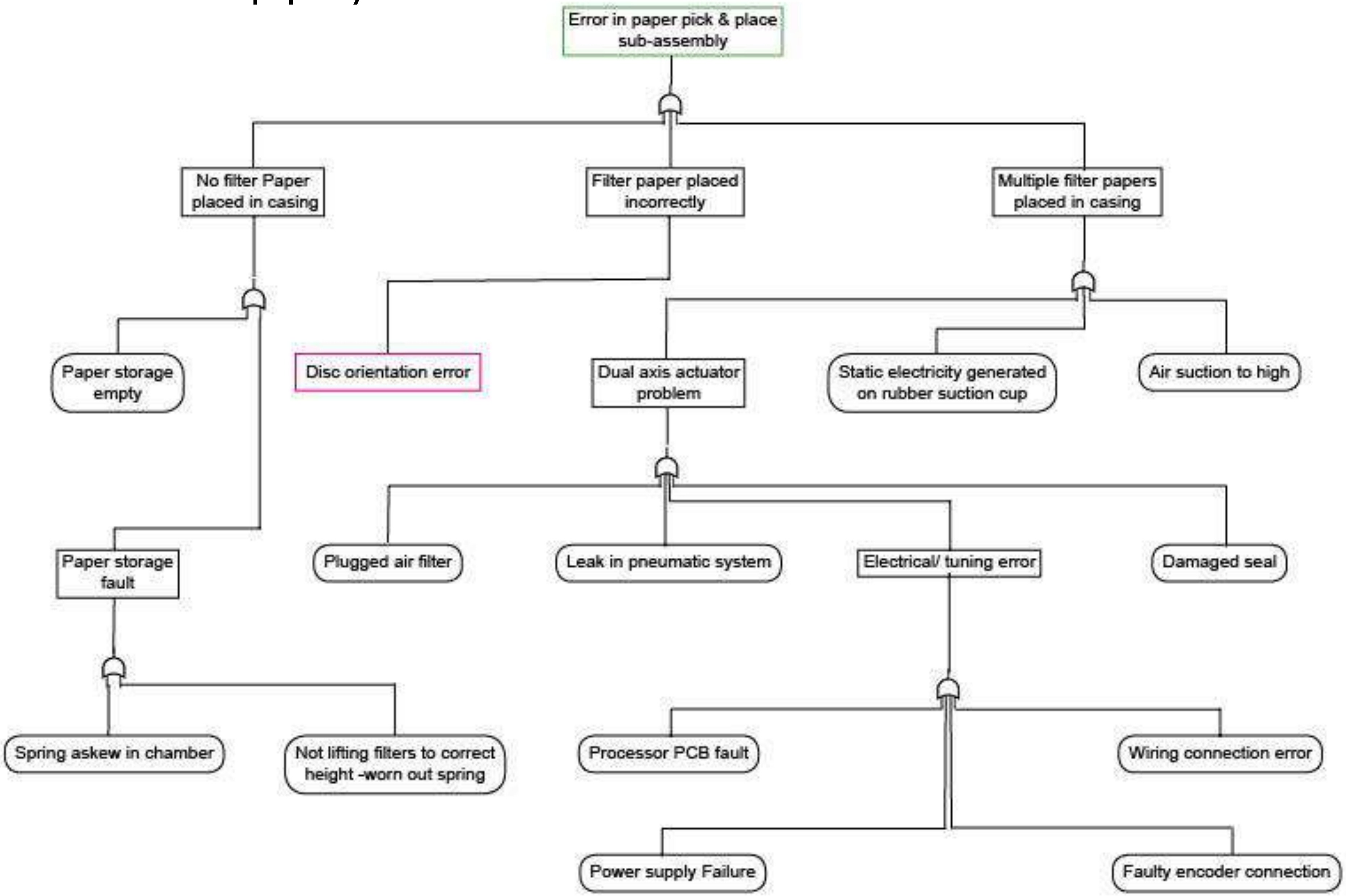
Trouble tree – Storage, orientation and delivery system



