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Research Article

Process Improvement in a Filter Manufacturing Industry through Six Sigma DMAIC Approach

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Abstract

Six-sigma is a project oriented, statistical data driven, scientific approach which can be effectively deployed to tackle the issues like process variation, rejection and rework. During present study; Six-sigma methodology was utilized for rejection reduction of a manufacturing line at a filter manufacturing industry. This line was top contributor in plant's PPM and COPQ. The defect PPM is a reflection for overall health of the manufacturing processes of organisation. Hence defect PPM is used as parameter to assess the Process Improvement and project effectiveness. Current project followed DMAIC approach. Initially, project objectives, scope, deliverables and constraints were defined. Then substantial data was collected to measure the current performance, process capabilities and PPM levels per defect. Significant root causes governing defect generation were identified through Cause and Effect, FMEA and Hypothesis testing. Thereafter, solutions were derived to mitigate the possibility of defect generation by process optimisation, mistake proofing and improvement actions. Finally various tools were implemented for tracking the process and maintaining it under control. The process variation, rework and scrap were reduced considerably as a result of current project. PPM level reduced to 6,500 from 24,000 corresponding rise in sigma level from about 3.43 to 4.02.

Keywords: *Process Improvement, Rejection Reduction, PPM Reduction, Six Sigma, DMAIC Approach*

1. Introduction

Six-sigma is not only having less than 3.4 defects per million opportunities but also to improve process capabilities, work processes, expand all employees' skills and change the work culture. Six-sigma is identified as problem solving methodology (J. de Mast, 2012). Six-sigma Projects are selected considering benefits, opportunities, risks, cost (G. Büyüközkan, 2010). Six-sigma is equally known for its organizational implementation as the tools/techniques employed during Six-sigma projects. A fundamental aspect of Six-sigma methodology is identification of critical-to-quality (CTQ) characteristics that are predominantly vital to customer satisfaction (R.G. Schroeder, 2008). Six-sigma is well known for analyzing the root causes of business problems and solving them (R.G. Schroeder, 2008; Blakeslee, 1999). Henceforth, the Six-sigma methodology was used to address the various issues with line under study. The DMAIC approach was followed during the course of project as DMAIC is a closed-loop process that eliminates unproductive steps, often focuses on new measurements and applies technology for continuous improvement (Y. H. Kwak, 2006).

Need of current project: There was profound need of the project due to, 1) Many customer quality complaints, 2) High defect PPM, 3) High COPQ, 4) Issues with 'right first time' products 5)High rework percentage

DMAIC Phases of Project:

1. Define: This is the first and foremost phase of the project where the quantified objectives, project scope, deliverables and constraints were clearly defined. This step acts as road map for the project and has wide implications on success of the project. 'As Is Process Map' was prepared for better understanding of the processes where every process is considered in isolation and overviewed with respect to its all possible inputs and desired output. The inputs are considered in the form of man, material, method, machine, Mother Nature and measurement. There are 20 operations on line. The sample representation for a particular process is given below,

Table No.01: Representation of Process Map for Oil Filter Line

AS IS Process Map	
Process: Pleating	
I/P of Process	O/P of Process
1. Media and mesh rows cut as per pleat height	1. Pleat height as per specification.
2. Pleating plates	2. No. Of Pleats per block.
3. Teflon tape	3. Visible marking on 1/2 pleats
4. Heater	4. Pleat Depth.
5. Temp. Of heater(65+/-5°c)	
6. Pleat counter	
7. Pack counter	

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AS IS Process Map	
Process: Pleating	
I/P of Process	O/P of Process
8. Pleat speed(100f/min)	
9. Marking time (5pliz)	
10. Power Fluctuation	
11. Teflon tape ware	
12. Speed of pleating	

The various tools like Thought Mapping, Walk Through process and As Is Process Map are effectively used during define phase to draw upon guidelines- The scope of present study is limited to the existing raw materials, machinery and work processes. The objective of project is to reduce defect PPM from 24000 to 12000 for present line under consideration by holding constant productivity and human skill required. Project deliverables are- 1) Improvement in process capabilities, 2)Reduction in rejection, rework and scrap, 3)Reduction in cost of poor quality 4)Reduced possibility of defective part passing to customer

2. Measure

During this stage, one measures the existing system and establish valid and reliable metrics to help monitor progress towards the project goals. Initially Identification, classification and description of the potential critical defects is carried out. Based upon historical data, collected data, brainstorming sessions and various tools like Pareto stratification; the key potential problems are identified. Measurement of Postural severity of various manual tasks using P-SVR© method was considered as ergonomic difficulty may lead to defect creation (V. N. Karandikar and S. M. Sane, 2013)

2.1 Defect Identification and Classification: The identification of all the possible defects was critical in order to find out possible scope for improvements.

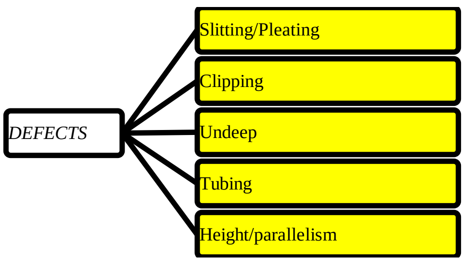


Figure No.1: Classification of Defects at Oil Filter Line

For further thorough study these major defects were subdivided into 7 sub categories.

