The Process Variation Control in Punching Process by using DMAIC approach for Achieving Six Sigma Level

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Abstract: An industrial problem was taken under the present work to show the process variation control by implementing six sigma in punching process. The lot of stainless steel punched washer was rejected by customer who was maintaining six sigma quality level in their manufacturing. Although all the part in the lot were within the given tolerance limits but on the variation of dimensions within the tolerance zone was too high and it was not confirming to Six-Sigma distribution.
The work reported in the paper present the method to find the factors that are influencing the manufacturing process variation of steel washer. There were five different thickness stainless steel washers taken under consideration for controlling process variation. Six-sigma DMAIC technique was used to identify the factors influencing the process variation, and to control the same. Outside diameter of the punch (O.D) and the sheet thickness, were found to be the two main parameters influencing the process variation; a relationship between them has been established to control the variation and location of the mean.
The capability index (Cpk) and capability ratio (Cp) of the process was in between 1.13 to 1.21 and 1.20 to 1.44 respectively after implementation of the result of this work the Cp=2.19 and Cpk =1.91 was achieved.

Key words: DMAIC, capability index (Cpk), capability ratio (Cp), six sigma

I. INTRODUCTION

The tool wear creating most of the dimensional inaccuracies is due to the breakdown of the corners of the tool tips, which increases the burr height. Several researchers [C.M.Choy (1996), R.Hambli (2001)] have demonstrated that the geometry of the tool after tool wear may be approximated by a rounded shape, creating a punch tip radius. Increase in the die clearance increases tool life. R.Hambli(2001) shows that doubling clearance from 2.5-5% (for M.S. sheet) doubles the tool life. Punch and Die life can be extended considerably by prudent sharpening at the ideal time. The number of holes produced between sharpening will vary according to the material thickness and hardness from conceivably 400 on very heavy material to about 25,000 on thin material.
Traditional quality control was replaced in the 1980s in many countries with the philosophy of continuous improvement [Juran(1993), Juran(1992), Deming (1986)] Unfortunately, many companies continue to practice the traditional philosophy of quality control.Traditionally a quality characteristic is acceptable as long as the value is between upper and lower specified limit. However the goal of implementing “Six Sigma” is to move product or service attributes within the zone of customer satisfaction and reduce process variation [Breyfogle (1999), Hoerl (2004]. “Six Sigma” closely examines companies’ repetitive processes using statistical methods and translates customers’ needs into separate tasks by defining the optimum specification for each task [Snee (2004)].“Process performance equals six sigma when variation in the individual process or product characteristic gives no more than 3.4 defects per million parts/ opportunities.”

1.1 Problem Definition:

As the whole lot of washers was rejected due to variation of dimensions within the tolerance zone was too high and it was not confirming to Six-Sigma distribution. The five different internal diameter of washers of two different thicknesses were taken in to consideration to understand the process variation in punching. The specifications of parts are given in table 1. The data provided by the customer along with the rejection report with a note that the supply don not conform six sigma quality standards. The calculated standard deviation of sample size 60 washers of each type along with Defects per million opportunities (DPMO) for the five washers as given in table 2.

Table1: Specification of Washers

Part name	OD (mm)	ID Ctq(mm)	LSL	USL	Plate thickness
A	65	41.25	41.25	41.38	3
B	65	40.20	40.20	40.33	1.5

C	65	20.75	20.75	20.88	1.5
D	65	28.75	28.75	28.88	3
E	65	27.5	27.5	27.63	3
OD= Outer Diameter, ID=Inner Diameter, LSL= Lower Specification limit, USL=Upper Specification Limit					

Table 2: Sigma level and DPMO of the lot

Part Name.	Standard Deviation of pilot sample	Sigma(σ)	DPMO
A	0.0306	3	55940
B	0.0270	3	39250
C	0.0279	3	29000
D	0.0151	4	466
E	0.0205	4	2075

2.0 Method:

To improve the quality standard of the process and ultimately the products a systematic approach DMAIC was used to achieve the six sigma quality standard in the process. DMAIC approach contain five steps namely D stand for define,M stand for Measure, A stand for analyze , I stand for Improve and C stand for Control .