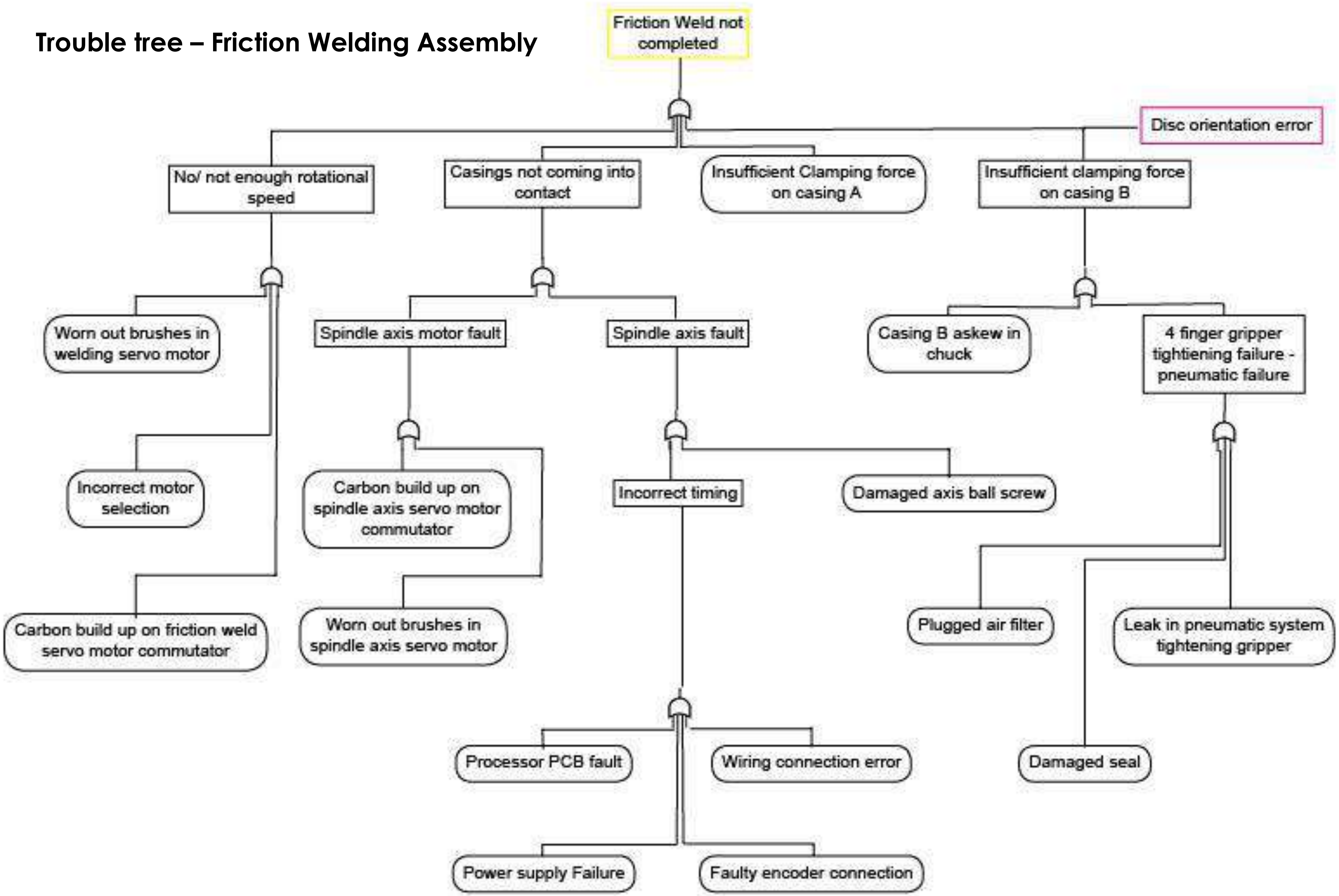
Trouble tree – Chuck Tightening Mech.



Trouble tree – Filter paper system



Trouble tree – Friction Welding Assembly



Failure Mode, Effects and Critical Analysis (FMECA)

Based on the trouble tree analysis the casing storage, orientation and delivery system was considered to be most likely to fail. Therefore, this was taken forward to the FMECA