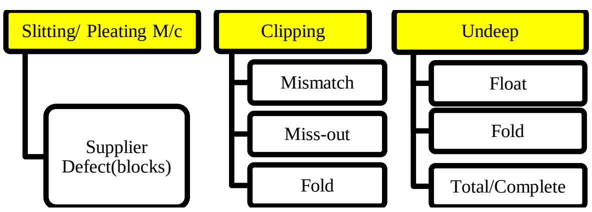


Figure No.2: Classification of Major Defects at Oil Filter Line

2.2 Defect data collection: Defect recording sheet was prepared according to the classification of defects in previous step. Data was collected by observation of 1,20,000 filters. For each part number defects were recorded.

2.3 Process Capability calculation: The process capabilities were calculated for all critical operations like adhesive dispensing, pleating, clipping, etc. This helped understand that which processes are stable, predictable and capable and which processes are running with special cause.

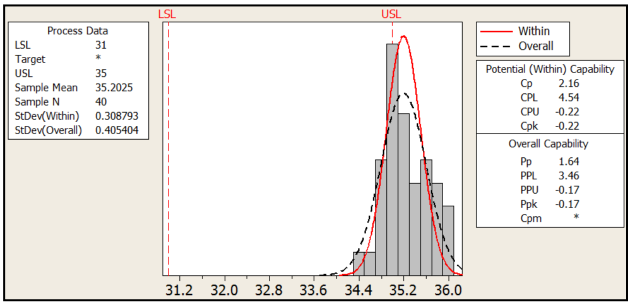


Figure No.3: Process capability calculation for Adhesive dispensing operation

Firstly, the predictability and stability of the process was checked and then calculations of process capability were done. The adhesive dispensing operation is used for representation. The figure No. 3 helps us to understand that the machine is dispensing excess quantity of adhesive. The C_{pk} value is -ve and shifted to USL. The tracing of this clue revealed that the operator used to set excess adhesive to ensure proper spreading. Similarly, all capabilities of all the critical operation were measured and interpreted.

3. Analyse

Statistical analysis is used to examine potential variables influencing the CTQs and seek to identify the most significant root causes and develop a prioritized list of factors influencing the desired outcome. Here one isolates and verify the critical processes. The potential list of the problems is narrowed to the vital few and the input/output relationship which directly affects specific problems is identified and potential causes of process variability were verified. Pareto analysis, cause and Effect, Failure mode effect analysis was performed during this phase. Job Difficulty Index© was considered to compare work severity (V. N. Karandikar and S. M. Sane, 2014).

3.1 Pareto analysis: Pareto analysis of existing data helped to understand the critical defects that contribute for majority of the PPM. Also, parts with top PPM contribution were identified.

Based on the Pareto analysis and critical to quality requirement of customer; Undip, Height oversize and parallelism loss was identified as critical defects. In next step, defect-wise PPM of every top contributing part number was analysed through Pareto charts to understand parts with higher rejection rate.

Table No.2: Rating scheme for Cause and Effect

Rating	
0	Not imp
1	Negligible
3	Somewhat
9	Significant

Table No.3: Representation of Cause and Effect Sheet for Oil Filter Line

I/P to Processes Identified through Process Mapping

Weight Assigned to Defects from customer point of view

Critical Defects Identified through Pareto Analysis

Cut Off Point

			10	10	8	
Sr.No.	**Process**	**Input to Process**	**Undip 1st**	**Undip 2nd**	**Height/ parallelity**	**Total**
1	Dipping 1st	Manual dipping	9	9	9	252
2	Dipping 1st	Workload Fluctuations	9	9	9	252
3	Ventury insertion	Placing the ventury in ca	9	9	9	252
4	Dipping 1st	Cap with adhesive advent	9	9	9	252
5	Dipping 1st	Manual pressing with palm after dipping	9	9	9	252
6	Pleating	Teflon tape on Pleating plates	9	9	1	188
7	Tubing	Centre tube	1	9	9	172
8	Dipping 2nd	Manual dipping of block in cap	0	9	9	162
9	Dipping 2nd	Workload Fluctuations	0	9	9	162
10	Dipping 2nd	Blocks after Dipping and Curing 1st	0	9	9	162
11	Final Inspection	Height and parallelism gauge	3	3	9	132
12	Curing 1st	Passing blocks through hot plate	9	0	1	98
13	Adhesive dispensing in cap 1st	Position of Nozzle	9	0	0	90
14	Adhesive dispensing in cap 2nd	Grammage of Adhesive	0	9	0	90
15	Adhesive dispensing in cap 1st	Grammage of Adhesive	9	0	0	90
16	Adhesive dispensing in cap 2nd	Position of Nozzle	0	9	0	90
17	Adhesive dispensing in cap 1st	Fixture of dispenser	9	0	0	90
18	Adhesive dispensing in cap 2nd	Fixture of dispenser	0	9	0	90
19	Final Inspection	Fluctuation in Workload	3	3	3	84
20	Dipping 1st	Tubing Block	3	3	3	84
21	Clipping	Cutting of clip	3	3	3	84
22	Clipping	setting of block into M/c	3	3	0	60
23	Adhesive dispensing in cap 1st	First Cap	3	0	3	54
24	Adhesive dispensing in cap 2nd	Cap second	0	3	3	54
25	Inspection 1st	visual inspection	0	3	3	54
26	Curing 1st	Temp. Of bed(220+/-10°c)	3	0	0	30
27	Dipping 1st	Slant connecting bed b/w table and oven	3	0	0	30