2.1 Define phase

The Target value for process was defined on the basis of problem definition and to reduce the variation of internal diameter of washers within the tolerance zone. The desired targeted process capability is 2.00 with a baseline capability of 1.33.

2.2 Measure Phase

As a clear definition of project has been established a clear measurable Y i.e the internal diameter of the punched part, the process is studied to determine the Key Process Steps and the Key Inputs for each process. After the key input list is established, the team considered the potential impact of each input with respect to the variation of the output Y. To prioritize the inputs the following steps were adopted

- Preparation of process Map.
- Preparation of Cause and effect matrix.
- Establishment measurement system capability

2.2.1 Process Mapping

Process mapping is helps in clearly identifying all the steps of the process and the stages at which inspections and control for achieving quality are to be implemented. For the process used in punching by MMT mapping is given in Figure 1.

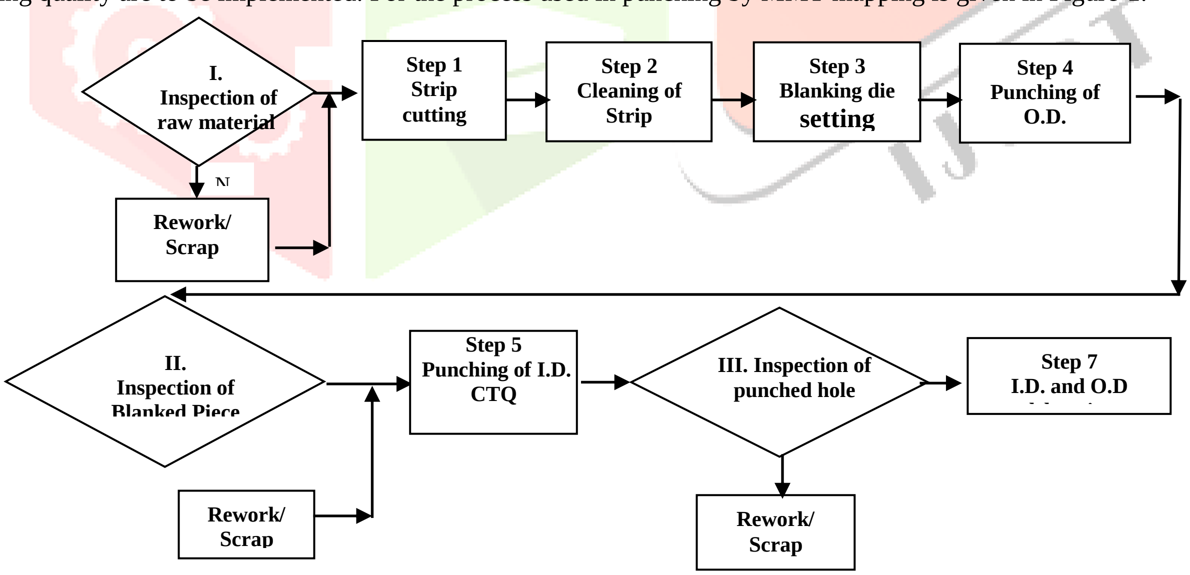

Figure1: Process mapping for punching process.

The brainstorming was done with the production personals and possible cause were identified which effect the variation of internal diameter of the washers as shown in figure 2 and ranked as given in table 3. The top five cause were taken under consideration which are majorly effect the punched hole dimension.

Table 3 : Ranking of causes effecting Punched hole size

S. No	Input variable (x)	Ranking
1	O.D of the punch	1

2	Wear of punch & die	2
3	Play between Pillar & bush	3
4	Ovality of the punch	4
5	ID of the Die	5

To establish the measurement system capability Gage repeatability and reproducibility (Gauge R& R) value of the digital venire caliper measured. The total Gauge R& R of venire caliper was found 0.0020 which shows that it uses only uses 0.2% of the tolerance limits. It is generally preferable that measuring instrument should not use the tolerance limits not more than or equal to 1.