Failure mode, effects and criticality analysis

Function	Potential Failure	Potential causes	Severity	Occurance	Current Process Controls	Detection	Risk priority	Actions Taken	Sev	Occ	Det	RPN
Casing Storage & Orientation	No casings entering rotarty chuck mechanism	Casing stuck in divider	8	1	Pressure sensor on release forks	6	48	Low level risk - No action taken	8	1	6	48
		Casing stuck in runners	6	6	Pressure sensor on release forks	6	216	Re-design runners to ensure more fluid flow of casings	6	3	6	108
		Casing stuck in temporary storage tube due toincorrect sorting of casings	8	4	Pressure sensor on release forks	6	192	Insert exit unit to remove incorrectly sorted filters from the system	8	1	6	48
	Bowl feeder broken	Electromagnetic coil burn out	10	1	No controls	8	80	Pre bought, closed part- No action taken	10	1	8	80
	Bowl feeder not feeding casings	Casing stuck in Orientation guides	6	7	No controls	6	252	Re-design orientation guides to higher spec	6	2	6	72
		Over Damped system	10	1	No controls	10	100	Ensure proper system anlyses for vibration isolater unit	10	1	10	100
	Release actuator failure	Release forks rotated preventing linear movment	8	3	No controls	8	192	Fasten Fork to shaft with superior method	8	1	8	64
		Air leak in pneumatic system	8	1	No controls	10	80	No action taken	8	1	10	80
		Plugged air filter	8	3	No controls	10	240	Regular maintenace of air filters	8	1	10	80

Severity scale

Production Stopped Perminently, without new parts or prevents initial production	10
Production stopped Long term	8
Production stopped Short term	6
Production slowed	4
Production unaffected	2

Detection

Undetected	10
Detected once production stops	8
Delayed sensor detection	6
Immediate Sensor detection	4

