



SIX SIGMA GREEN BELT PROJECT

THERMAL LIDDING JIG: PROCESS IMPROVEMENT AND
CAPABILITY STUDY

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1. Introduction

1.1 Renishaw

Renishaw was founded in 1973, the first product that the company marketed was touch trigger probing for precise inspection of the Olympus engines at Rolls Royce (Renishaw, 2023). Renishaw is a worldwide leader within the metrology, encoders, and machine tool sector of industry.



Figure 1 - Renishaw Products (Renishaw, 2020)

1.2 The Resolute Product

The Resolute Encoder is just one of many Encoders that Renishaw produce and market. Along with several other Encoders, the manufacturing site at Miskin South Wales has recently taken over the production of the Resolute Linear Encoder. As explained by Renishaw (2023), ‘an Encoder is an electromechanical device converting one format into another’.

A positional encoder works to convert linear or rotational movement into an electrical signal to determine position, speed, and direction to ultra-high precision (Renishaw, 2023). Encoders are essential to any machinery that moves and requires positional feedback, industries such as robotics and automation are amongst a vast market.

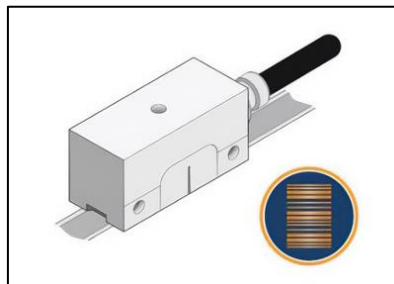


Figure 2 - Encoder & Scale (Renishaw, 2023)

1.1 Project Reasoning

Renishaw Miskin manufacturing site has recently taken responsibility for the Resolute Encoder assembly line. This has meant that all the equipment moved from the Woodchester site has required stringent validation. With customer orders for the encoder soaring, the Encoders Product Division (EPD) have identified several rigs that will need to be duplicated to meet required demand. With tight deadlines, rigs have been validated at a much higher pace which has led to some error. A CCAR (Corrective Action Report) has been raised for an issue with the lid pressing which needs further investigation.



Figure 3 - Resolute Encoder Parts (Renishaw, 2023)

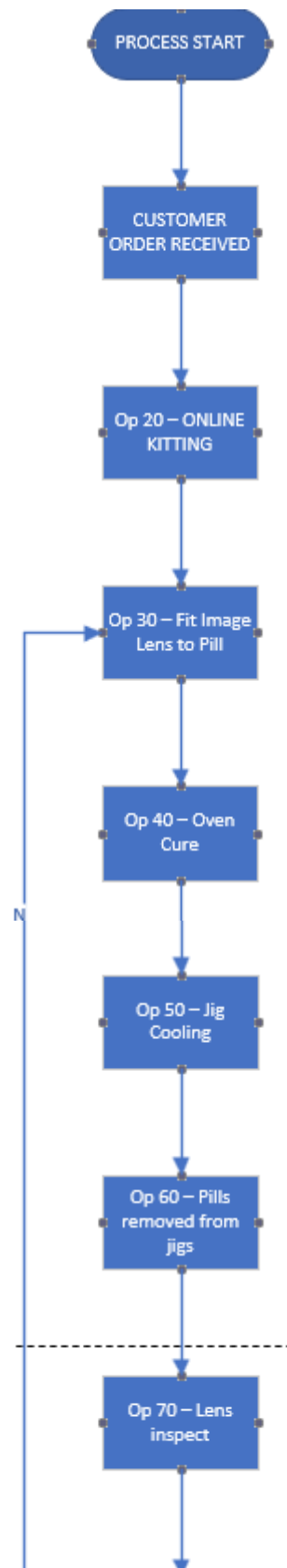
2. Define

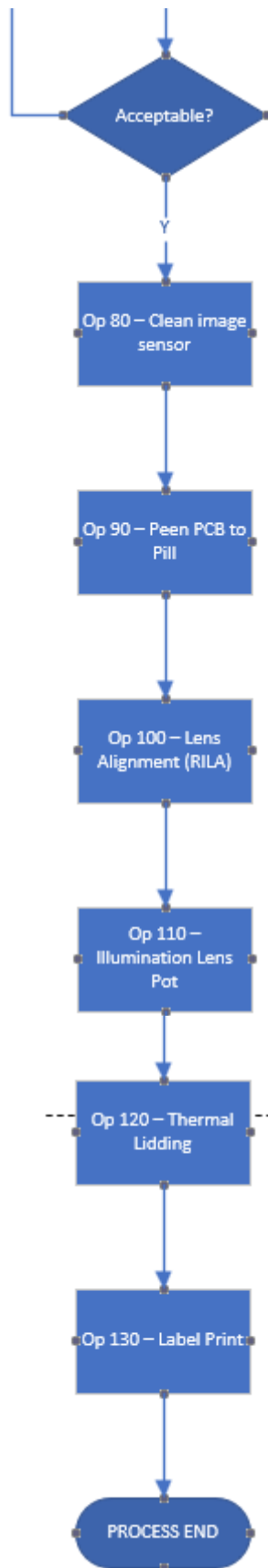
2.1 Problem Statement

EPD has recently identified an increase of Resolute Encoder sales from 550 units per two shift (16 hrs) to 830 units per two shift (16 hrs). This is a target for production after the sales division released a 5-year plan for the product. As a result, several assembly rigs have been identified for duplication to increase productivity by 34%. The speed of this duplication project has led to some quality issues. There has been an increase in first time failure rates which requires further investigation.

2.2 Process Map

The process map has been used as a tool to map out the Resolute assembly. This tool is useful in visualising the route of the assembly to identify potential problems and understand where they may occur. **Appendix 1** offers a far more detailed map of the Resolute coring and customisation line.

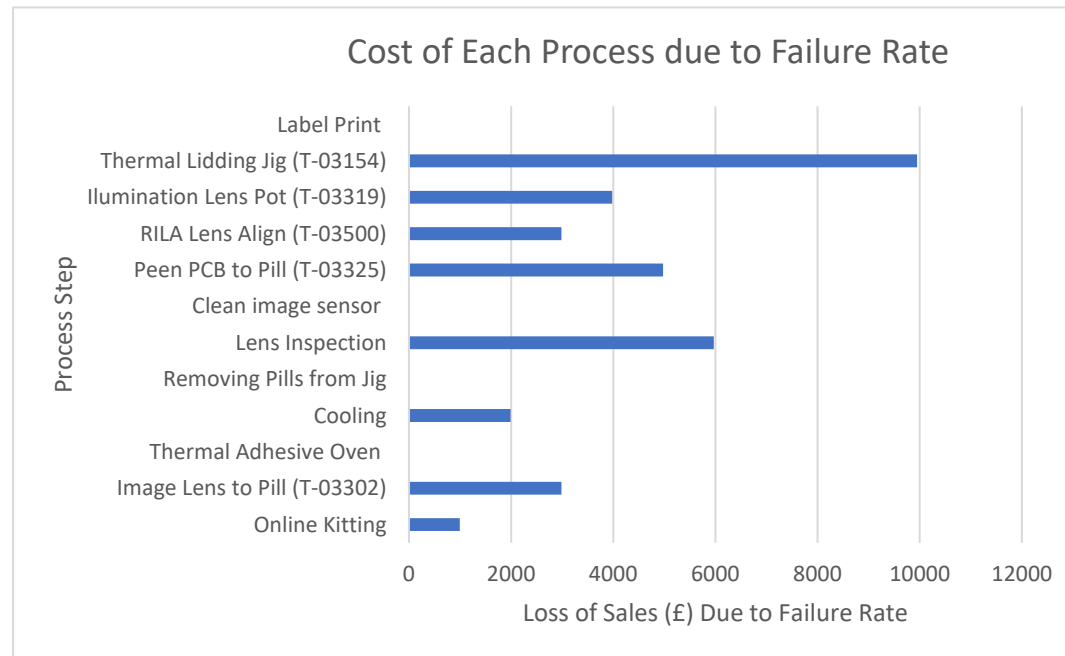




2.3 Failure Mode Breakdown per Op

Op Number	Process Step (Jig ID)	Description	Failure Rate (Per 830 units)	Loss of Potential Sales (£)	Cost to Renishaw (£)
20	Online Kitting	Online Kitting - Items Kitted for Resolute assembly depending on variant of encoder.	1	995	100
30	Image Lens to Pill (T-03302)	Fit Image Lens to Pill - Image Lens pressed into pill with epoxy pre-form ready for oven cure.	3	2985	300
40	Thermal Adhesive Oven	Thermal Adhesive oven - Pill assembly fitted into Oven Jigs and placed in adhesive oven. This process sets the Epoxy pre-form securing the lens in place.	0	0	0
50	Cooling	Cooling bench used to allow pills to cool before next Op.	2	1990	200
60	Removing Pills from Jig	Pills removed from Jig once cool.	0	0	0
70	Lens Inspection	Lens inspected under a microscope to ensure that the lens is seated correctly.	6	5970	600
80	Clean image sensor	Image sensor is cleaned if necessary, this is decided at Op 70.	0	0	0
90	Peen PCB to Pill (T-03325)	PCB is fitted to the the pill via a peen provided by Jig.	5	4975	500
100	RILA Lens Align (T-03500)	The lens is aligned within the pill, this is crucial to encoder functionality.	3	2985	300
110	Illumination Lens Pot (T-03319)	Lens is finally secured after adjustment in previous Op.	4	3980	400
120	Thermal Lidding Jig (T-03154)	Thermal Adhesive applied around the top and bottom of the Resolute PCB, The lid is then peened to secure the Encoder.	10	9950	1000
140	Label Print	Label printed and job at the customisation phase is complete, the encoder then moves onto cable fitment and Final Test.	0	0	0

Figure 4 - Table to Show Failure Rate per Op



To distinguish the main cause of increased failure rate, the author looked at failure mode per 830 units or over 2 shifts. The following data (Figure 4) is an average taken from a weeks' worth of production with each 16-hour shift hitting the 830-unit target.

It's clear to see that the highest failure rate was Op 120 or the Thermal Lidding Process, this process was responsible for 29% of the failure costing the company approximately £9950 in loss of potential sales. The graph offers a better visual of failure per Op. Improving the Lidding Process is the main target for this Six Sigma Improvement project.

2.4 VOC (Voice of the Customer)

It is imperative that the voice of the customer is listened to when undertaking any six-sigma project. Listening to the voice of the customer relates to greater customer satisfaction (Stank, 2006).