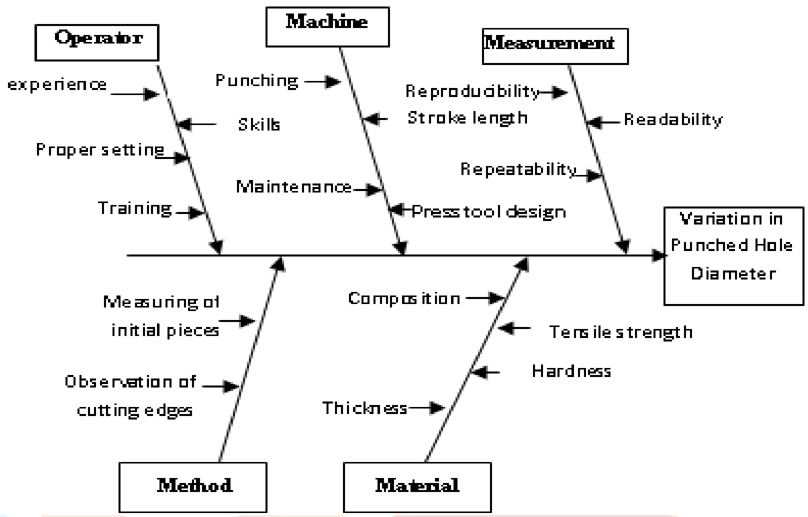

Figure 2: Cause and effect diagram

3.0 Analyze Phase:

In this phase the root causes of the problem that needs improvement were determined by carrying out Capability analysis of the present process.

3.1 Capability analysis:

For capability analysis a sample of 60 piece of each component were taken in both production shifts at an interval 10-15 minutes. The data and the analysis result of all five washers are given in the tables 4 and the calculated process capability along with other data is given in table 5.

Table 4: Dimensions of Internal diameter of all five type of Washer

S.No	Hole Size(mm)					S.No	Hole Size(mm)				
	A	B	C	D	E		A	B	C	D	E
1	41.26	40.21	20.79	28.79	27.56	31	41.27	40.23	20.83	28.81	27.55
2	41.26	40.22	20.79	28.79	27.55	32	41.27	40.25	20.84	28.82	27.58
3	41.27	40.22	20.79	28.78	27.53	33	41.27	40.28	20.84	28.80	27.56
4	41.27	40.23	20.79	28.77	27.56	34	41.27	40.24	20.84	28.80	27.55
5	41.31	40.21	20.79	28.79	27.56	35	41.28	40.25	20.84	28.82	27.60
6	41.33	40.23	20.80	28.77	27.55	36	41.28	40.24	20.76	28.82	27.58
7	41.27	40.22	20.80	28.80	27.55	37	41.28	40.26	20.76	28.81	27.58
8	41.33	40.24	20.80	28.79	27.53	38	41.26	40.27	20.76	28.81	27.58
9	41.33	40.22	20.80	28.81	27.60	39	41.26	40.27	20.76	28.80	27.59
10	41.34	40.24	20.80	28.80	27.55	40	41.26	40.27	20.77	28.79	27.59
11	41.34	40.24	20.80	28.79	27.55	41	41.29	40.28	20.77	28.78	27.58
12	41.34	40.25	20.80	28.78	27.55	42	41.29	40.28	20.77	28.80	27.59
13	41.33	40.25	20.81	28.82	27.55	43	41.29	40.29	20.77	28.80	27.58
14	41.33	40.24	20.81	28.81	27.55	44	41.30	40.29	20.86	28.83	27.6
15	41.33	40.23	20.81	28.81	27.56	45	41.30	40.29	20.86	28.81	27.56
16	41.32	40.23	20.81	28.80	27.53	46	41.30	40.30	20.85	28.82	27.57
17	41.34	40.25	20.81	28.80	27.59	47	41.30	40.30	20.85	28.83	27.54
18	41.34	40.25	20.81	28.77	27.55	48	41.31	40.25	20.85	28.80	27.55
19	41.33	40.24	20.81	28.78	27.56	49	41.31	40.31	20.86	28.79	27.59
20	41.26	40.29	20.82	28.81	27.54	50	41.31	40.30	20.87	28.79	27.58