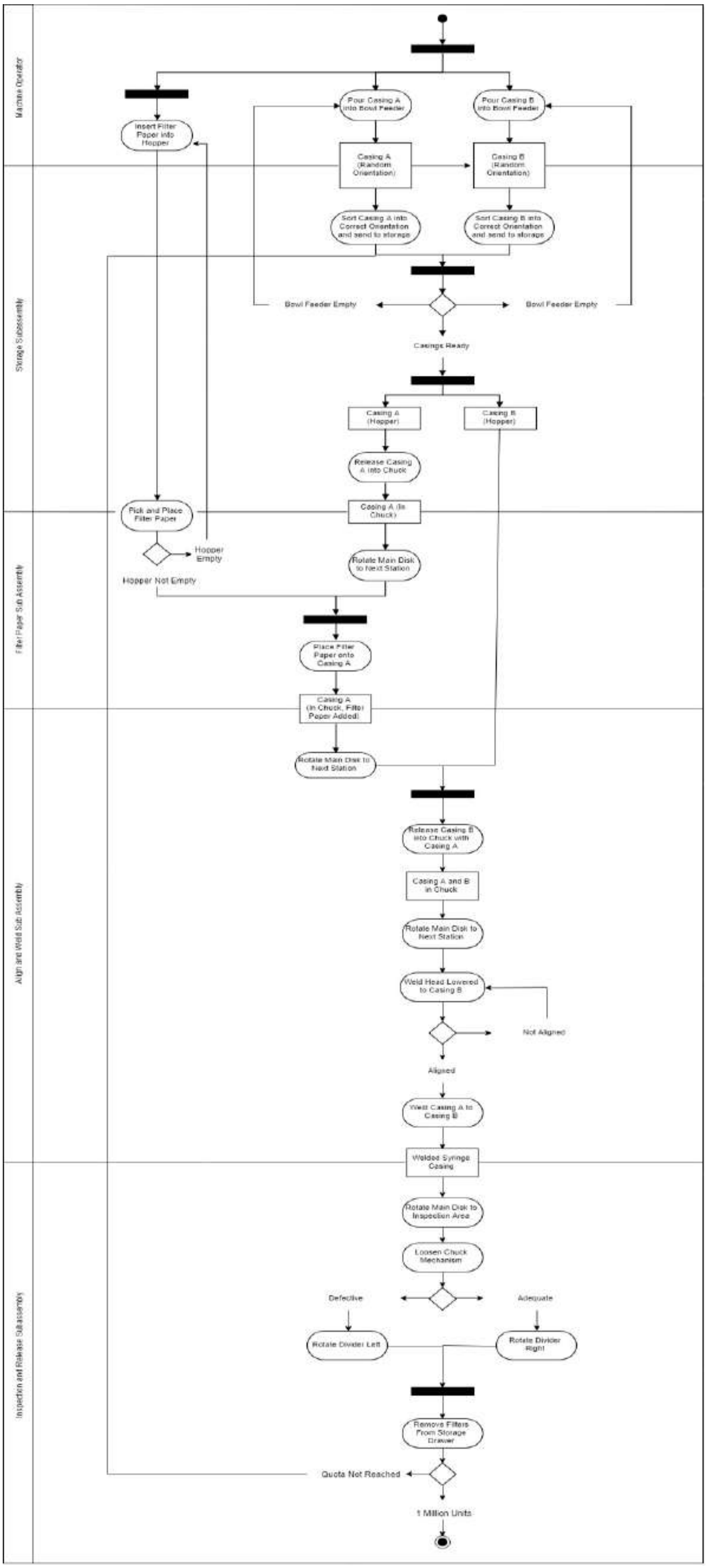
Estimated Occurance rate

Every unit	10
Every 10 units	9
Every 100 units	8
Every 1000 units	7
Every 10e^3 units	6
Every 10e^4 units	5
Every 10e^5 units	4
Every 10e^6 units	3
> 10e^6 units	1

Having conducted the FMECA the highest likely hood of failure was considered to be that a casing would get stuck in the runners or divider. In order to resolve this issue, the casing would have to be

removed manually. This highlights a serious safety risk as the operator would need open up the machine casing exposing themselves to the inner workings. To counteract this problem, operations could be implemented to reduce the chance of a fault. Regular maintenance was also highlighted as a necessary requirement to insure constant functionality of the actuator system. These issues could have been resolved if better attention had been payed to BSI standards and safety requirements during the design process.

Operating Sequence



Systems Analysis

Checking the casings are ready to be assembled

Both Casing A and casing B initially pass through the bowl feeder and are separated by the integrated sorting mechanism. The casings are then fed to their respective temporary storage hoppers. While there is an electronic distance sensor designed to indicate when the bowl feeder is empty there should also be electronics to detect whether both of these temporary stores are empty and if this is the case, the main disk assembly should not be allowed to proceed, and manufacturing should cease. This could be achieved by simple pressure sensors mounted on the casing release forks combined with AND statements to ensure the machine does not operate if one or more of these conditions is not met. However, there must be a noticeable delay in the system, so the machine is not unnecessarily halted during the small amount of time in which either casing A or Casing B is released from the temporary store.

Checking the filter paper store is not empty

It is important to ensure that the filter paper stack is never empty. To achieve this a similar electronic distance sensor used in the bowl assembly could be utilised. This would allow a signal to be transmitted when a pre-determined distance is achieved indicating that the hopper is low on filter paper and should be re-filled.

Positioning of the rotary disk assembly

Since multiple operations are carried out simultaneously around the perimeter of the main rotary disk assembly its exact positioning is of the upmost importance. The main motor selected to carry out the rotational movement of the rotary disk assembly was specifically chosen due to the presence of a break and an absolute safety multi turn encoder. The rotary disk is required to move through a precise angle of 72 degrees between each operation in the manufacturing process. Therefore, closed loop control is required for this operation with constant response to the motor position. Due to the minimal nature of this rotation speed is not a necessity and thus, a controller with minimal oscillatory response is desired. This could be achieved by a PI controller with minimal steady state error.

Position of the 4-finger gripper

The 4-finger PZV100 gripper was chosen primarily due to its easy integration with the OPS 100 impact sensor. This sensor could be linked with both the encoder in the EMME-AS-100 motor used for the friction welding process and the encoder for EMME-AS-60 motor used to operate the spindle axis linear encoder. When the impact sensor is triggered this indicates that Casing B has made contact with the 4-finger gripper and is correctly positioned and thus the EMME-AS-60 motor should cease to operate. This should signal the fingers to close and the EMME-AS-100 to begin its operation. The OPS 100 sensor would also provide the ability to confirm the desired weld pressure is being applied.

Solution Specification

By the end of the design process the following solution specification was produced which provides and overview of the main functions and components.

Friction welding process

- 1 filter produced at a time
- Main Motor: Festo EMME-AS-100-MK-HS-AMXB
- Spindle Axis: Festo EGC-70-100-BS-10P
- Spindle Axis Motor: EMME-AS-60-S-LS-AMB

Production Rate

- 1.5 seconds weld time, 1 second spin up, 1.5 second clamping/unclamping, 2 seconds disk rotation
- 1 filter produced every 6 seconds
- Shift Pattern: 3x8 hour
- 1 million casings produced in 70 days

Estimated Cost

- University of Bath Manufactured parts including labour: £1,685.04
- Externally Sourced Components: £20,236
- Total Cost: £21,921.04

By the design process a machine was produced that was completely designed and specified as per the client's request. Overall it was felt that the finalised machine adequately met all the desired functions however it was felt there could be improvements in reliability, design for manufacture and producing the design to international standards. CAD drawings for the full assembly and relevant sub-assemblies are available upon request.