Identifying the VOC was crucial to the project's success. Having held a meeting with key stakeholders, the sales team revealed that they required production to raise current production levels by 34% to meet customer demand. From the authors point of view the main customer for this project is Renishaw's production team. Some of the key voices of the customer were raised from the meeting:

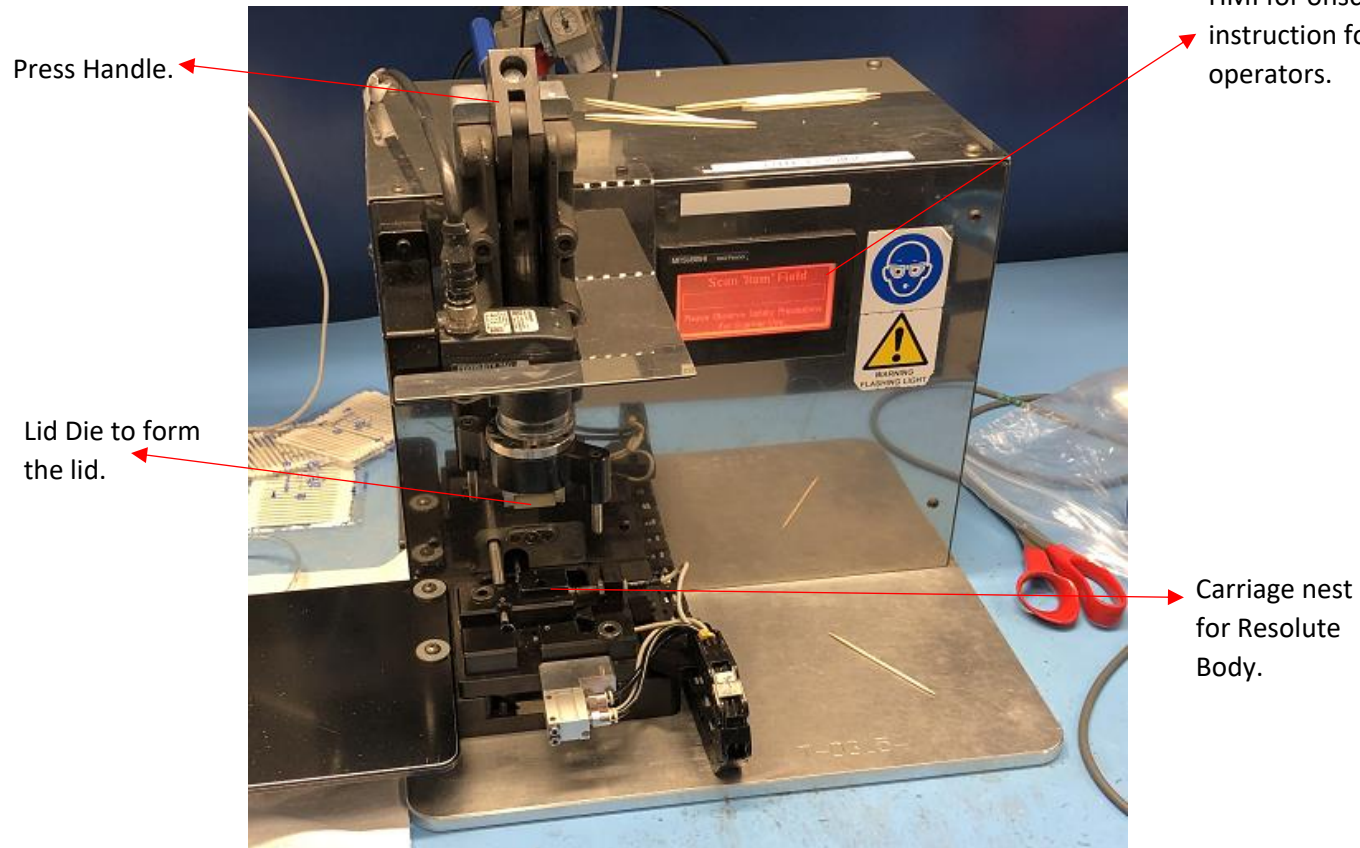
- **Production Requirements**
Extra assembly rigs have been built and introduced to the production line, however, have inherent problems which has increased failure rates. Current demand is not being met as a result. The Lidding Jig is currently causing the highest failure rate, leading to a loss of £9950 just in potential sales per 16 hours. This is required to be solved to reduce any further losses.
- **Failure Rates**
Current Failure rates are not acceptable. Having presented the failure rate per jig data gathered during an average week of shifts, Production accept that the main cause of product failure needs to be targeted first.
- **Importance of Quality**
Production don't want to decrease quality by increasing output, this is something that has been emphasised. The encoder needs to function perfectly due to its high precision applications. The solution must not affect the encoders quality, as stated by Renishaw (2023), 'Every Encoder design is built to last' therefore product quality is critical.

2.5 Project Scope

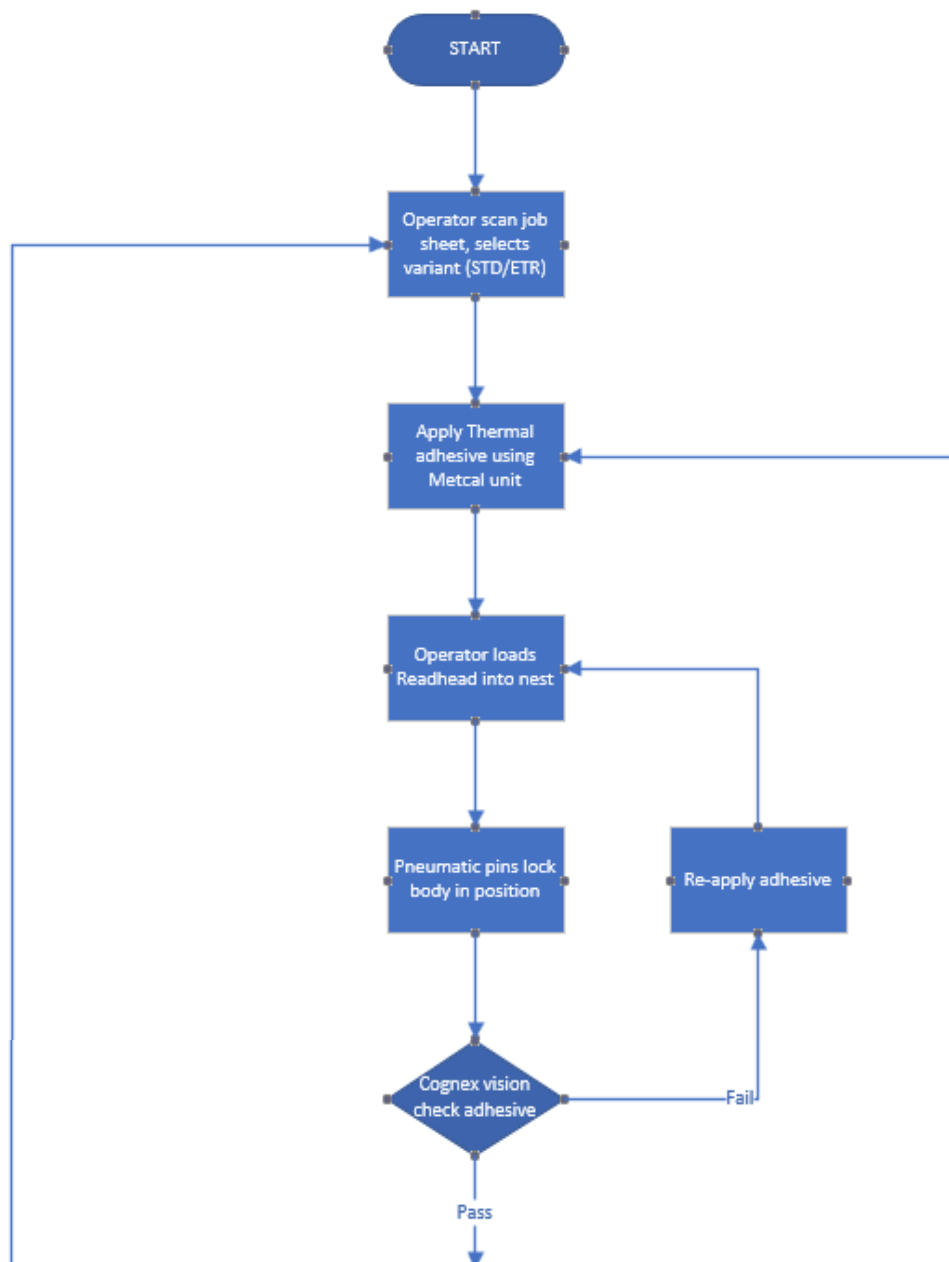
After identifying the main voices of the customer, it is critical to nail down the project scope. This project aims to target the Lidding Jig as the main cause of failure, investigate why it is failing and finally implement a solution to reduce failure rates in a bid to increase overall assembly efficiency.

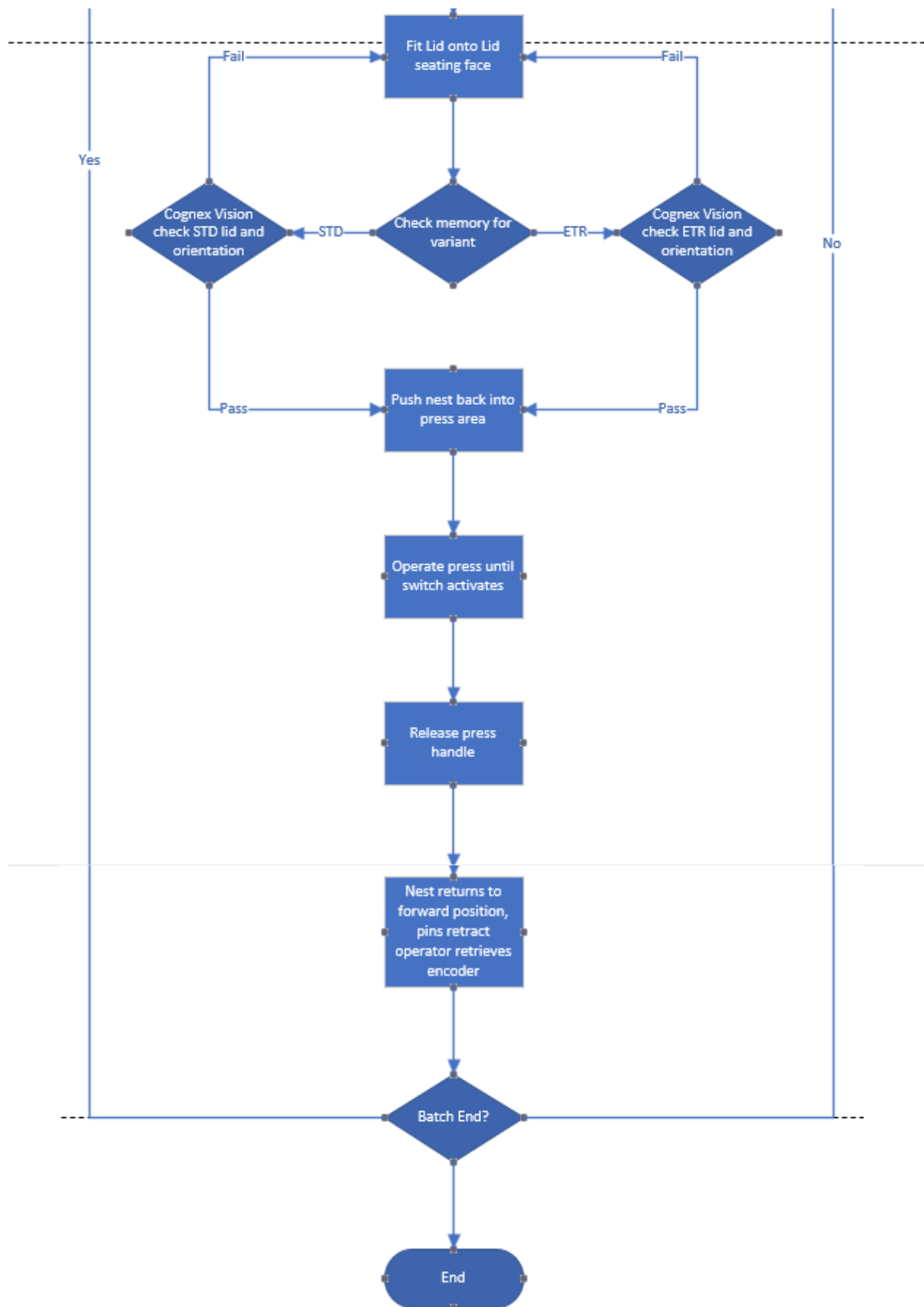
2.6 The Lidding Jig

Lid of the Standard Resolute and Resolute ETR is required to both make guaranteed electrical contact with the body and to stay in position while the glue seal is applied around it. The purpose of this jig is to secure Resolute lids within the body in accordance with the method designed for the lid. The Lidding Jig is shown below:



2.6.1 The Lidding Jig Process





2.7 Project Charter

Project Charter: Resolute – T-03154 (Lidding Jig) Process Study & Improvement	
Process Name & Purpose: Resolute Lidding Jig ID T-03154, this Jig is used during the customisation phase of the Resolute encoder assembly. Some of the Resolute encoder variants include STD & ETR, these can also have either a side exit or standard exit cable. The Lidding Jig is one of the final phases of the assembly, this is where thermal adhesive is placed around the PCB and the Lid is peened to secure the encoder.	Production Owner: Steven Evans
	Engineering Team Leader: Jack Brooks
Process Boundaries: Starting Point: This process starts after Op 110 which is Illumination lens potting. Ending Point: This process ends before Op 140 which is Job Complete (Label Print) and Final Test.	Team Members: Line operators – For expertise of the process CPEG (Engineering Team) – Jack Brooks & Ben Willis (Senior Process Engineer & Process Technician) ASG (Systems) – Ryan Harris, Conor Kenny (Development Technician & Engineer)
Process Sponsor: Steven Evans (Production Manager) Paul Richards (Assembly Systems Manager)	Process Sponsor Expectations: To undertake a process capability study and identify improvements required to not only the system efficiency but also understand and improve any mechanical issues. Implement changes that will increase first time pass rate thus improving throughput.
Resource Team: Line operators – For expertise of the process Ryan Harris – Lidding Jig project lead Gareth Evans – Six Sigma Analysis Expertise EPD (Encoders Product Division) – Budget Conor Kenny – Resolute Project Manger	
Stakeholders: Line operators, Production Owner, Engineering Team, Product Division.	