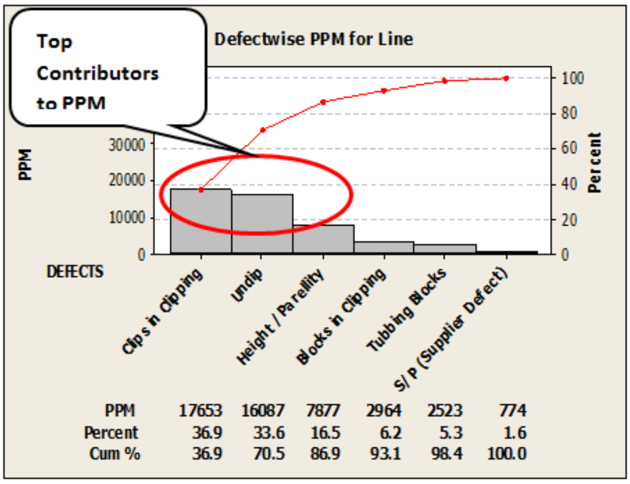


Figure No.4 (A): Defect wise PPM of Oil Filter Line

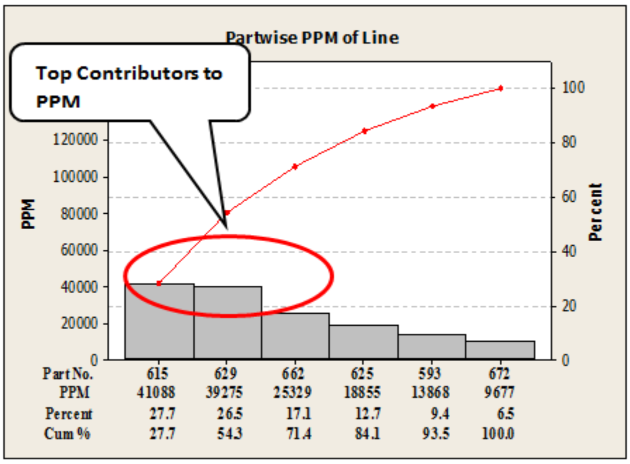


Figure No.4 (B): Part wise PPM of Oil Filter Line

3.2 Cause and Effect sheet: In Cause and Effect sheet, the vital defects from the customer point of view identified in Pareto analysis are considered and given weight depending upon their severity on a scale of 0 to 10 where '10' being most sever. Then the processes and its inputs, identified from As Is Process map, were linked to these defects and rating was assigned to them on scale of 0 to 9. This rating was given considering the effect of an input in relation to the particular defect. For rating, the whole team was involved. The team consisted of line supervisor, Line quality engineer, Production manager, Six-sigma consultant; so as to draw up on the vital experience and knowledge of all. Everyone was to rate simultaneously and if there was difference in score then the reason behind it was understood and higher score was selected.

Once the rating was completed then the whole sheet was sorted according to final score in column of 'Total' in descending order. Then the last column was searched from top to bottom for significant change in values of scores. The cut off was made at a score of 60 (i.e. 21 Inputs out of 83 were shortlisted). All the process inputs above this score are to be considered for Failure Mode Data Analysis.

3.3 Failure Mode Effect Analysis: Failure Modes and Effects Analysis (FMEA) is a systematic, proactive method for evaluating a process to identify where and how it might fail and to assess the relative impact of different failures and it's possible Causes, in order to identify the parts of the process that are most in need of change. The rating system used for FMEA is given below. In all, 183 possible Causes were identified during FMEA. The Sample representation of FMEA performed during course of this project is given below

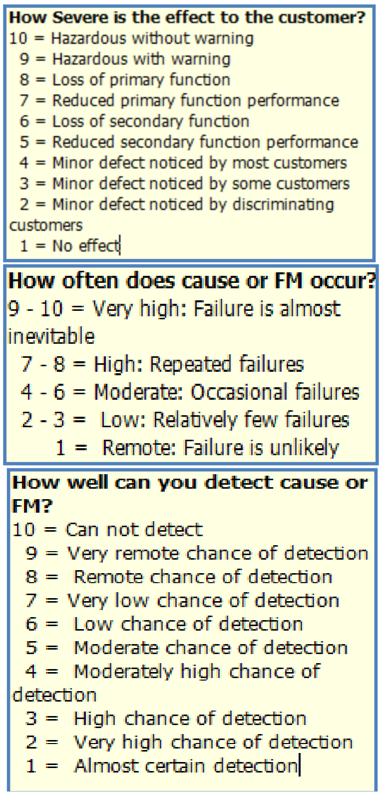


Figure No. 5: Rating Scheme used for FMEA

3.4 Hypothesis Testing: A hypothesis test is a method of statistical inference using data from a scientific study. During the course of this study, Hypothesis testing is used to understand; if the cause identified from the FMEA (inputs) has significant impact on output/quality parameter under consideration. Only the significant inputs and inputs with high Percentage impact on o/p are selected for actions. A hypothesis test is explained below.

3.4.1 Representative Hypothesis Test

- Purpose of Study: To Check The Effect of Speed of Rotation of Dispenser fixture on Adhesive Spreading in End cap
- Null Hypothesis (N_0): There is no effect of change in speed of Rotation of Dispenser fixture on Adhesive Spreading. Alternate Hypothesis (A_0): There is effect of change in speed of Rotation of Dispenser fixture on Adhesive Spreading.
- Input: 1) Speed of Dispenser fixture = 17 and 2) Speed of Dispenser fixture = 24.5
- Output Measured: Min. Adhesive Thickness
- Normality Test: From P value of the Normality tests, we can see that for first data set (Speed=17), data is