21	41.33	40.24	20.82	28.77	27.55	51	41.33	40.21	20.87	28.81	27.54
22	41.34	40.25	20.82	28.80	27.53	52	41.34	40.22	20.79	28.82	27.53
23	41.34	40.24	20.82	28.79	27.54	53	41.33	40.22	20.8	28.8	27.54
24	41.33	40.25	20.82	28.82	27.57	54	41.33	40.25	20.8	28.81	27.56
25	41.34	40.23	20.82	28.80	27.58	55	41.34	40.26	20.8	28.81	27.53
26	41.32	40.25	20.83	28.79	27.57	56	41.27	40.24	20.8	28.8	27.57
27	41.35	40.24	20.83	28.80	27.56	57	41.28	40.3	20.81	28.83	27.53
28	41.35	40.25	20.83	28.79	27.6	58	41.29	40.29	20.81	28.8	27.54
29	41.35	40.25	20.83	28.79	27.56	59	41.28	40.3	20.82	28.79	27.55
30	41.36	40.24	20.83	28.80	27.56	60	41.29	40.29	20.82	28.79	27.58
Mean	41.30	40.26	20.81	28.80	27.56						
Std. Dv.	0.015	0.016	0.0177	0.0167	0.018						

After data analysis, the process capability in terms capability index (Cpk) and capability ratio (Cp) of the process for all five of washer was calculated and given in table 5. After analyzing the existing process and finding out existing process capability, each factor which may be the cause of variation as given in cause effect diagram of was analyze.

Table 5: Die and punch specification with process capability

Specification	Part name				
	A	B	C	D	E
Ctq(mm)	41.25	40.20	20.75	28.75	27.5
Punch OD(mm)	41.35	40.27	20.85	28.84	27.6
Die ID(mm)	41.65	40.7	21.27	28.9	27.62
Radial Clearance (mm)	0.15	0.215	0.21	0.03	0.01
Shrinkage mean (mm)	0.02	0.04	0.04	0.05	0.07
% Clearance	5.0	7.2	14.0	1.0	0.5
Cp	1.38	1.35	1.22	1.44	1.20
Cpk	1.21	1.10	1.16	1.14	1.13

Operator: The operators deputed for the operation are skilled and experienced .It was observed that if the setting of the machine was not proper then there will be deformed components but there were no deformed component. Hence the variation due to operator may not be significant.

Measurement: It was observed that gage R&R was satisfactory as discussed in section 2.2 and hence chances of variation due to measurement system are also negligible.

Method: As the team of the process expert's team had developed the process chart and the process was same as the other firms use for producing such components within the six-sigma limits. So the variation due to the method was ruled out.

Material: After testing of SS304, we observed chemical composition and mechanical properties were found as per specification. Hence the variation because of material was also ruled out.

Machine & Tool: It was observed that when the Die & punch were new they are producing the components without burrs but with time, the same tool causes variation due to the wear of the punch; and extensive deburring had to be used. Hence there are more chances of variation because of the improper Die and Punch. As the process was shifted towards the lower limit even with proper setting of machine, there must be some problem with the tool design.

As it was seen from the data collected that the radial clearance in the die and punch set varies from 1% to 14% for the same raw material i.e. SS304, but during literature it was found that for stainless steel the clearance should be kept 7.5% per side of the sheet thickness so the die and punch may be the cause of the variation. Consequently Die designer and Die maker were called and discussion about the die design and die making was held.

After discussing with die designer and die maker some fact were come into picture as

1. Die designer had decided the clearance according to his past experience, i.e. btween 4 to 9 %.but he has no experience of making punching die for SS304 washer.
2. Die designer had taken allowance for elastic recovery 0.001 to 0 .009 mm to punch.
3. It is required to reworked the punch after every 800 punching operation.
4. the die maker told that he is not sure about the precision level of the machine on which he had made this die.
5. Instead of standard pillar bushes, self manufactured pillar bushes were used in the die.