2. Measure

To determine the measurement plan, it is crucial to understand exactly what needs to be measured. The measurement phase is critical to measuring the overall success of the project. At this point in the project, the author drafted a process map of the Thermal Lidding process, shown on page 12-13.

3.1 Identify Measurement Variation

With reference to the Lidding Jig process map, the author has identified two variables to measure. The author will measure both the time variation between ops as well as force required to sufficiently peen the lids of the Resolute encoder. Understanding variation in measurement is essential to gathering accurate and reliable data, Hessing (2022) explains 'Data accuracy is one of the fundamental requirements in the DMAIC process'. The author will create a well-structured data collection plan to minimise the variation in the types of data.

3.2 Determining Data Type

Determining the data type was essential in applying the correct measurement analysis tools. This project used both Discrete and Continuous data. Continuous data is data that can be measured on an infinite scale, Timings was example of this. Discrete data is data that relates to occurrences or proportion. Pass or Fail rates are an example of the discrete data used in this project. The two main data types are below:

- Force required to overcome a peen measured in Newtons is a form of continuous data.
- Time taken per Op is a form of Continuous data.
- Camera check pass/fail is a form of Discrete data.

3.3 Data Collection Plan

To ensure that the project would identify the exact issue surrounding the Lidding Jig process, A meeting was called with Key stakeholders to draft potential sources of error that led to first time failure rates. A short breakdown of areas the project team targeted is shown below, an in-depth Data collection plan is illustrated in **Appendix 3** where several potential problems were identified.

The two main targets for this project:

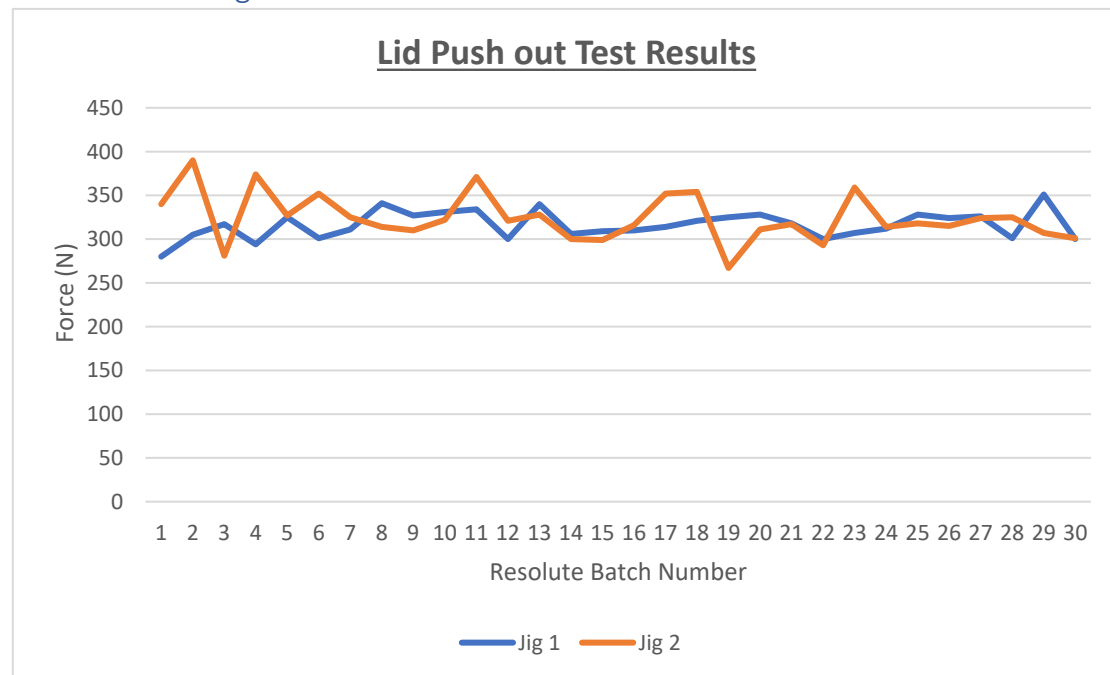
- Lid Force Testing

With the Introduction of the new lidding jig (Thermal Lidding Jig 2), the author will peen 30 Resolute encoders on each rig and will analyse pass/fail rate. The Mecmesin (**Appendix 5**) will be used to evaluate the force required to successfully push lids out. Lids are required to be peened >200N.

- Timing of Lidding Jig Process

The Lidding process will be timed by the author, this process is illustrated as a Process Map on page 12-13, The same operator will be used as well as the same batch of units to minimise any variation. This will be known as short term data gathering. The operator will be timed building a full batch of 30 units on each rig to identify any variation between rigs.

3.4 Lid Force Testing Results



Force Measured (N)		
Encoder	Jig 1	Jig 2
1	280	340
2	305	390
3	317	281
4	294	374
5	325	327
6	301	352
7	311	325
8	341	314
9	327	310
10	331	322
11	334	371
12	300	321
13	340	328
14	306	300
15	309	299
16	310	316
17	314	352
18	321	354
19	325	267
20	328	311
21	318	317
22	300	293
23	307	359
24	312	314
25	328	318
26	324	315
27	326	324
28	301	325
29	351	307
30	300	301

Table 1 – Push Out Test Results

The Lid Push out test was completed on 30 Resolute encoder units. Each lid was then pushed out using the Mecmesin Machine. The table 1 illustrates the results of the force push out in Newtons.

The Upper Specification for the push out test is 400N and the Lower Specification Limit is 200N. The graph shows that there was slightly more variation in Lidding Jig 2's results, however Jig 1 average push out was 316N and Jig 2's average was 324N.

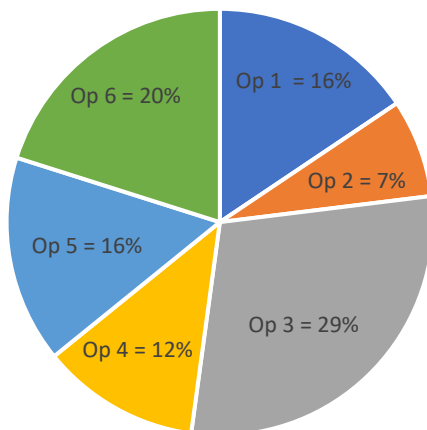
Both values are very close to being 300N which is the perfect force for the lids.

3.5 Lidding Jig Process Breakdown Results

Resolute Encoder	Thermal Lidding Jig 1							Thermal Lidding Jig 2						
	Op 1	Op 2	Op 3	Op 4	Op 5	Op 6	Cam Fail?	Op 1	Op 2	Op 3	Op 4	Op 5	Op 6	Cam Fail?
1	15	2	6	4	9	9	N	12	5	26	10	15	9	Y
2	12	4	8	5	10	12	N	13	6	18	7	12	12	N
3	13	3	5	3	11	17	N	9	4	22	12	11	17	N
4	17	2	4	4	15	18	Y	10	3	20	11	15	15	N
5	11	4	7	5	7	16	N	11	5	31	15	17	13	Y
6	10	2	9	4	8	14	N	12	6	27	12	12	14	Y
7	15	2	6	7	6	13	N	13	6	28	10	10	15	Y
8	9	4	8	2	7	12	N	14	7	23	9	9	16	N
9	16	2	5	7	9	8	N	15	8	22	8	8	17	N
10	12	4	4	4	10	9	N	12	8	25	7	9	20	N
11	17	2	3	6	11	11	N	10	7	18	9	10	19	N
12	18	3	7	5	12	16	Y	9	4	29	8	12	29	Y
13	11	2	8	8	5	6	N	8	5	24	10	16	31	N
14	13	5	4	7	8	7	N	11	5	26	11	17	16	Y
15	15	4	4	4	7	10	N	14	6	14	12	18	17	N
16	8	3	3	2	14	7	N	13	7	17	14	15	12	N
17	11	2	3	4	12	8	N	10	7	19	9	12	19	N
18	9	4	6	6	10	18	Y	12	9	32	8	13	18	Y
19	13	3	7	5	11	9	N	13	6	28	7	11	17	Y
20	17	2	3	4	12	11	N	16	8	29	5	10	16	Y
21	12	3	5	5	14	11	N	9	7	22	7	9	15	N
22	14	2	4	6	8	8	N	8	5	17	10	8	19	N
23	18	2	2	5	9	9	N	13	5	16	9	9	20	N
24	8	6	7	5	7	9	N	17	6	14	8	15	13	N
25	7	3	8	7	6	11	N	18	5	18	9	14	11	N
26	10	5	4	6	5	12	N	16	5	15	10	17	10	N
27	10	5	3	7	6	14	N	14	4	29	11	10	9	Y
28	9	5	4	5	8	15	N	11	4	17	6	14	8	N
29	8	5	7	4	9	16	N	10	7	20	7	9	9	N
30	9	5	8	5	7	10	N	9	3	30	8	8	11	Y
Total per Op (s)	367	100	162	151	273	346	3	362	173	676	279	365	467	11

Table 2 – Lidding Jig Timing Result Per Op

Lidding Jig 2 Op Breakdown



Key

Op 1 = Scan Job & Apply Thermal Adhesive

Op 2 = Load Resolute Encoder into nest

Op 3 = Camera Check 1 (Top Blob Position)

Op 4 = Camera Check 2 (Bottom Blob Position)

Op 5 = Load Lid & Camera Check 3 (Lid Confirm)

Op 6 = Press Operation & Remove Resolute Encoder

Cam Fail = Has the camera check failed at any of the 3 checks

Note: All Op's have been timed in Seconds

Data collection process for Lidding Jig process breakdown

The data illustrated in table 2 was collected by the author across both Thermal Lidding Jig 1 and Jig 2. The Lidding jig was broken into Ops shown in the key above. Each Op was timed for each individual unit across a batch of 30. The same operator and batch were used to minimise variation.

The pie chart breaks down the overall time taken per Op. The Resolute line aims to build 830 units per 16 hour (2 shifts), the estimated cost of failure for the Thermal Lidding Jig is estimated to be £9950. Per batch of 30 the cost £359.63. Op 3 from the pie chart is clearly the highest cost in downtime at 29% which represents a cost of £104.29 to the assembly process. This cost is only per a batch of 30, across a 16-hour period the cost of this process could be as high as £2,885.50.

4.0 Analyse

4.1 Normality Test

The author utilised Minitab as a software to aid with the data analysis.