Appendix A - Costing

Chuck Tightening		**Material**	**Length (mm)**	**Width (mm)**	**Height (mm)**	**Volume (m^3)**	**Cost / m3**	**Quantity**	**Cost**
UOB-ME20025-BF-01-001	Actuator Mounting Bracket	Mild Steel	110	59.6	60	0.000393	6490	1	2.55
UOB-ME20025-BF-01-002	Chuck Tightening Socket	Mild Steel	N/A	N/A	N/A	0.000062	6490	1	0.40
UOB-ME20025-BF-01-003	Tightening Socket Grub Skrew	Stainless Steel	N/A	N/A	N/A	N/A	34621	1	N/A
UOB-ME20025-BF-01-004	Motor Mounting Bracket	Mild Steel	504	107	71	0.003829	6490	1	24.85
UOB-ME20025-BF-01-005	Actuator Constraint Plates	Mild Steel	160	12	5	0.000010	6490	2	0.06
UOB-ME20025-BF-01-006	Minitech Slot Mount	Aluminium	504	13.4	15.3	0.000103	5994	1	0.62
Friction Welding									
UOB-ME20025-BF-01-007	Spindle Axis mounting Plate	Mild Steel	160	60	18	0.000173	6490	1	1.12
UOB-ME20025-BF-01-008	Motor Shaft Grub Skrew	Stainless Steel	N/A	N/A	N/A	N/A	34621	4	N/A
UOB-ME20025-BF-01-009	Casing B Custom Clamps	Aluminiuim	50	36	14.4	0.000026	5994	1	0.16
UOB-ME20025-BF-01-010	Sensor Mounting Plate	Mild Steel	N/A	N/A	N/A	0.000385	6490	1	2.50
UOB-ME20025-BF-01-011	Motor Mounting Plate	Mild Steel	123	120	100	0.001476	6490	1	9.58
Rotary Disk									
UOB-ME20025-BF-01-012.1	Ratchet Sub Sytem	Carbon Steel	150	150	10.5	0.000236	4301	1	1.02
UOB-ME20025-BF-01-012.2	Chuck Mounting Plate	Mild Steel	450	450	20	0.004050	6490	1	26.28
UOB-ME20025-BF-01-013	Top Shaft Bearing Housing	Aluminium	110	80	30	0.000264	5994	1	1.58
UOB-ME20025-BF-01-014	Main Shaft	Mild Steel	N/A	N/A	N/A	0.000780	6490	1	5.06
UOB-ME20025-BF-01-015	Bottom Shaft Bearing Housing	Aluminium	110	80	30	0.000264	5994	1	1.58
UOB-ME20025-BF-01-016	Main Motor Mount	Mild Steel	170	105	52	0.000928	6490	1	6.02
UOB-ME20025-BF-01-017	Coupling Keyway	Carbon Steel	N/A	N/A	N/A	N/A	4301	1	N/A
UOB-ME20025-BF-01-018	Taper Bush Keywas	Carbon Steel	N/A	N/A	N/A	N/A	4301	1	N/A
UOB-ME20025-BF-01-019	Custom Chuck Jaws	Carbon Steel	110	41	26	0.000117	4301	1	0.50
Filter Paper									
UOB-ME20025-BF-01-020	Vacuum Holder Mounting Plate	Mild Steel	119	25	9	0.000027	6490	1	0.17
UOB-ME20025-BF-01-021	Lift and Place Mounting Mechanism	Stainless Steel	N/A	N/A	N/A	0.000716	34621	1	24.79
UOB-ME20025-BF-01-022	Filter Paper Drawer	Mild Steel	290	60	20	0.000348	6490	1	2.26
UOB-ME20025-BF-01-023	Filter Paper Storage Tube	Mild Steel	N/A	N/A	N/A	0.000401	6490	1	2.60
Casing Release									
UOB-ME20025-BF-01-024	Custom Made Casing Release Forks	Mild Steel	67	45	6	0.000018	6490	4	0.12
UOB-ME20025-BF-01-025	Tempory Casing Storage	Steel Tube	N/A	N/A	N/A	0.000016	6490	2	0.10
UOB-ME20025-BF-01-026	Custom Minitech Mounting Bracket	Mild Steel				0.000000	6490		
Case Storage									
UOB-ME20025-BF-01-027	Casing Orientation Mechanism	Aluminium	230	92	45	0.000952	4301	1	4.10
UOB-ME20025-BF-01-028	Casing B Stacking Mechanism	ABS	N/A	N/A	N/A	0.000342	Negligable	1	0.00
UOB-ME20025-BF-01-029	Casing A Stacking Mechanism	ABS	N/A	N/A	N/A	0.000442	Negligable	1	0.00
UOB-ME20025-BF-01-030	Intergrated Casing Sorting Unit	ABS	800	165	300	0.039600	Negligable	1	0.00
UOB-ME20025-BF-01-031	Casing B Guide Rail	Steel Tube	N/A	N/A	N/A	0.000079	6490	2	0.51
UOB-ME20025-BF-01-032	Casing A Guide Rail	Steel Tube	N/A	N/A	N/A	0.000047	6490	2	0.31
UOB-ME20025-BF-01-033	Initial Casing Rail Guide	Steel Tube	N/A	N/A	N/A	0.000039	6490	3	0.25
Filter Sorting									
UOB-ME20025-BF-01-034	Filter Delivery Pipe	Sheet Mild Steel	N/A	N/A	N/A	0.000083	6490		0.54
UOB-ME20025-BF-01-035	Sorting Cover	Sheet Mild Steel	450	300	3	0.000405	6490		2.63
UOB-ME20025-BF-01-036	Filter Sorting Mechanism	Sheet Mild Steel	300	200	3	0.000180	6490		1.17
UOB-ME20025-BF-01-037	Pop Rivet	Sheet Mild Steel	N/A	N/A	N/A	N/A	6490		N/A
UOB-ME20025-BF-01-038	Filter Divider	Sheet Mild Steel	140	60	8	0.000067	6490		0.44
UOB-ME20025-BF-01-039	Slope Base Plate	Sheet Mild Steel	300	200	3	0.000180	6490		1.17
								Total	125.04