Table No.4: Representation of FMEA Sheet for Oil Filter Line

Failure Mode Effect Analysis										
Sr. No.	Process Step	Key Process Input	Failure Modes - What can go wrong?	Effects	SEV	Causes	OCC	Current Process Controls and Detection	DET	RPN
1	Dipping 1st	Manual dipping	Incomplete Dipping (Float)	BYPASS	8	Adhesive depth variation	8	No	9	576
2	Dipping 1st	Cap with adhesive and Ventury (C)	Uneven Spreading of Adhesive	BYPASS	8	Inadequate number of rotations of adhesive Dispenser Fixture	8	No	9	576
3	Dipping 2nd	Cap with adhesive and Ventury (C)	Uneven Spreading of Adhesive	BYPASS	8	Inadequate number of rotations of adhesive Dispenser Fixture	8	No	9	576
4	Dipping 2nd	Manual dipping	Incomplete Dipping (Float)	BYPASS	8	Adhesive depth variation	7	No	9	504
5	Dipping 2nd	Manual dipping	Incomplete Dipping (Float)	BYPASS	8	Height of centre Tube is higher by more than 0.5 mm than pleat height	8	No	7	448
6	Dipping 2nd	Block closed with cap from one side(C)	Excess Height of centre Tube	BYPASS	8	C. T. ID undersize than resting Radius of End Cap	7	No	8	448
7	Dipping 1st	Cap with adhesive and Ventury (C)	Uneven Spreading of Adhesive	BYPASS	8	Dipping element in cap before adhesive spreads	9	Visual	6	432

- normally distributed but for second data set (speed=24.5), data is non normal since the p value is Less than 0.05(Figure No. 6); therefore we consider Data as non normal. Hence Mann-Whitney Test is selected.
- *Comparison of Data Means:* The comparisons of data means of the two sample sets in chart (Figure No.7); signifies the difference between two data sets. We can also notice, at higher speed of rotation of fixture, average value of min. Adhesive thickness increases and it is desired to have higher adhesive thickness so as to facilitate the proper dipping.
- *Mann-Whitney Test:* The p value of Mann-Whitney Test is 0.000 (Figure No. 8); henceforth we reject null hypothesis and accept alternate hypothesis.
- *ANOVA:* To understand the percentage impact of Speed of rotation of adhesive dispenser fixture on the spreading of adhesive; ANOVA is carried out.

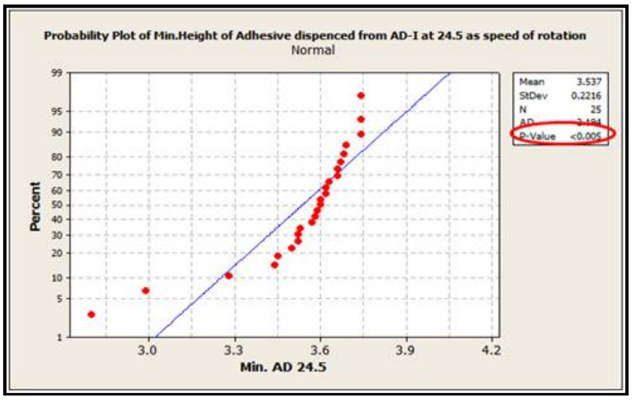


Figure No. 6: Normality Test

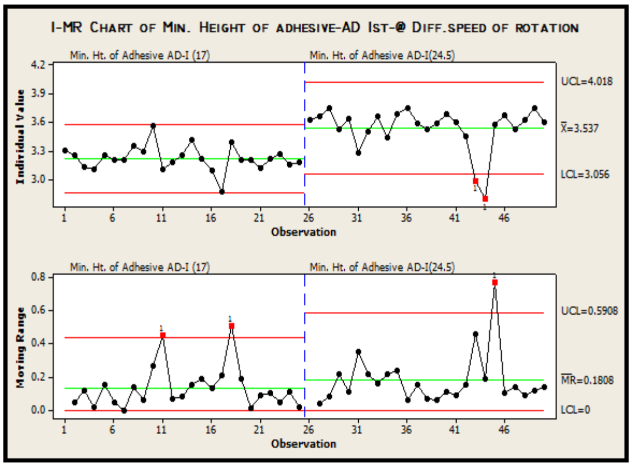
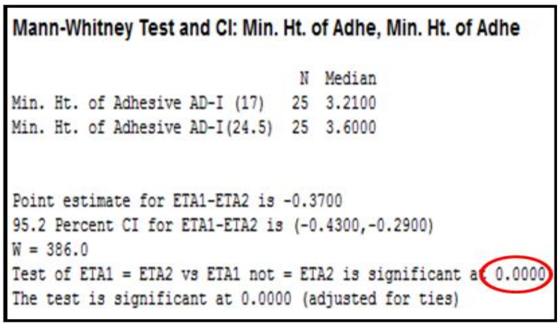


Figure No. 7: Comparison of Data Sets



Mann-Whitney Test and CI: Min. Ht. of Adhe, Min. Ht. of Adhe

```
                            N  Median
Min. Ht. of Adhesive AD-I (17)    25  3.2100
Min. Ht. of Adhesive AD-I(24.5)   25  3.6000

Point estimate for ETA1-ETA2 is -0.3700
95.2 Percent CI for ETA1-ETA2 is (-0.4300,-0.2900)
W = 386.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)
```

Figure No. 8: Mann-Whitney Test

Interpretation: From ANOVA (Figure No. 9), we understand that; the P value by One-Way ANOVA is also

0.000 (i.e. < 0.05); therefore there is significant effect of Speed of rotation of fixture of Adhesive Dispenser first on Adhesive Spreading and It's Percentage is 42.71% . Moreover, the distribution of data sets suggests that higher speed of rotation assists better spreading of adhesive in cap. Similarly, in all 18 diff. hypothesis tests were conducted during study. Out of which 13 were found to be significantly impacting the output while 5 were insignificant.