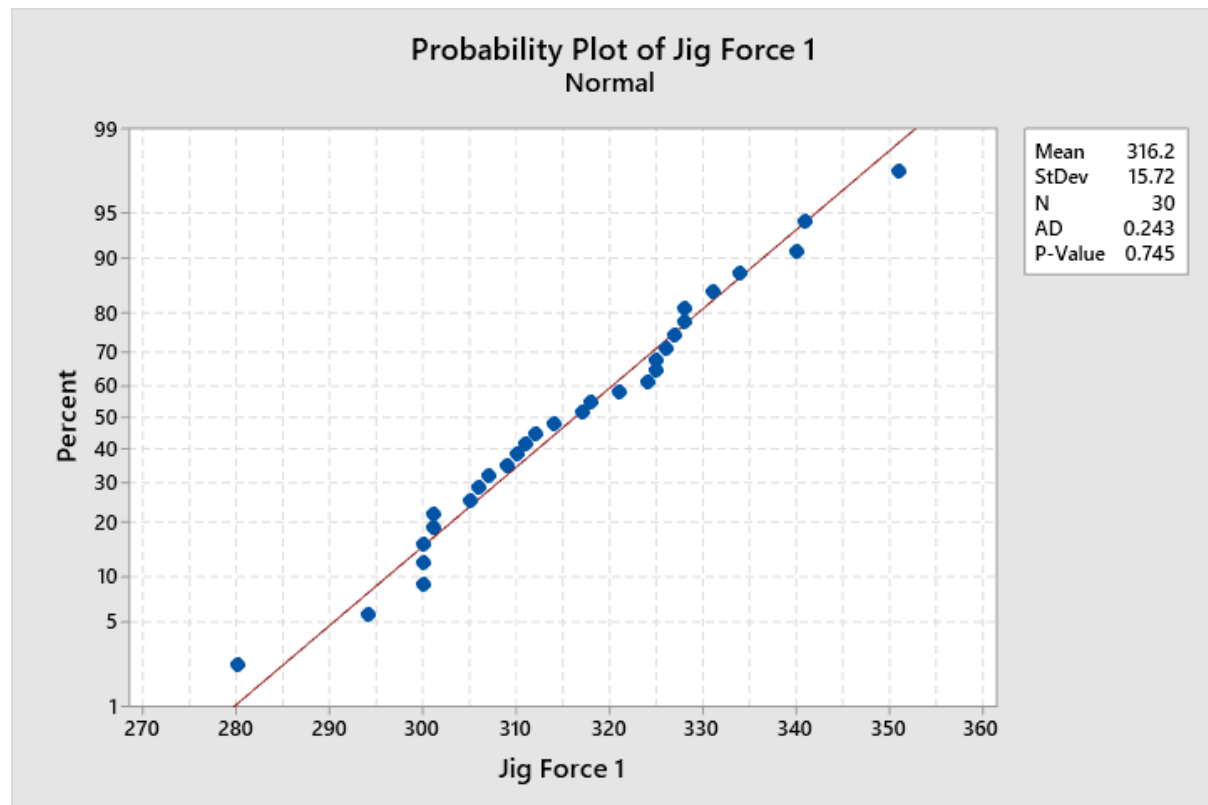


Figure 5 - Jig 1 Data Normality Testing Graph

Normality testing was used before starting any data analysis. Normality testing helps to ensure that the data conforms to normal distribution thus confirming the reliability of the data. The above normality test is an Anderson-Darling Test, Minitab (2023) explains this as 'a test that compares the ECDF (empirical cumulative distribution function) of the sample data with distribution expected if the data were normal'. The data fits the line of best fit well and there are no concerning anomalies.

As Figure 5 above shows, The P-Value is 0.745 as a rule of thumb, anything greater than 0.05 means that the data follows a normal distribution. The above data is accurate and therefore a capability study can be undertaken.

4.2 Jig 1 Force Push Out

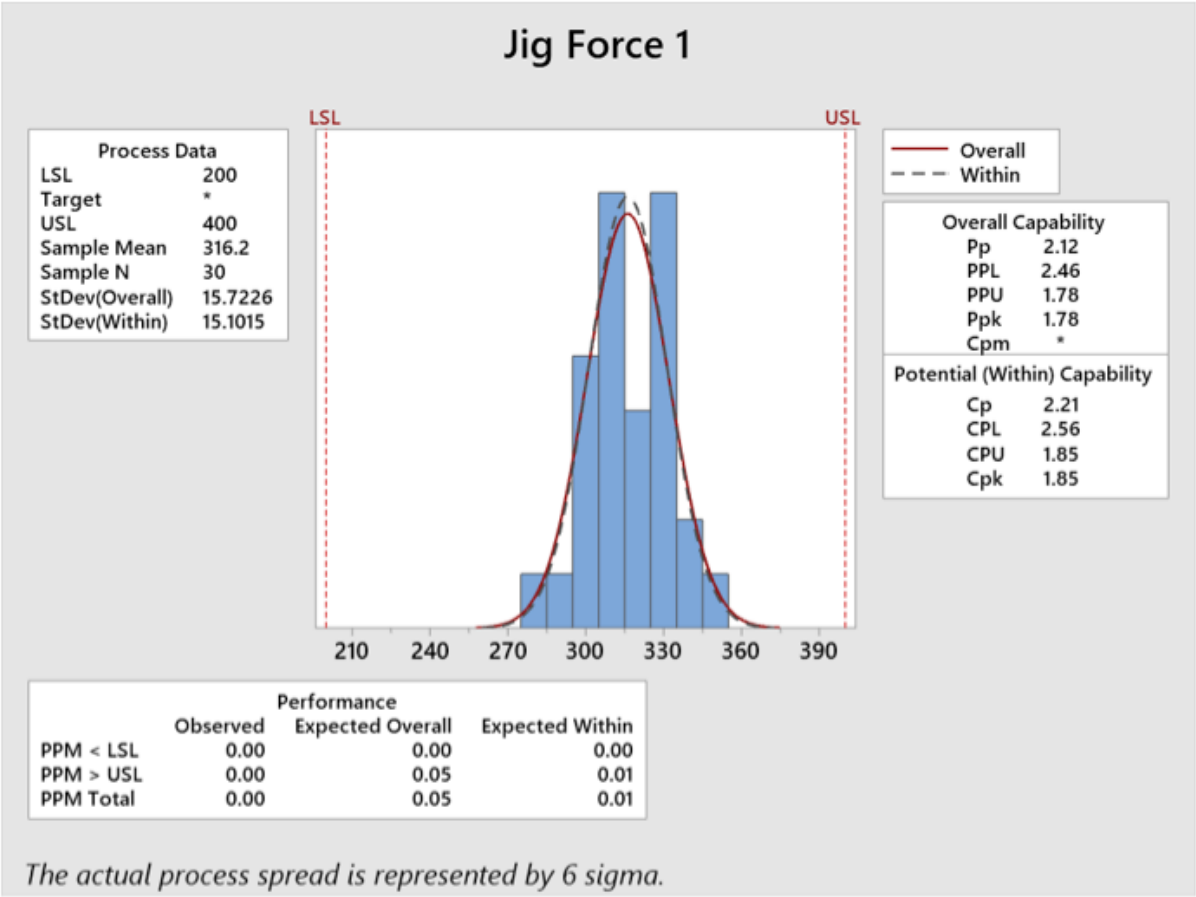


Figure 6 - Jig 1 Force Testing Graph

Figure 6 shows Lidding Jig 1 is well within both the upper and lower specification limit of 200 and 400 Newtons. The mean value for this data is 316.2N which is more less perfect tolerance as seen by the centralised data within the bell curve. To be over critical the data is slightly skewed towards the right, this means that the lids are potentially over-peened which is not an issue. This is represented by the Parts Per Million (PPM) value of 0.05. The CP is above 1.33 or 4 sigma which is the minimum acceptable level for a process. Overall, the peening process on Jig 1 is more than capable.

4.3 Jig 2 Force Push Out

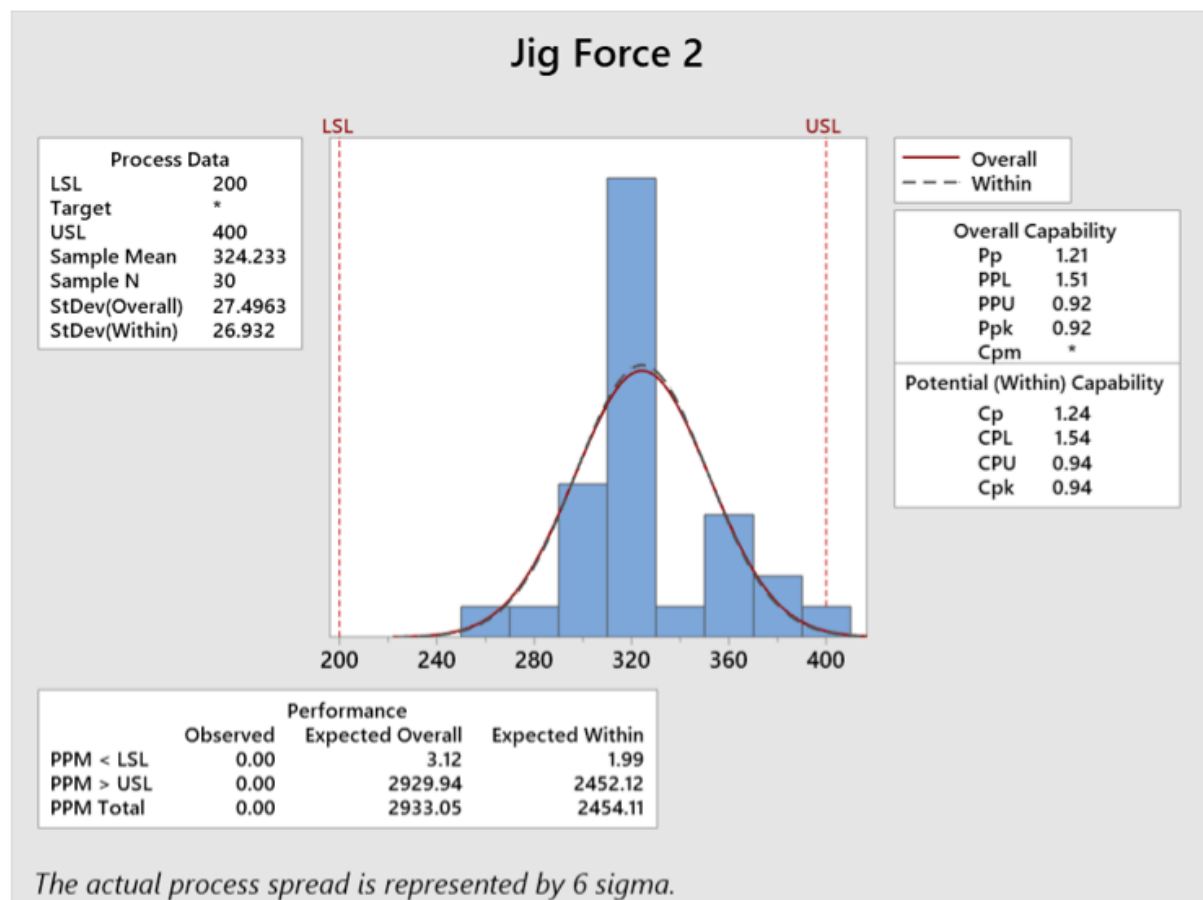


Figure 7 - Jig 2 Force Testing Graph

The following data is below 1.33 or 4 sigma range, this means that on paper the process is not at a capable level. This is due to there being far more variation in the force push out test for Lidding Jig 2, as shown by the Standard Deviation value. There is hardly any shift between short term (CP) and long term (PP) capability with data skewed towards the USL. Looking at PPM rate, far more peens are expected to be over specification than under, this is acceptable as over peening means that there is a tighter seal.