Motors					
Function	**Type**	**Link**	**Price (£)**	**Quantity**	**Cost**
Friction Welding	EMME-AS-100-MK-HS-AMXB	https://www.festo.com/cat/en-gb_gb/products_EMME_AS?CurrentIDCode1=emme-as	£850	1	£850
Disk	EMME-AS-100-MK-HS-AMXB	https://www.festo.com/cat/en-gb_gb/products_EMME_AS?CurrentIDCode1=emme-as	850	1	£850
Tanks	EMME-AS-40-S-LV-AMB	https://www.festo.com/cat/en-gb_gb/products_EMME_AS?CurrentIDCode1=emme-as	500	2	£1,000
Friction Mover	EMME-AS-60-s-LS-AMB	https://www.festo.com/cat/en-gb_gb/products_EMME_AS?CurrentIDCode1=emme-as	700	1	£700
Actuators					
Tanks	M/146116/M/100	https://www.imi-precision.com/uk/en/list/actuators/rodless-lintra-cylinders/stroke-length-is-100-mm/port-size-is-m5	500	2	£1,000
Ratchet Mechanism	RM/92020/M/60	https://www.imi-precision.com/uk/en/detail/actuators/compact-cylinders/port-size-is-m5/stroke-length-is-60-mm/rm_92020_m_60/short-stroke-cylinder	77	4	£308
Gripper	PZV 100	https://schunk.com/gb_en/gripping-systems/series/pzv/	300	1	£300
Chucks					
Main Chucks	ROTA-S plus 2.0 250-62 Z235-SFG	https://schunk.com/gb_en/clamping-technology/product/39580-0819003-rota-s-plus-2-0-250-62-z235-sfg/	985.38	5	£4,927
Linear Actuators					
Pick and Place	HP140T	http://www.weissna.com/Pick-Place-HP.518.0.html	800	1	£800
Friction	EGC-70-100-BS-10P	https://www.festo.com/cms/en-gb_gb/12486.htm	600	1	£600
Sensor					
Impact Sensor	OPS-100	https://schunk.com/gb_en/gripping-systems/series/ops/	832.07	1	£832
Black Box	N/A	N/A	5000	1	£5,000
Coupling					
Disk Coupling	EAMC-65-90-19-25	https://www.festo.com/cat/en-gb_gb/products_KSE?CurrentPartNo=533707	449.78	1	£450
Friction Coupling	EAMM-A-S38-60P-G2	https://www.festo.com/cat/en-gb_gb/products_EAMM?CurrentIDCode1=EAMM-A-S38-60P-G2&CurrentPartNo=3637958	800	1	£800
Suction Cup					
Paper Vacuum	101569	https://www.piab.com/Products/suction-cups/shape/flat/f---flat-15-150-mm/0101569/	4.92	1	£5
Vacuum Holder	FSCM.P.18.45.G38F.G14FDR	https://www.piab.com/Products/end-of-arm-tooling-eoat/flexible-suction-cup-mount/flexible-suction-cup-mount/#ordering			
MiniTec			16.84	26	£438
Frame	45 x 45 UL	https://www.minitec.de/en/products/profile-system/profiles/profile-series-45/profile-45-x-45-ul	5.19	67	£348
Bracket	Mounting Angle 45 GD	https://www.minitec.de/en/products/profile-system/fastening-elements/mounting-angles/mounting-angles-profile-series-45/mounting-angle-45-gd			
Bearings					
Bottom Bearing	SKF 320/32 X Tappered Roller Ball	https://www.skf.com/group/products/bearings-units-housings/roller-bearings/tapered-roller-bearings/single-row-tapered-roller-bearings/single-row/index.html?designation=320%2F32%20X	25	1	£25
Top Bearing	SKF W 61809 Deep Ball	https://www.skf.com/uk/products/bearings-units-housings/ball-bearings/deep-groove-ball-bearings/deep-groove-ball-bearings/index.html?designation=W%2061809-2Z	4	1	£4
Bowl Feeder					
Vibrating Bowl Feeder	600 Vibratory Bowlffeder Drive Unit	https://www.premierbowlfeeders.co.uk/Bowl-Feeders/600-Drive.aspx	1	1000	£1,000
				Total	£20,236