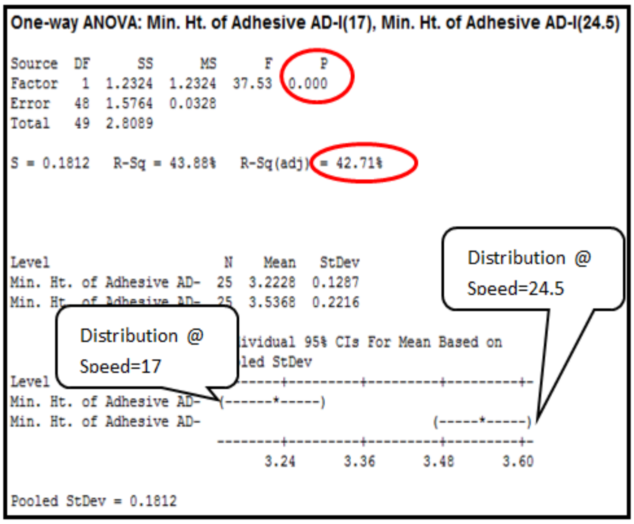


Figure No. 9: ANOVA Representation

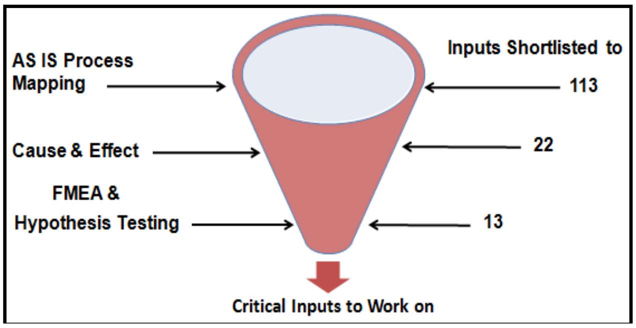


Figure No. 10: Travel to Identification of Critical Inputs of Process

4. Optimization and Improvement

This Phase of the project comprises the optimisation of significant parameters derived from hypothesis testing. Simultaneously improvement actions for significant parameter are implemented during this phase so as to reduce risk associated with a particular Failure mode or cause. Various actions taken during the course of this project are enlisted below.

Action 1: Achieving Complete and uniform Spreading of Adhesive in cap during dispensing itself

Initially there was issue with complete and uniform spreading of adhesive in cap during dispensing which used to result in defects. So following actions were taken to ensure complete and uniform spreading.

Action 1- A] At least two rotations of Adhesive Dispenser Fixtures, during dispensing of set quantity of adhesive, were ensured by optimizing Dozing Pressure.

Initially the dozing pressure was about 5 Bar for both the Dispenser. Then it was optimized to 3.25±0.25bar for dispenser 1stand 3.75±0.25bar for Dispenser 2nd and this range accommodates all part families.

Action 1- B] Optimization of Rotary Speed of Adhesive Dispenser Fixture.

Initially the speed of Adhesive Dispenser fixture was around 18 and 25 for Dispenser 1stand 2nd respectively. There was no SOP for speed of the adhesive Dispenser fixture. After comprehensive study; Speed of adhesive dispenser fixtures was increased from 18 to 35±2 for Dispenser 1stand from 25 to 28±2 for Dispenser 2nd.

Action 1- C] Optimization of Position (Orientation) of Nozzle of Dispenser.

Initially there was no SOP for position (orientation) of nozzle. Hence there was high level of operator dependency, which leads to incomplete and uneven spreading of adhesive in the cap. Position of nozzle has 26% impact on adhesive spreading. Hence the best position of Nozzle was optimized and validated by 'One factor at a time' study.

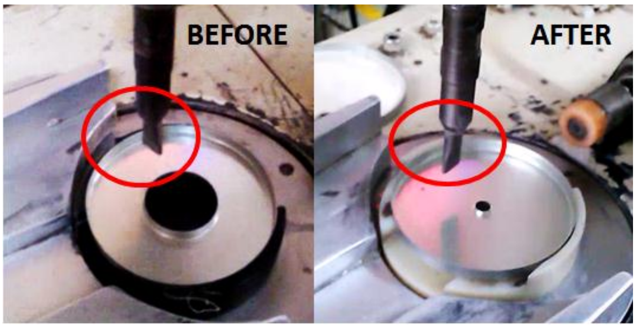


Figure No. 11: Before and after comparison of position of Nozzle

By Actions 8A, 8B, 8C Complete and uniform Spreading of Adhesive in cap during dispensing itself is ensured. The Noises such as Atmospheric Temperature, Viscosity of adhesive, Density of adhesive, delay required after dispensing were also taken care due to above action.

Action 2: Design, Pilot run, Validation and Implementation of Press fixture.