4.3.1 Concluding the Push Out Test

To conclude, the author will not be looking any further into the peening process as requiring improvement. Both Lidding Jig 1 & 2 are within both the USL and LSL, with both slightly skewed to the right or potentially peened at a higher force than the mean. Jig 1 is averaging 316N and Jig 2 is averaging 324N which is more than acceptable if 300N is a perfect peen.

4.4 Jig 1 Op 3 Capability

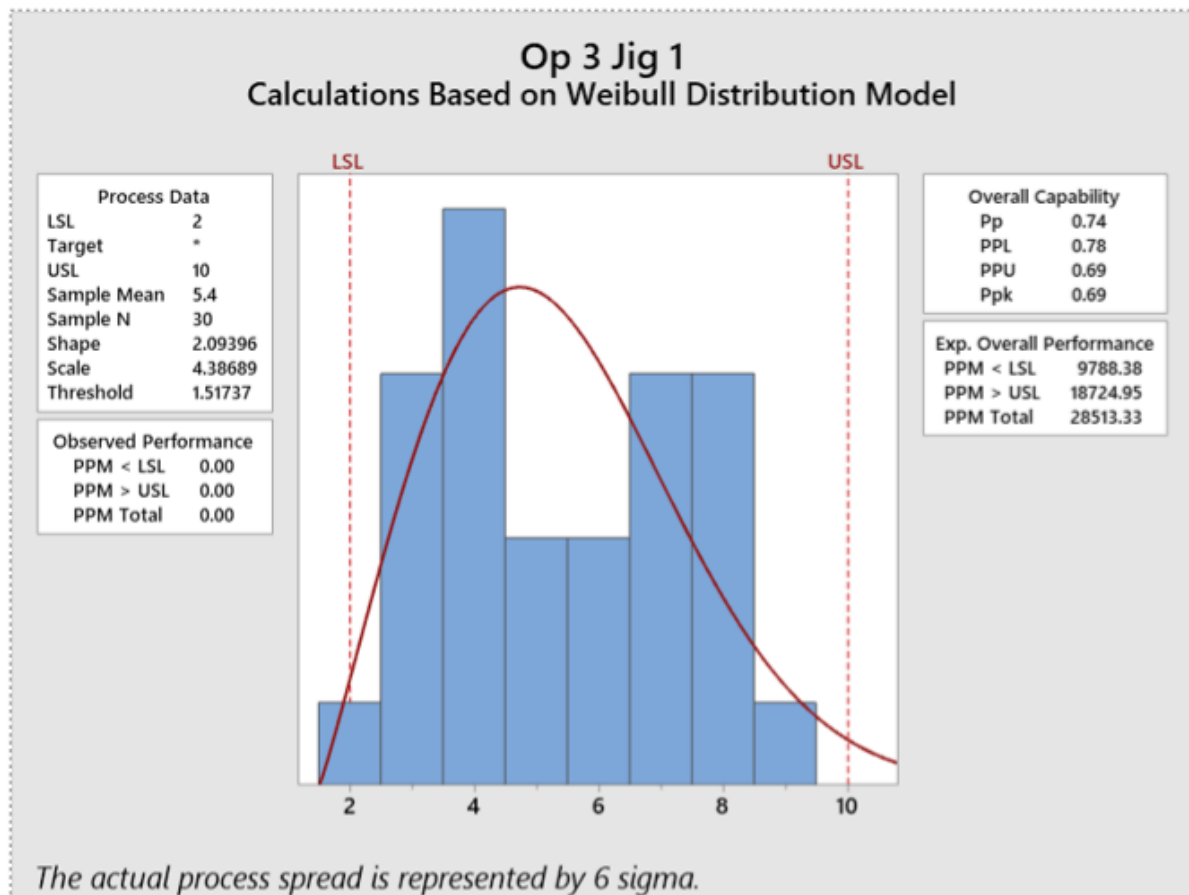


Figure 8 - Jig 1 Op 3 Timing Graph

Figure 8 shows the results of 30 Resolute Encoders built on Jig 1, illustrating the time taken to complete Op 3 (Top Blob Position check). The target for Op 3 to be completed is between 2 and 10 seconds, The mean for this process is 5.4 seconds which is very close to being perfect. The only issue is the variation in results across the Op 3's completion. As for the PPM, the process is more likely to produce data skewing towards the USL, it is important to note that Op 3 on Lidding Jig 1 is more than acceptable for the process.

4.5 Jig 2 Op 3 Capability

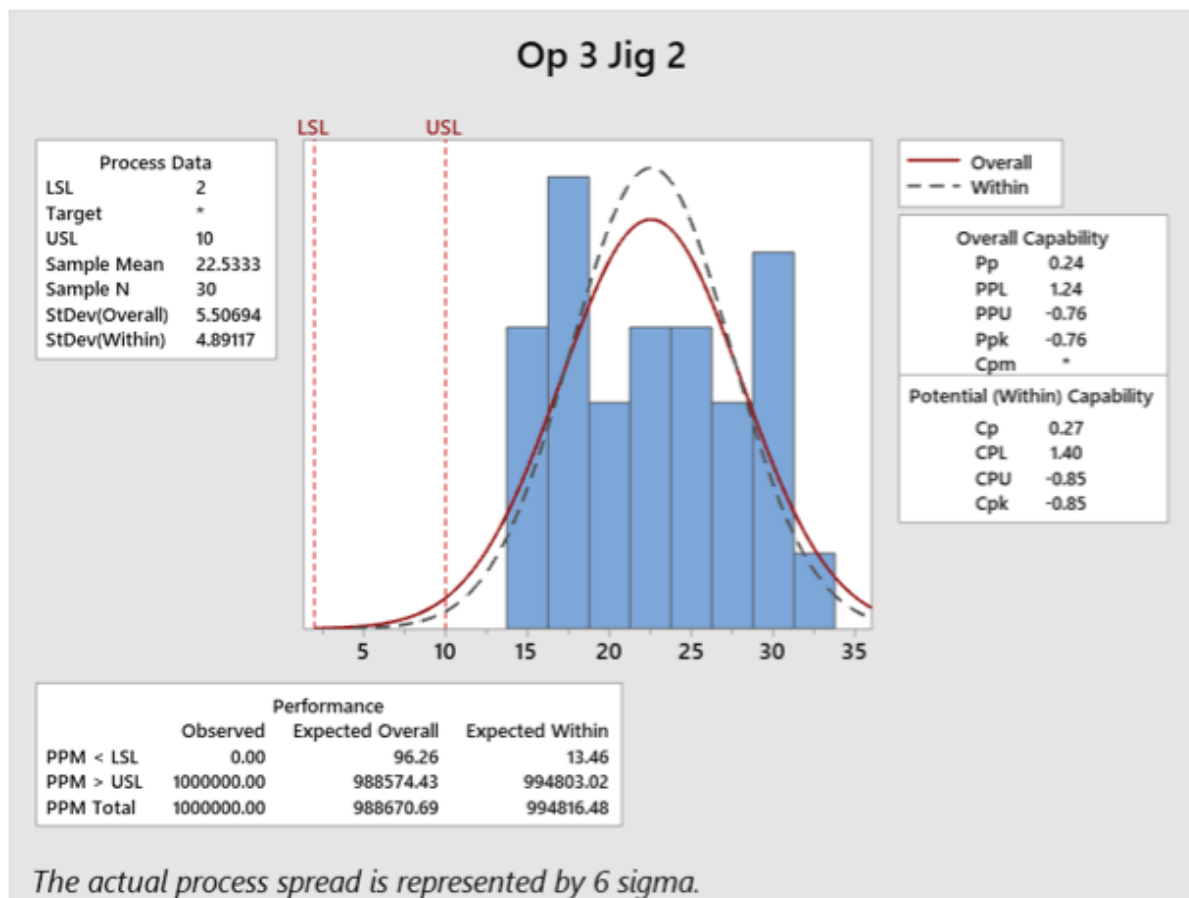
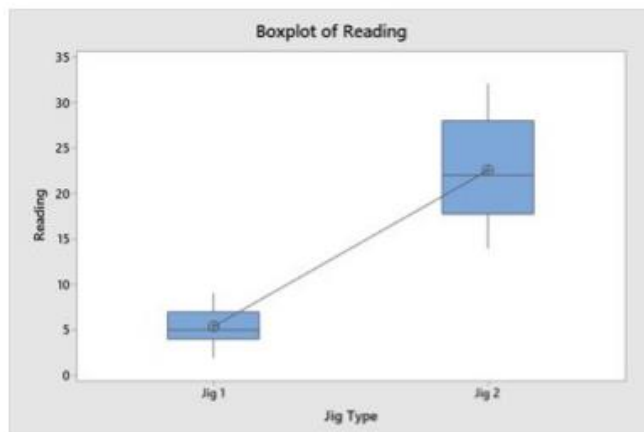


Figure 9 - Jig 2 Op 3 Timing Graph

Figure 9 shows the results of the same Op3 timing but for Lidding Jig 2. The process is not capable (Sigma=0.27), all data is past the USL of 10 seconds. The PPM outside of the USL is 1 million, this indicates that in its current state Op 3 will always be above 10 seconds which is unacceptable. The variation in results is far better however this process needs to be brought within the specification limits.

4.6 Anova study – Jig 1 vs Jig 2



One-way ANOVA: Reading versus Jig Type

Method

Null hypothesis All means are equal
Alternative hypothesis Not all means are equal
Significance level $\alpha = 0.05$

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Jig Type	2	Jig 1, Jig 2

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Jig Type	1	4403.3	4403.27	256.76	0.000
Error	58	994.7	17.15		
Total	59	5397.9			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.14119	81.57%	81.26%	80.28%

Means

Jig Type	N	Mean	StDev	95% CI
Jig 1	30	5.400	1.993	(3.887, 6.913)
Jig 2	30	22.53	5.51	(21.02, 24.05)

Pooled StDev = 4.14119

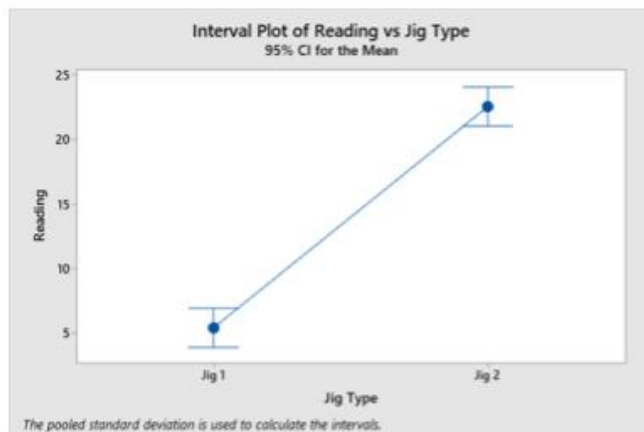


Figure 10 - Anova Study Graph

The author utilised the analysis of variation (ANOVA) tool to compare both Op 3 on Jig 1 and Jig 2. The P value is 0, this indicates that the Jigs are performing Op 3 differently. In comparing the mean time taken to complete Op 3, Jig 2 on average takes 17.1 seconds more to complete the Top Blob Position Check. With reference to the box plots on Figure 10, Jig 2 has far more variation in results compared to Jig 1.