From the discussion with die designer and maker and by the analysis of the data The above analysis leads to

1. The shrinkage allowance (elastic recovery) of the punch must be fixed carefully but the designer did not do the same.
2. The Die manufacturer did not provide die clearance to the die as per specification.
3. The pillar bushes have to be of standard make,
4. A system has to so that the operators come to know that number of component has reached the limit at which the punched need reworking.

Since a new design was need it was decided to use standard pillar bushes to eliminate this possible cause of variation.

The fourth cause was eliminated by introducing a bin of appropriate size to give a reasonable estimate of the part produced.

4.0 Improve phase

The shrinkage or elastic recovery allowance is given on the punch diameter i.e. the punched diameter is increased by the desired allowance. However as discussed by Prakash & Joshi 1996 that the allowance depends on sheet thickness, hole size and material properties; and its final selection is done on the basis of trials only. Clearance is given on the die diameter [W.B Lee 1997]. Thus the two causes identified in the previous section lead to appropriate selection of punch and die diameter; for which design of experiment was adopted.

4.1 Full factorial design of experiment:

The effect of the punching parameters on die in die punch has been investigated. In order to have a better approximation of the proposed mathematical models, The two independent variable included are sheet thickness and hole size. Using these two variables at different levels an experimental predictive model was developed.

As the clearance to the die and the shrinkage of the hole have to be selected properly, four dies & two punches for performing the full factorial experiment are needed.

1. In these die & punch proper clearance was taken and it was made sure that the prescribed clearance are given to the dies. (no mechanical error is there).
2. The following formulas were used to get the desired dimensions of dies and punches for the experiment [Wlingerberg (2000),K.lange (1985)]

Punch diameter (D_p) =D_h + hole shrinkage(S)* (1)

Die hole diameter ($D_{d)}$ = D_p +2*Clearance(c) (2)

c = .075* thickness of the Sheet (T) (3)

*S is the factor, which is not known as it depends on material elastic recovery. The mean shrinkage in all five lots of sample components is 0.04 mm given in table 5 (mean of 0.04, 0.05, 0.04, 0.02, 0.08).The punches & dies combination & their dimensions are given in table 6.

Table 6 : Die Punch set dimension for factorial design

Die Punch set	D=Washer ID (mm)	Dp=Punch OD (mm) **(D_p)=D_h+hole shrinkage**	Dd= Die ID (mm) **($D_{d)}$ = D_p +2*Clearance(c)**	Plate Thickness (T) (mm)	c= Clearance (mm) **c = .075* (T)**
1	41.31	41.31+0.04=41.35	41.35+2*0.11= 41.57	1.5	1.5 * 0.075=0.11
2	20.81	20.81+0.04=20.85	20.81+2*0.11= 21.03	1.5	1.5 * 0.075=0.11
3	41.31	41.31+0.04=41.35	41.35+2*0.22= 41.79	3.0	3.0 * 0.075=0.22
4	20.81	20.81+0.04=20.85	20.85+2*0.22= 21.09	3.0	3.0 * 0.075=0.22

The experiments were carried out as per DOE table of full factorial design and the experiments and their results are given in table7.

Table 7: DoE Table

Std Order	Run Order Center pt	center Pt.	Block	A	B	T	H, CTQ	Punch OD	Die ID	Measured Hole size		Shrinkage
										R1	R2	
1	1	1	1	-1	-1	1.5	20.81	20.85	21	20.85	20.84	0.005
2	2	1	1	1	-1	3	20.81	20.85	21.15	20.83	20.84	0.015
3	3	1	1	-1	1	1.5	41.31	41.35	41.5	41.29	41.3	0.055
4	4	1	1	1	-1	3	41.31	41.35	41.65	41.29	41.28	0.065
5	5	1	1	-1	-1	1.5	20.81	20.85	21	20.84	20.84	0.01
6	6	1	1	1	-1	3	20.81	20.85	21.15	20.83	20.83	0.02

7	7	1	1	-1	1	1.5	41.31	41.35	41.5	41.3	41.3	0.05
8	8	1	1	1	1	3	41.31	41.35	41.65	41.28	41.29	0.065
9	9	1	1	-1	-1	1.5	20.81	20.85	21	20.84	20.84	0.01
10	10	1	1	1	-1	3	20.81	20.85	21.15	20.82	20.83	0.025
11	11	1	1	-1	1	1.5	41.31	41.35	41.5	41.29	41.29	0.06
12	12	1	1	1	1	3	41.31	41.35	41.65	41.28	41.28	0.07
T= sheet Thickness, H= Hole size.												