- *Why Press Fixture (Need):* 1)Uplift of centre tube after dipping leading to undip, 2)Tilting of block after dipping leading to undip or parallelism loss, 3)Undip due to incomplete dipping, 4)Excess height of element. There was profound need to encounter these all causes; to avoid defect generation stated above. Hence the fixture was designed. DFMEA was carried for design of fixture.
- *Construction and working:* Initially the press fixture is designed for a particular part and it can parallel implemented for all the parts with minor modifications

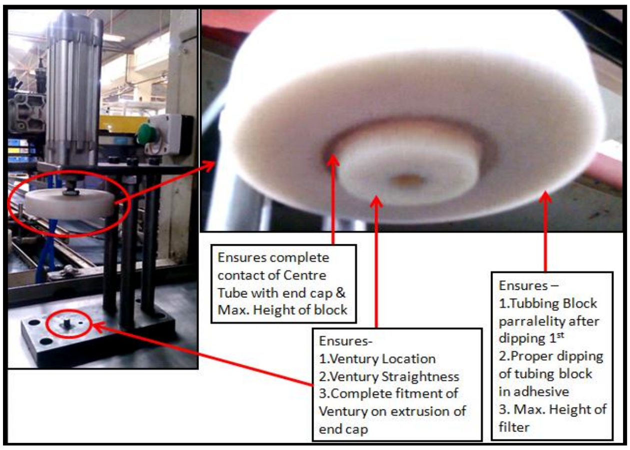


Figure No. 12: Problems Addressed In Press Fixture

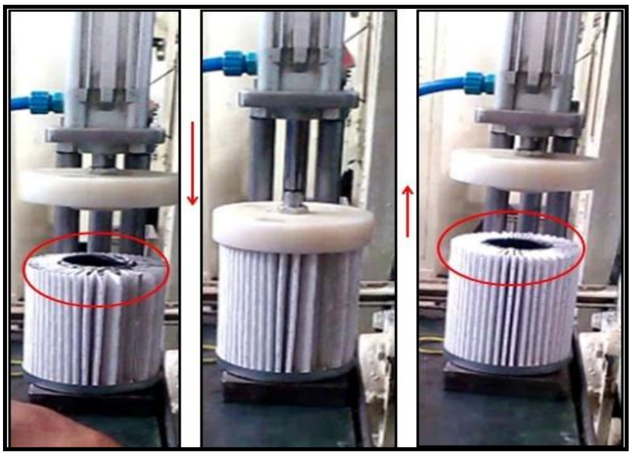


Figure No. 13: Working of Press Fixture

- *Results:* About 16000 filters were produced with use of this fixture and the PPM trend before and after use of fixture explains the effectiveness of this fixture in reduction of PPM.

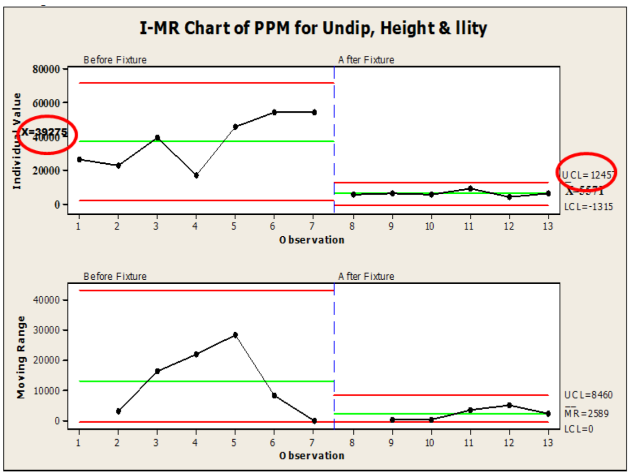


Figure No.14: I-MR chart Indicating Reduced Levels of Rejection by use of Press Fixture

The PPM of this part was reduced to 5571 from 39275 after use of this fixture along with other improvements. The operation of Pin insertion to ensure ventury location, can be eliminated with few changes to this fixture.

Action 3: Optimization of pleat depth value within Specified tolerance limit to reduce defects

The FMEA led to identification of 'higher tubing OD than Cap ID' as one of the cause with high RPN for Undip. Tubing OD is directly governed by value of pleat depth. It was found that pleat depth has 21% impact on the output. Initially there was practice of setting pleat depth at higher tolerance limit. But from the ANOVA distribution, It was found that the setting pleat depth at minimum tolerance limit would help to reduce 'paper on Skirt' (Undip) and same practiced was accepted as standard practice.

Action 4: The Pre-Heater before Slitting operation is made functional

There was issue of variation in pleat depth within a single block. The study in same regards, revealed that there is provision of Pre-heater before pleating operation. But actually this pre-heater was not used in daily practice. The pre-heater pre heats the paper so as to facilitate pleating operation. So pre-heater was started. Ever since the Pre-heater was made functional, quantity of blocks with pleat depth variation reduced drastically. This also translated in considerable reduction of undip caused due to pleat depth variation.

Action 5: Implementation of height master piece for setting of height gauge at final inspection (Improving Detection).

The setting of height gauge used at final inspection was based on scale. There was a strong possibility of wrong setting of gauge height due to difficulty involved in adjusting gauge, parallax error etc. The tolerances are within ±1.5mm for element height. Height oversize elements were passed to internal customers many times. To avoid all these possible causes; height master piece was designed and implemented. Advantages of action: 1) Improved the detection for height oversize and parallelism loss elements. 2) Improved the detection of undip element as 66% of the Undip element also account for height oversize.

Action 6: Correction of Error in display of two adhesive dispensers and Pleating M/c .

Action 6 A]: There was diff. b/w set and actual adhesive dispensed by Dispenser, in case of both the Dispensers. This lead to increased operator dependency and 'trial and error' method was used to set the required grammage of adhesive, resulting in defects. For correction of Dispenser display, regression analysis and fitted line plot were again used for stating relation b/w Display and actual grammage quantity is given below. Then regression equation was used to correct the display error. The calculation shows that there is 99.3% strong relation b/w Display and Actual grammage and henceforth it is verified that there is no other factor responsible for this error except display error. Based on this study, the maintenance department applied their expertise to resolve the issue.