4.6.1 Concluding Op 3 Timing Test

Having analysed the data, Thermal Lidding Jig 2 is the bottleneck in the Lidding process when completing Op 3 (Top Blob Position Check). This will need to be further investigated and improved. Thermal Lidding Jig 1 performs within the Specification Limits

4.7 Process Analysis Tools

4.7.1 Cause and Effect Diagram

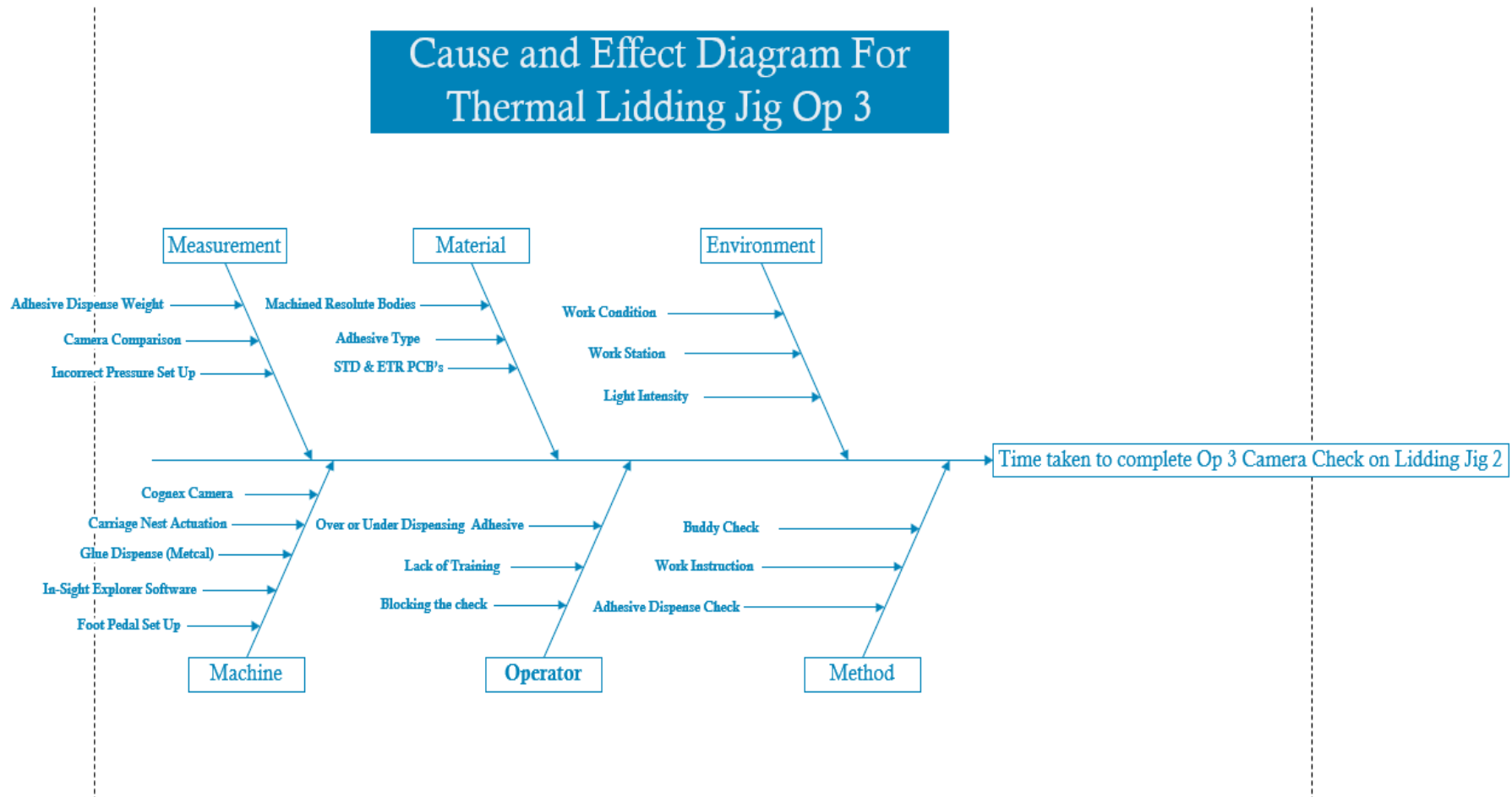


Figure 11 - Cause & Effect diagram for Op 3

4.7.2 FMEA (Failure Mode Effect Analysis)

The author utilised FMEA as a process to breakdown Op 3 on Thermal Lidding Jig 2. This was completed to further understand the reasoning behind time taken to complete this Operation.

FAILURE MODE AND EFFECTS ANALYSIS																		
FMEA Type:		☒ Process FMEA	☐ Concept FMEA	☐ System FMEA	☐ Design FMEA	☐ Other FMEA												
Part Number:		T-03154									FMEA Number:		FMEA No. 362		Iss.		1	
Part / Process Name:		Thermal Lidding Jig							Responsibility:		Encoders Product Division		Prepared by:		Ryan Harris			
Application:		To apply thermal adhesive and lid to Resolute Encoder							Design / Process				Date (Orig.)		15/02/2023			
Core Team:		Ryan Harris, Gareth Evans, Conor Kenny											Date (Rev.)					
Op / #	Item or Process / Function Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s) / Mechanism(s) of Failure	Occur	Current Design/Process Controls Prevention	Current Design/Process Controls Detection	Detection	R.P.N.	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
														Actions Taken	Sev	Occur	Defect	R.P.N.
3	Cognex Camera check for Thermal Adhesive Top Blob Position	Insight Explorer software incorrect	Detecting incorrect levels of adhesive / rejecting acceptable levels of adhesive	8		Variation in Levels of adhesive, or not detecting adhesive	7	Operator Training	Cognex Camera Check	8	448	In sight software review and update for Op 3 Camera check						
		Luminosity around Jig	Camera unable to recognise items within the encoder body	8		Variation in Resolute's passing and failing checks	3	The lighting is stable within the work area and is not subject to variation	N/A	3	72							
		Operator Training	Incorrect adhesive level dispensed. Variation in positioning	8		Variation in adhesive quantities, lids incorrectly peened	2	Operators are well trained with structured work instruction	Cognex Camera Check	2	32							
		Incorrect Adhesive Dispense Metcal Unit	High or Low quantity of adhesive dispensed	8		Faulty Metcal unit	2	Operators are well trained with structured work instruction	Glue weights checked before shift start	2	32							
		Incorrect Pressure level Metcal Unit	Lid unsecure, connection problems	8		Pressure incorrectly set by Operator	2	Operators are well trained with structured work instruction	N/A	4	64							
		Operator Covering Camera	Unable to complete camera check, slowing process	4		Operator Training	2	Operators are well trained with structured work instruction	N/A	1	8							
		Camera Positioning on the Rig	Camera incorrectly detecting	8		Camera set up during rig build	1	Camera needs to be initiallt set up in In sight explorer, would not work if positioning was out	N/A	1	8							
		Carriage nest actuation / positioning	Unable to peen lid symmetrically and camera unable to detect part in nest	6		Incorrect set up or faulty pneumatics	1	This would be a very detectable issue with Operator / Technician training	N/A	1	6							

Figure 12 - FMEA for Op 3

4.7.3 Five Why's

DEFINE THE PROBLEM	Time taken to Complete Op 3 on Lidding Jig 2					
WHY IS THIS A PROBLEM?	PRIMARY CAUSE Why is it happening? 1 Lidding Jig 2 is averaging 17.1 seconds more to complete Op 3 check than Jig 1. Why is that? 2 Jig 2 seems to be unstable. Why is that? 3 Op 3 Failing Camera check when there is an acceptable level of adhesive on Resolute body. Why is that? 4 Cognex Camera set up. Why is that? 5 Cognex Camera's Software has variation on Top Blob position check (Op 3). ROOT CAUSE NOTE: If the final "Why" has no controllable solution, return to the previous "Why."					
CORRECTIVE ACTION TO TAKE	CORRECTIVE ACTION Review and correct the Cognex Camera's Insight Explorer Top Blob position check on Thermal Lidding Jig 3 and confirm changes have made an improvement. <table border="1"> <tr> <td data-bbox="1491 954 1841 1027">PARTY RESPONSIBLE ASG Miskin (Ryan Harris)</td> </tr> <tr> <td data-bbox="1491 1027 1841 1101">DATE ACTION TO BEGIN 09/03/2023</td> </tr> <tr> <td data-bbox="1491 1101 1841 1174">DATE TO COMPLETE 23/03/2023</td> </tr> </table>			PARTY RESPONSIBLE ASG Miskin (Ryan Harris)	DATE ACTION TO BEGIN 09/03/2023	DATE TO COMPLETE 23/03/2023
PARTY RESPONSIBLE ASG Miskin (Ryan Harris)						
DATE ACTION TO BEGIN 09/03/2023						
DATE TO COMPLETE 23/03/2023						

Figure 13 - 5 Why's Study

4.8 Process Analysis Conclusion

Each of the tools used in the process analysis phase helped the author to come to an end solution. The Top Blob position check has been identified as the root cause for the time taken to complete Op 3 on Lidding Jig 2.

The cause-and-effect diagram helped to visualise possible causes to the problem, identifying the main causes helped the author to structure problems into categories. The diagram pointed heavily towards the Jig being the main issue.

FMEA was utilised as a tool to structure the failure modes potentially contributing to the time taken in completing Op 3. The tool also helped to calculate the RPN Value (Risk Priority level), further solidifying an order in which to prioritise resource. From completing the FMEA it was clear that 'Insight Explorer software incorrect' had the highest RPN value at 448.

The five why's technique was used to determine the root cause. A project meeting was called to use this technique effectively. The team worked backwards from the problem at each stage asking why the problem occurred. This tool ultimately pointed in the same direction as the FMEA.

After using the process analysis tools, the root cause is understood to be an issue with the Insight Explorer software checking the Top Blob position. A solution needs to be finalised and implemented.

5. Improve

5.1 Brainstorming Potential Solutions



Figure 14 - Brainstorm of Solutions

Key stake holders were called for a brainstorming meeting to identify some potential solutions to the problem. Figure 14 shows the brainstorm from that session.

5.2 Decision Matrix

Proposed Project Feasibility Criteria	Idea 1 – Re-design Top Blob Check	Idea 2 – Automate Adhesive Dispense	Idea 3 – Operator Training
Technical Feasibility	3	2	3
Economic Feasibility	3	1	2
Legal Feasibility	3	2	3
Operational Feasibility	3	1	1
Scheduling Feasibility	3	1	3
Overall score	15	7	12

Feasibility Key	Rating / colour
Very Feasible	3
Moderately Feasible	2
Not Feasible	1

Technical Feasibility – Technically any of the above ideas are feasible. The main constraint is time. The Resolute line is already losing production due to the issue. Therefore, it is ideal to implement Idea 1 which is both a quick and solid solution.

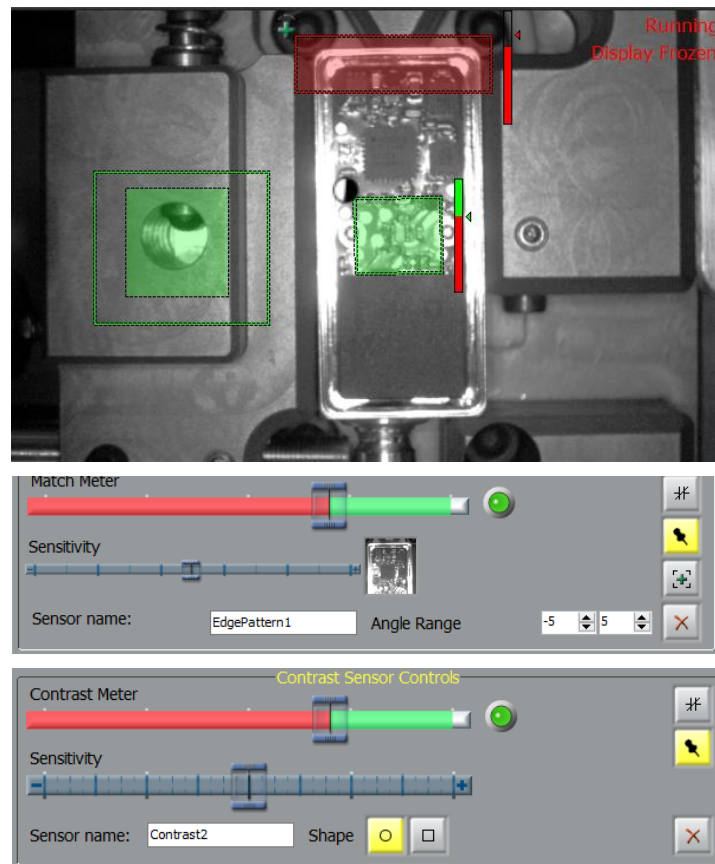
Economic Feasibility – From a budget standpoint, production would like to limit the expense in developing and implementing a solution. The Lidding Jig itself had a sizeable budget and from this, idea 1 is the most economically feasible solution at this time.