4.2 DoE analysis from MINITAB given below

Full Factorial Design

Factors: 2 Base Design: 2, 4 Runs:12 Replicates: 2 Blocks: none Center pts (total): 0

4.2.1 Regression Analysis

The regression equation is : Shrinkage = - 0.0507 + 0.00778 T(A) + 0.00228 H(B), (4)

Predictor	Coef	StDev	T	P
Constant	-0.0507	0.0049	-10.42	0.000
T(A)	0.0078	0.0015	5.25	0.001
H(B), CTQ	0.0023	0.0001	21.00	0.000

S = 0.003849 R-Sq = 98.1% R-Sq(adj) = 97.7%

4.2.2 Analysis of Variance

Source	DF	SS	MS	F0	P
Regression	2	0.0069417	0.0034708	27.56	0.000
Residual Error	9	0.0001333	0.0000148	440.99	
Total	11	0.0070750			

Source	DF	Seq SS
T(A)	1	0.0004
H(B), CT	1	0.0065

The Pareto chart shown in figure 4 show that both the factor i.e. hole size and sheet thickness are significant factor as the standardized effect value exceeding the red line for both factor.

The Pareto chart shown in figure 3 show that both the factor i.e. hole size and sheet thickness are significant factor as the standardized effect value exceeding the red line for both factor.

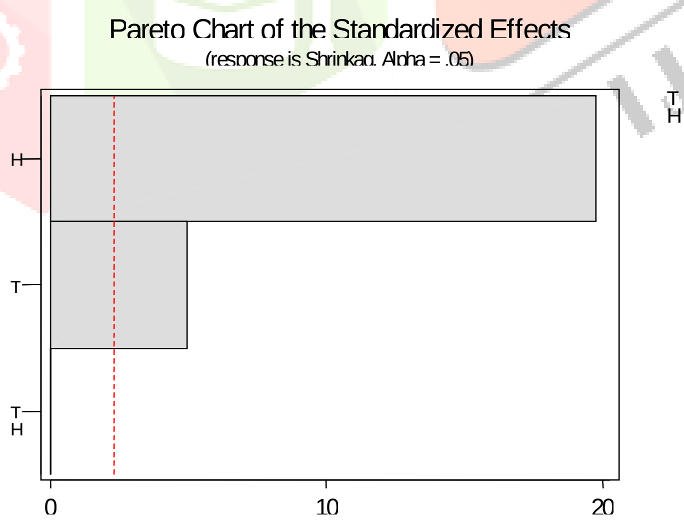

Figure 3: Pareto Chart of Standardized Effect

The main effect plot shown in figure 4 illustrates the impact sheet thickness and hole size on shrinkage and it is also depicted from main effect plot that the hole size is more significant.

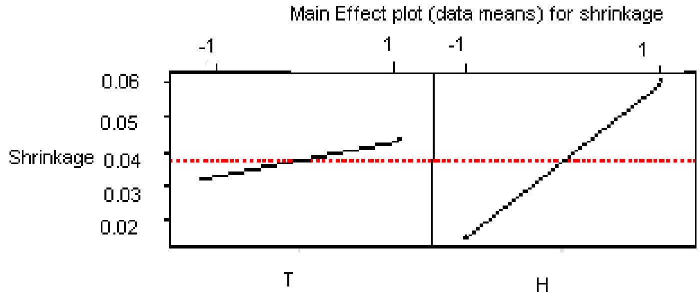

Figure 4: Main effect plot for data mean shrinkage

Figure 4: Main effect plot for data mean shrinkage

4.3 Testing of Improvement:

Once the relation between hole size, sheet thickness & elastic recovery (hole shrinkage) is found, the punch and die diameters was to be corrected according to the correct shrinkage allowance found in section 4.1: for which two new punches & four dies were made according to the new shrinkage allowances & formulas given in section equation 1 to 3. The resulting dimensions are given in table 8.