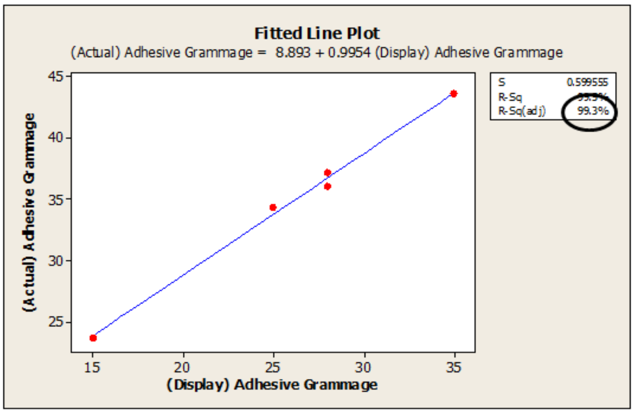


Figure No. 15: Fitted Line Plot for Display (Set) and Actual Grammage Quantity

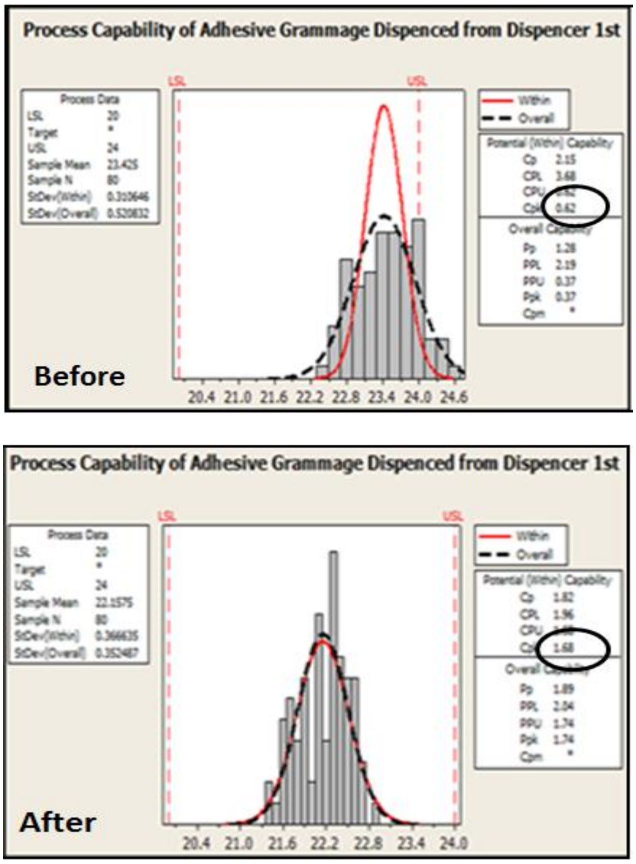


Figure No. 16: Before and After Comparison of Process capability (Cpk) of Adhesive Grammage

The above comparison of Cpk values shows that before the display was corrected the operator used to set high grammage as he used to add his own factor of safety to compensate for setting error. This used to result in improper quantity of adhesive leading to defects. But when display was corrected (Action 6 B) and Spreading issue of adhesive was resolved (Action 1) then operator started setting exact value of adhesive.

Action 6 B]: Similarly, Pleat depth display error of 7.20mm which was possibly reducing the probability of setting exact pleat depth value.

Action 7: Modification Of Dipping Table

Initially the dipping table was divided into two parts. This lead issues such as; 1) Inconvenience to operator 2) Lifting of element after dipping by operator which could uplift the element from adhesive; resulting in defects such as undip or parallelism loss. 3) Less space available for operator to maintain inventory. 4) The cap filled with adhesive used to move on to slant surface due to lack of flat space for inventory, leading to uneven thickness of adhesive. This could probably lead to undip.

In order to resolve all these issues, with ergonomic approach to workstation design (S. S. Mujumdar, V. N. Karandikar and S. M. Sane, 2013); the two stage dipping table comprising half horizontal and half slant surface was converted to a single horizontal surface.

Before **After**

Figure No. 17: Before and After Comparison of Dipping Table

Action 8: Actions related to issue of 'excess height of centre tube after dipping 1st' for a part which is top contributor to PPM in Pareto Analysis.

The Part primarily faced two issues- 1) Incomplete and Uneven spreading of adhesive and 2) Height of centre tube more than 0.5 mm excess with reference to pleat height after dipping 1st. The first issue was addressed when the work was carried out to ensure complete and even spreading of adhesive during dispensing itself (Action 1).

Figure No. 18(A): Undip Observed due to too Excess C.T. Ht. with Reference to Pleat Ht

Table No. 5: Control Plane for Oil Filter Line

Control Plan								
Process / Operation	Characteristics			Methods				Reaction Plan
	No.	Product	Process	Product / Process Spec / Tolerance	Measurement Technique	Sample Size	Sample Freq.	
Oil Filter Manufacturing line	1	Height		As Per Part Height Specification	Height gauge	100%	All Parts	Inform supervisor if out of tolerance parts observed
	2	Parallelism		1.5mm	Height gauge	100%	All Parts	Inform supervisor if out of tolerance parts observed
	3	No Undip		No pleat on skirt, Float, fold and Paper be Completely Dipped in adhesive	Visual	100%	All Parts	Inform supervisor if parts with defects are observed
	1		Pleat Depth (PD)	Between Minimum and Average tolerance value	Low force Vernier	5	Per Pleat Depth Setup	Inform Supervisor to check PD if 3 cases of paper on skirt are observed.
	2		Clip length	AS Per part Specification	Vernier	5	Per Part Set Up	Check Setting and Set the clip length as per spec.
	3		Paper and mesh Alignment after tubing	Paper and mesh Should be exactly aligned after tubing	Visual	100%	All Parts	Remove the excess mesh wire
	4		Adhesive dispenser (AD) Istand2nd Grammage	AS Per part Specification	Weighing M/c	5	Per Part Setup	Check Grammage and Set the it as per spec.
	5		AD first fixture speed	35±3	Display on panel	1	Per Part Setup	Check the set Speed as per spec.
	6		AD first Dozing pressure	3.25±0.25 Bar	Pressure Indicator	1	Per Part Setup	Check Dozing pressure and Set it as per spec.
	7		Diff. In Ht. of C.T. and paper after dipping 1st	0 to 0.5mm	Vernier (proposed Height gauge)	100%	All Parts	Check all Tube ID and End cap resting radius if more than 5 out of tolerance parts are Detected.
	8		AD 2nd fixture speed	28±2	Display on panel	1	Per Part Setup	Check Speed and Set the Speed as per spec.
	9		AD 2nd Dozing pressure	3.75±0.25 Bar	Pressure Indicator	1	Per Part Setup	Check Dozing pressure and Set the Dozing pressure as per spec.