Appendix B - Calculations

Main Disk

Area = $2.726 \times 10^5 \, mm^2$
Thickness = $4.5mm$

=> Volume = $1.2267 \times 10^6 \, mm^3$.

Small Disks x 5

Area = $4.77 \times 10^4 \, mm^2$
Thickness = $6mm$

=> Volume = $2.862 \times 10^5 \, mm^3$.

Main Disk Inertia

$I = \frac{1}{2} MR^2$ $\qquad R = 348 mm$

$m = \rho \times V = 1.2267 \times 10^6 \times 0.005 = 6.133 kg$.

$I = \frac{1}{2} MR^2 = \frac{1}{2} \times 6.133 \times 0.348^2 = 0.371 \, kg/m^2$.

Small Disk Inertia - Point Mass

$m = \rho \times V = 2.862 \times 10^5 \times 0.005 = 1.431 kg$

$I = mR^2 = 1.431 \times 0.220^2 = 0.0693 \, kg/m^2$

5 disks => $0.3465 \, kg/m^2$

Inertia of Chucks

$I = mR^2 = 28.8 \times 0.220^2 = 1.3939\ kg/m^2$

5 chucks $\Rightarrow$ 6.9696 kgm^2

Total Inertia

$0.371 + 0.3465 + 6.9696 = 7.6871\ kgm^2$

1 rotation = 72° Using Velocity profile.

36° acceleration in 1s
36° = 0.54105 radians

$\alpha = \frac{V - U}{T} = 0.54105\ rads^{-2}.$

$T = I\alpha = 7.6871 \times 0.54105$
$= 4.159\ Nm.$

Friction Welding Calculations

Weld Speed = $5\ ms^{-1}$

$V = r\omega$ $\quad\quad \frac{V}{r} = \omega$

$\omega = \frac{5}{0.0225} = 222.2\ rad/s = 2121\ rev/min$

Work done = 778 W

$W = T\theta$ $\quad\quad$ in 1 second moves 222 radians.

$\Rightarrow 778 = T \times 222 = 3.51\ Nm$ – Clamping Torque

$T = FR$ $\quad\quad$ Radius = 25 mm

$\Rightarrow F = \frac{3.51}{0.025} = 140.4\ N$ – Clamping Force