Legal Feasibility – Legally, each of the ideas is feasible. The least feasible would be to automate the adhesive dispense as this may affect the CE (Conformity) status of the Lidding Jig.

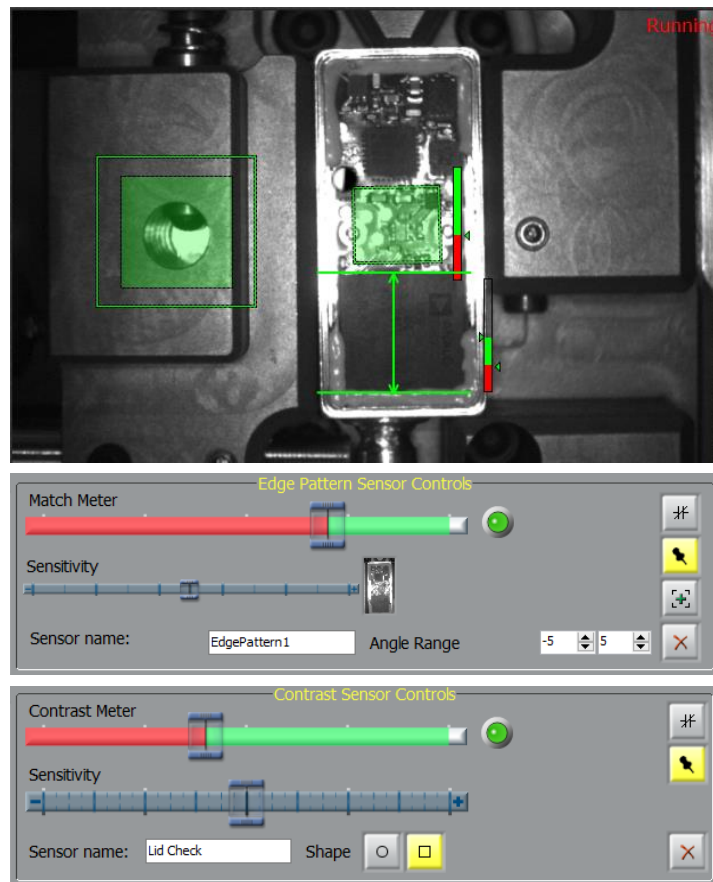
Operational Feasibility – From an operational standpoint. The operators on the Lidding Jig are highly skilled and understand the correct adhesive levels required. Automating the adhesive dispense will take both time and incur cost. Idea 1 will be the best operational solution as there is good company understanding of the insight explorer software.

Scheduling Feasibility – Due to the nature of production on the Resolute assembly line, key production stakeholders are reluctant to take any of the rigs out of action. Automating the adhesive dispense will take time away from production. From a scheduling point of view the best option would be to re-design the top blob position check.

5.3 Implement Solution



The current Top Blob position check was completed using the 'Pattern Feature' technique. Even though there is an acceptable level of adhesive, the above figure is indicating a failure on Op3 (Top Blob Position) Check. It was found that this was occurring inconsistently which explained the down time and failure rates.



The author removed the 'pattern feature check' and replaced the check with an 'edge pattern' check. This was used for both Top and Bottom adhesive checks. As a result, both the failure rate and time taken to complete a batch of 30 reduced as shown in the results shown in section 5.4

5.4 Analyse Solution

5.4.1 Validate Improvements

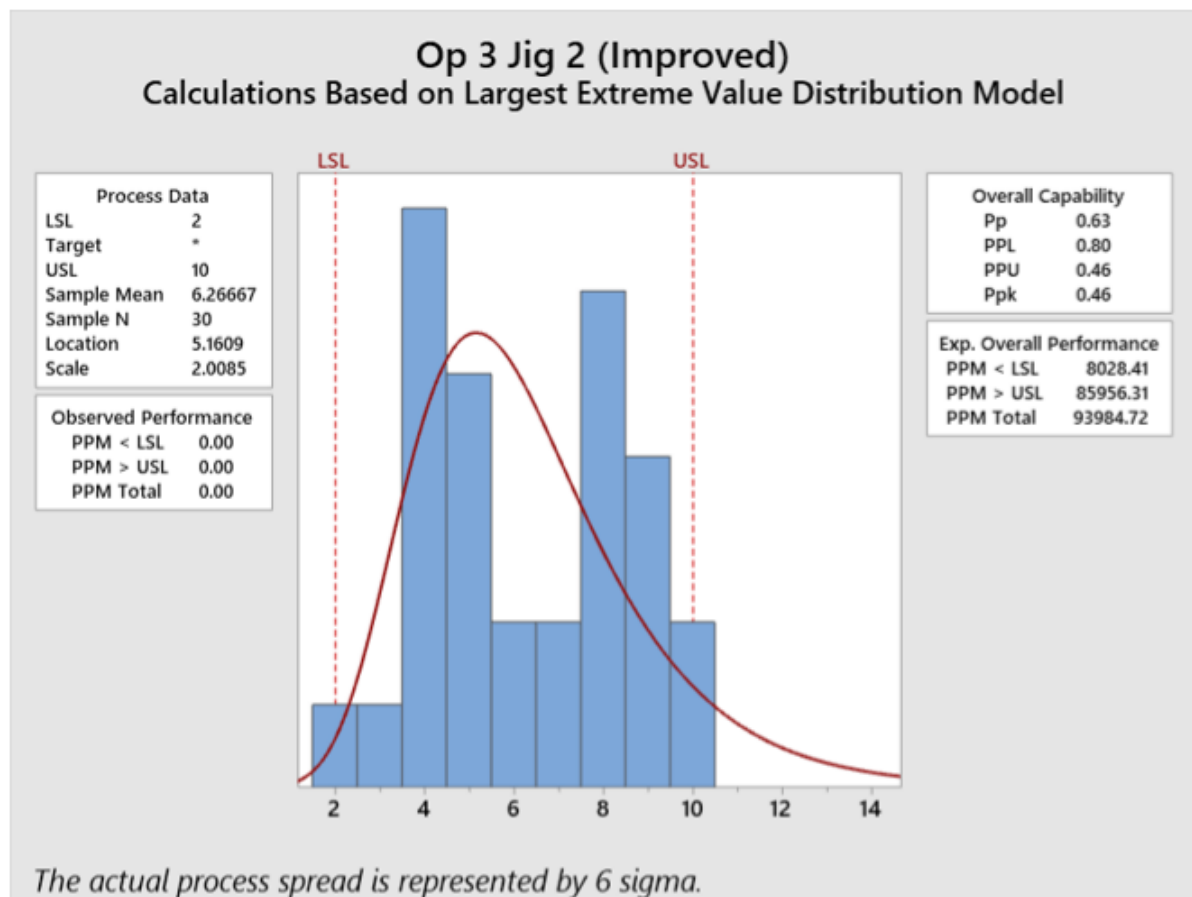
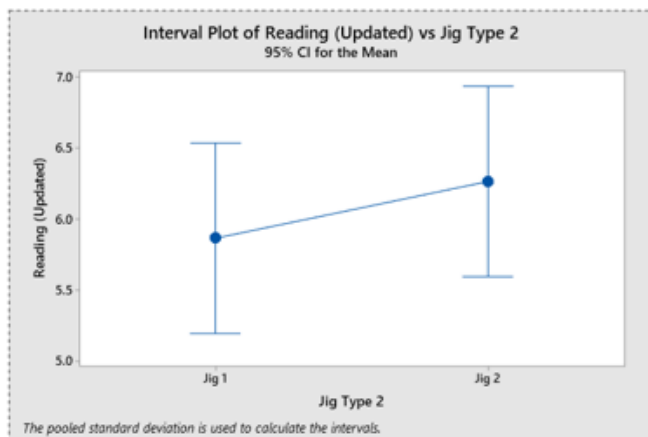
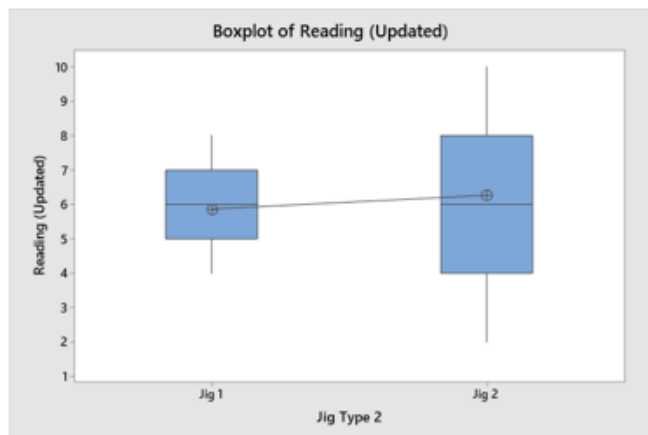


Figure 15 - Jig 2 Op 3 Improvement Graph

A batch of 30 Resolute Encoders was made on the improved Lidding Jig 2. The data is now within the specification limits with the sample mean now at 6.27s per check, which is a 72% reduction in time taken to complete Op 3. PPM in USL is higher however this is more than acceptable when compared to the Jig's previous state. The improvement made to Op 3 check has had a substantial impact on the process. The projected cost saving across a double shift is estimated to be £2,077.56. From a six sigma perspective, more improvements are required to control the process variation.



WORKSHEET 1

One-way ANOVA: Reading (Updated) versus Jig Type 2

Method

Null hypothesis All means are equal
 Alternative hypothesis Not all means are equal
 Significance level $\alpha = 0.05$

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Jig Type 2	2	Jig 1, Jig 2

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Jig Type 2	1	2.400	2.400	0.71	0.402
Error	58	195.333	3.368		
Total	59	197.733			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.83516	1.21%	0.00%	0.00%

Means

Jig Type 2	N	Mean	StDev	95% CI
Jig 1	30	5.867	1.252	(5.196, 6.537)
Jig 2	30	6.267	2.273	(5.596, 6.937)

Pooled StDev = 1.83516

Figure 16 - Annova Study Improved

With the new data gathered for the improved Op 3 camera check on Lidding Jig 2, the author re-compared Op 3 on Jig 1 and 2 by completing an ANOVA study. The ANOVA study has shown great improvement with Jig 1's mean being 5.9s and Jig 2's mean being 6.3s. Jig 1 is still the better performer; however, Jig 2 has made a drastic improvement from 22.5s to 6.3s per Op 3 check. As the box plot shows, the means are much closer, however there is still scope for improvement to reduce variation on Jig 2.