Table No. 6: Revised FMEA for Oil filter Line

Sr. No.	**1**			**2**	**3**
Process Step	Dipping 1st			Dipping 1st	Dipping 2nd
Key Process Input	Manual dipping			Cap with adhesive and Ventury (C)	Cap with adhesive and Ventury (C)
Failure Modes	Incomplete Dipping	(Float)		Uneven Spreading of Adhesive	Uneven Spreading of Adhesive
Effects	BYPASS			BYPASS	BYPASS
Severity	8			8	8
Causes	Adhesive depth	variation		Inadequate number of rotations of Dispenser Fixture	Inadequate number of rotations of Dispenser Fixture
OCC	8			8	8
DET	9			9	9
RPN	576			576	576
Actions Recommended	Ensure the uniform adhesive depth during dispensing			Ensure at least 2 rotations of dispenser fixture to dispense set quantity of adhesive	Ensure at least two rotations of dispenser fixture to dispense set quantity of adhesive

Sr. No.	**1**			**2**		**3**	
Actions Taken	Uniform adhesive depth ensured by optimizing- 1.Min. No. Of rotations of dispenser fixture 2.Dozing Pressure	3.Position of Nozzle	4.Speed of rotation	Min. Number of required rotations ensured by optimizing-	Dozing Pressure	Min. Number of required rotations ensured by optimizing-	Dozing Pressure
Revised SEV	8			8		8	
Revised OCC	3			3		3	
Revised DET	9			9		9	
Revised RPN	216			216		216	

Figure No. 18(B): Representation of excess C.T. Ht With Reference to Pleat Ht.

Action 8 A]: Implementation of control charts at centre tube line (internal supplier line) for control in longer run.
Action 8 B]: Implementation of Fixture to enlarge tubing ID-Centre tube(C.T.) production machine used to produce Centre tube with undersize inner diameter(ID), due to its inherent tooling issue. In order to tackle the problem on immediate basis, a fixture was provided to enlarge C.T. ID.

Figure No.19: Center Tube

Figure No.20: Fixture to Enlarge C.T. ID

5. Control

5.1 Control Plan: The last but most critical stage of a six sigma project is Control phase. It is Difficult to induce change to any established system and is equally a daunting task to maintain the improved system. The simple and effective tool to serve this purpose is control plan. In a designing of control plan, one can easily be tempted to control all the factors on each stage of the line but through six sigma funneling process, till now we have reached up to few vital factors which control the majority of the output. Hence we include only those points in control plan which will have significant impact on output.

5.2 Revised FMEA: FMEA is a live document. Initially we act upon causes and Failure Modes with high RPN; then RPN is revised as per changes in Occurrence and Detection. Then we again sort the FMEA as per RPN value and act upon highest RPN causes and Failure modes. During the course of study many unknown causes of process variation, defect creation is identified. Then all such possible causes are updated in FMEA. Maintaining an updated FMEA will establish a system and person dependency would be reduced. The revised FMEA recorded 190 identified cases. Out of these 190 causes, possible actions were recommended for 59 causes. In actual practice the actions were taken on 43 causes to reduce their RPN. The remaining recommended actions are under consideration and its validation is going on.

6. Results and Discussion

Initially, the PPM for Undip, Height oversize and parallelism loss was around 24,000. After a series of improvement actions based on the Statistical data and scientific tests, the PPM reduced to level of around 6,550 which corresponds to Sigma level rise from 3.43 to 4.02.

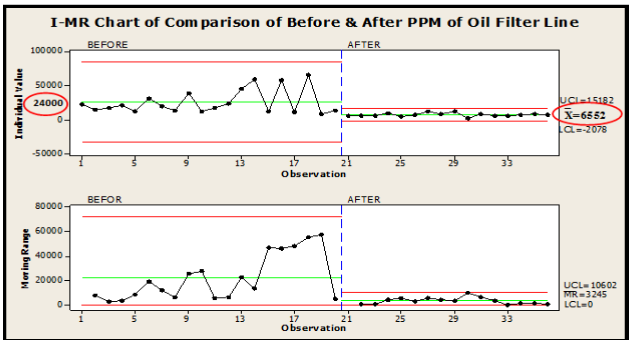


Figure No. 21: Before and After Comparison of PPM for Oil Filter Line

The I-MR chart given below represents the improvement on the line. The means of PPM values before and after project help to understand the above mentioned fact. The project also resulted in reduced chances of defective part passing to customer, improvement in right 1st time, reduced cost of rework and scrap, improved Process capability. In short, Manufacturing Process was improved.

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