5.4.2 FMEA Improvement

Op / #	Item or Process / Function Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s) / Mechanism(s) of Failure	Occur	Current Design/Process Controls Prevention	Current Design/Process Controls Detection	Detection	R.P.N.	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
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3	Cognex Camera check for Thermal Adhesive Top Blob Position	Insight Explorer software incorrect	Detecting incorrect levels of adhesive / rejecting acceptable levels of adhesive	8		Variation in Levels of adhesive, or not detecting adhesive	7	Operator Training	Cognex Camera Check	8	448	In sight software review and update for Op 3 Camera check	Ryan Harris is responsible to complete recommended actions by 16/03/2023	Op 3 Top Blob Position check changed from 'Pattern Feature' to 'Locate Edges' in insight explorer software	8	3	1	24
		Luminosity around Jig	Camera unable to recognise items within the encoder body	8		Variation in Resolute's passing and failing checks	3	The lighting is stable within the work area and is not subject to variation	N/A	3	72							
		Operator Training	Incorrect adhesive level dispensed. Variation in positioning	8		Variation in adhesive quantities, lids incorrectly peened	2	Operators are well trained with structured work instruction	Cognex Camera Check	2	32							
		Incorrect Adhesive Dispense Metcal Unit	High or Low quantity of adhesive dispensed	8		Faulty Metcal unit	2	Operators are well trained with structured work instruction	Glue weights checked before shift start	2	32							
		Incorrect Pressure level Metcal Unit	Lid unsecure, connection problems	8		Pressure incorrectly set by Operator	2	Operators are well trained with structured work instruction	N/A	4	64							

Figure 17 - FMEA Improved

Having implemented the Op 3 check improvement on Lidding Jig 2, the key project members held a meeting to re-assess the FMEA. The author changed the insight explorer software to 'locate edges' to effectively check adhesive levels in the Top Blob Position of the Resolute Encoder. The new PRN value was assessed and changed to 24 which is drastic improvement from 448.

6. Control

As the Improve phase had only finished on the 16th of March it was difficult to fully implement a control strategy. The control phase will be ongoing for as long as the Resolute line is operational, it is critical to quality that processes are under control. As 6sigmastudy (2021) explains, 'the main focus of the phase is to ensure that all project gains that were obtained during Improve are maintained'.

Discussion Points to Implement on-going measurement.

- **Statistical Process Control**

SPC focuses on optimising continuous improvement by using statistical tools to analyse data and make correction decisions based on the data (Hessing, 2023). The team will use SPC's to monitor Lidding Jig 2's performance on a weekly basis for 1 month and compare with Jig 1. Run charts will be used as the primary form of visualising performance.

- **Control Plans**

A control plan will be drafted to ensure that line technicians can understand steps to take to keep the process running effectively. Any dip in performance will be monitored from the run charts, a build manual will be drafted which will instruct technicians on how to get the lidding jig running at an acceptable performance level if performance does dip. Simpliaxis (2023) explains that the control plan should not replace any Standard Operating Procedures (SOP), The plan will help to keep the process within limits.

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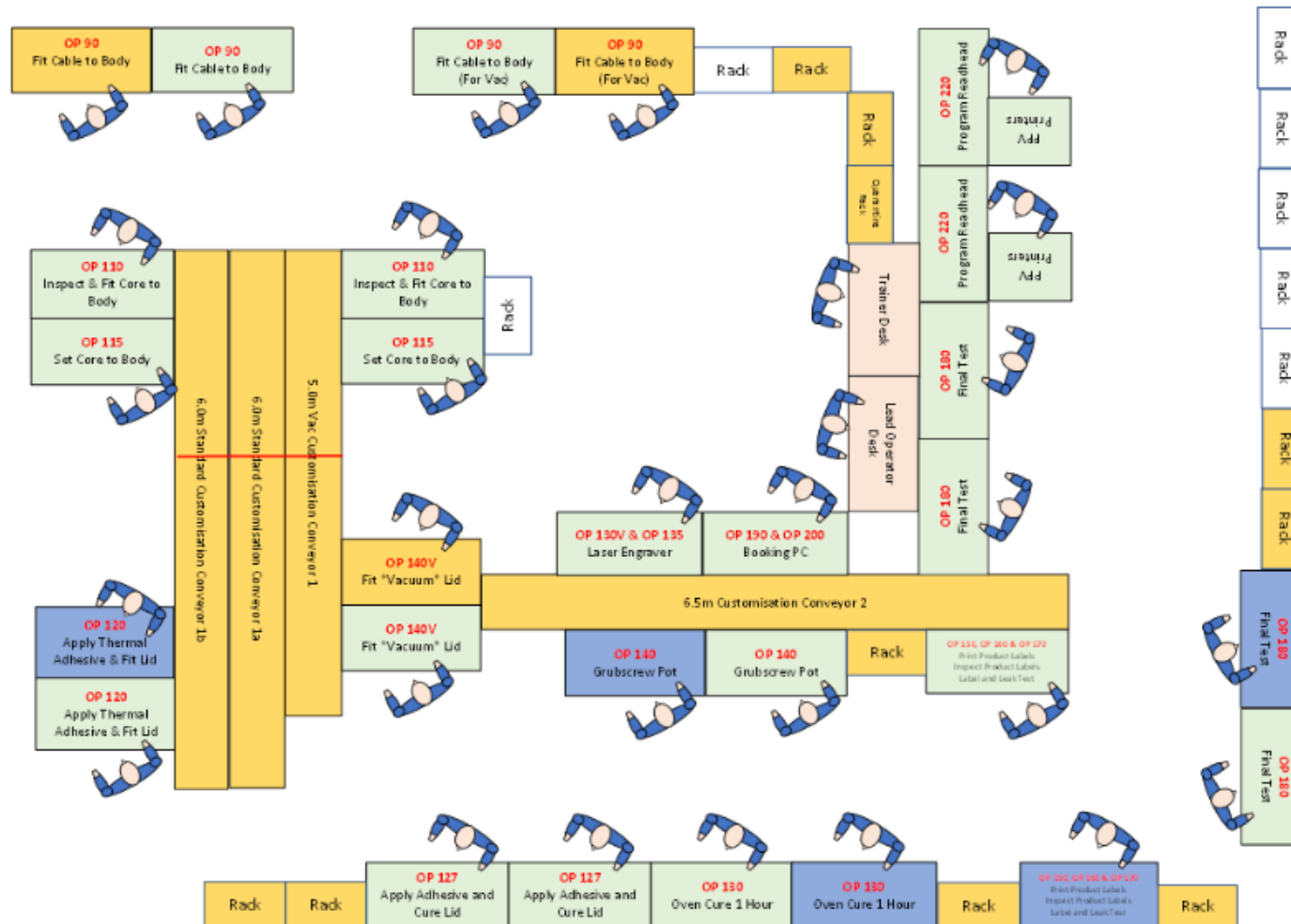
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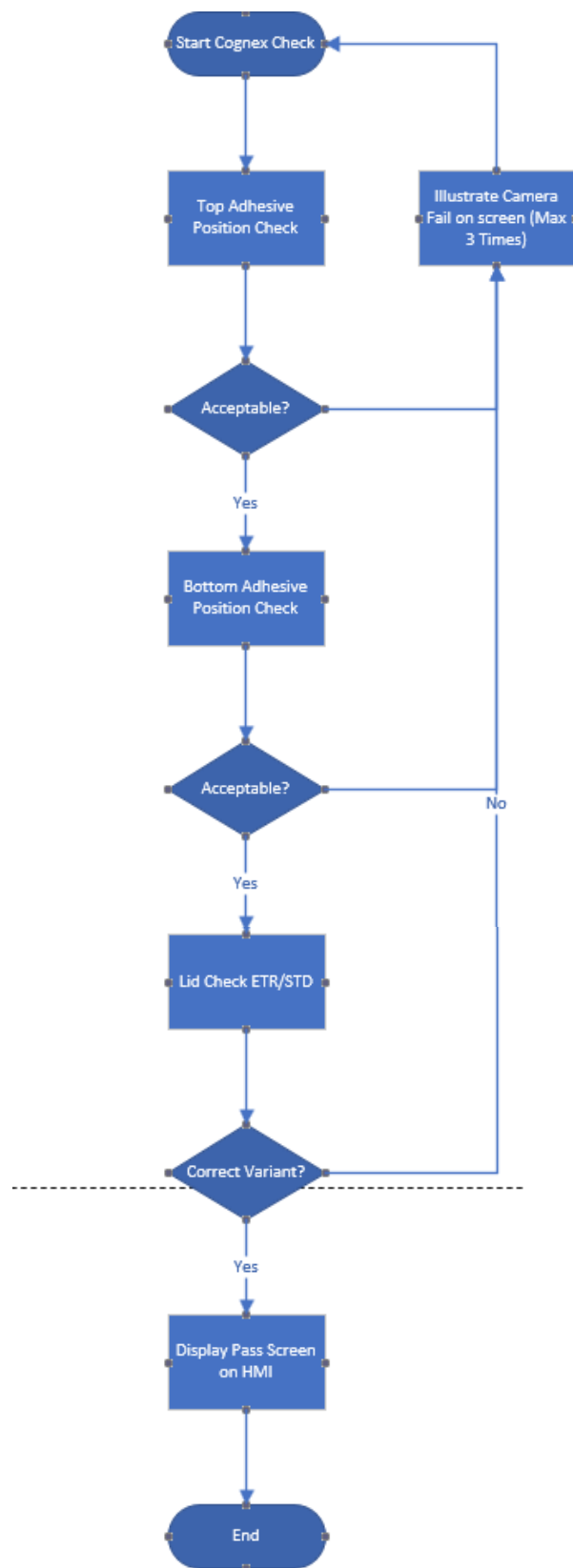
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Appendix 1 – Coring & Customisation Detailed Process Map



Appendix 2 - Lidding Jig Cognex Camera Check Process Map



Appendix 3 - Data Collection Plan

Data Collection Plan					
Measure	Data Type	Operational Definition	Stratification Factors	Sampling Notes	Who and How
Bench is ESD Safe	Attribute	Ensure that the bench is ESD safe within 1×10^4 to 10^6 ohms/square.	Performed by the Internal Quality Team.	Sampled every 12 months to ensure that all the equipment is earthed correctly.	Performed by the quality team using resistance meters to ensure that the ESD benches and mats are within acceptable levels. Pass/Fail.
Adhesive dispenser correctly set	Continuous / Discrete	Ensure that correct level of pressure is set on the metcal unit 4 Bar.	Performed by operators every shift, per 8 hour. Must be trained operators	Check the pressure gauge to ensure correct pressure is set per Work Instruction.	To be performed by the Operator and adjusted by a competent Technician if alteration is required.
Operation of sensors	Discrete	Ensure that all proximity sensors are operating correctly as per manual.	Performed by an engineer every 12 months.	Log into engineers screen using jig build manual and ensure the sensors output when required.	Log into engineers screen using jig build manual and ensure the sensors output when required. Note Pass/Fail results.
Force tests on lids	Continuous	Force test 10 off Lids from Jig 1 & Jig 2 and ensure that the results are $>200N$	Performed by tan Engineer 10 times per jig.	Use Mecmesin push out tester to ensure that both Jig 1 & Jig 2 peening process ensure that the Lids are $>200N$.	Engineers to complete the testing and note down results, comparing both jigs and confirming the results are $>200N$.
Camera Checks	Discrete	Ensure that camera passes/fails when required	Performed by an engineer 5 times per check	Use Cognex software ensuring that the camera passes and fails when required. Compare both Jig 1 and Jig 2.	Use Cognex software ensuring that the camera passes and fails when required. Compare both Jig 1 and Jig 2.
Time all Ops of the Lidding Jig	Continuous	Time each step of the Lidding process, broken up into 6 different Ops.	Timed by a Technician/Engineer. Ensure same operator timed across both Lidding Jig 1 & Jig 2. Same batch of 30.	Time each Op of the Lidding Process and note the differences between Jig 1 & Jig 2.	Using a stopwatch, an Engineer/Technician will time each operation which is to be clearly broken down.

Appendix 4 - Peened Lids from Measurement Phase



Appendix 5 - Mecmesin Machine

A pull off test was completed using the Mecmesin machine to pull off the lids of the resolute encoder. Mecmesin (2023) describe this test as Pull-off' or 'pull-out' testing generally involves the separation of two secured parts under tension.

This may be to test joints in assemblies of any kind ranging from the tensile strength of crimped or welded wire terminals, the seal integrity of adhesive joints, the mechanical strength of industrial fixings and fasteners, stoppers, lids, and push-fit closures.



Mecmesin (2023)

Appendix 6 – Project Gantt Chart