Table 8: Dimensions of improved die and punch (All dimensions are in mm)

S.No.	Punched hole size (D_h)	Sheet Thickness (T)	Shrinkage (S)	Punch size (D_p)	Clearance per side (c)	Die I.D (D_d)
1	41.31	1.5	0.05591	41.36	0.11	41.58
2	20.81	1.5	0.00876	20.80	0.11	21.03
3	41.31	3.0	0.6761	41.37	0.22	41.81
4	20.81	3.0	0.0246	20.83	0.22	21.07

In table 9 a comparison of calculated values and measured values of Shrinkage (elastic recovery) obtained using the die and punch given in table 8.

Table 9: Comparison Table of measured 'Ya' value and calculated 'Yc' value Using derived formula

Sr. No	Ya	T (mm)	H(mm)	0.0078 * T	0.0023 * H	Yc = -0.0508+0.0078* T + 0.0023* H	Ya-Yc	%Error
1	0.056	1.5	41.31	0.0117	0.0950	0.05591	0.000090	0.160714
2	0.068	3	41.31	0.0234	0.0950	0.06761	0.000390	0.573529
1	0.01	1.5	20.81	0.0117	0.0479	0.00876	0.001240	12.4
2	0.021	3	20.81	0.0234	0.0479	0.02046	0.000540	2.571429
1	0.056	1.5	41.31	0.0117	0.0950	0.05591	0.000090	0.160714
2	0.068	3	41.31	0.0234	0.0950	0.06761	0.000390	0.573529
1	0.01	1.5	20.81	0.0117	0.0479	0.00876	0.001240	12.4
2	0.025	3	20.81	0.0234	0.0479	0.02046	0.004540	18.16
1	0.058	1.5	41.31	0.0117	0.0950	0.05591	0.002090	3.603448
2	0.07	3	41.31	0.0234	0.0950	0.06761	0.002390	3.414286
1	0.009	1.5	20.81	0.0117	0.0479	0.00876	0.000240	2.666667
2	0.021	3	20.81	0.0234	0.0479	0.02046	0.000540	2.571429
Ya= actual shrinkage of hole and Yc is the calculated Shrinkage by developed model								

5.0 CONTROL PHASE

Key Points:

- Implement control plan.
- Verify long-term capability.
- Continuously improve process.

Once the process improved now the problem is to sustain this quality level for this it is essential to control the occurrence of malfunctioning. In this work to control the process CTQ a control Plan was given as follows:

5.1 Control plan:

1. Regrinding period:

Two bin was designed one was to hold only 800 components and other large bin to contain 40,000 components. As the smaller bin got filled the punch is sent for grinding and after filling of the large bin the punch was discarded.

This method helped in preventing the production of unwanted parts and helped in maintaining the six-sigma level.

2. Checking of pillar bushes: As discussed earlier self made pillar bushes were replaced by standard bushes of standard make. A schedule was introduced to check a possible play in bushes over a period of time

5.2 Verification of process capability:

After developing the mathematical modal: **Yc = -0.0508 + 0.0078 * T + 0.0023 * H** all the dies & punches were changed and made according to the method disused in section 3.1.

The observation of washer E of 30 piece sample is given in table 10 where the process capability of C_p =2.22, C_{pk} =1.91 was obtained as shown in table 11 and distribution is shown in figure 5 .

Table 10: showing measured dimensions of washer "E" after improvement

Punched Hole Dimension(All Dimension Are In mm)					
1	27.55	**11**	27.56	**21**	27.56
2	27.55	**12**	27.57	**22**	27.56
3	27.54	**13**	27.55	**23**	27.55
4	27.54	**14**	27.55	**24**	27.56
5	27.55	**15**	27.56	**25**	27.55
6	27.55	**16**	27.55	**26**	27.56
7	27.56	**17**	27.53	**27**	27.56
8	27.57	**18**	27.56	**28**	27.56
9	27.56	**19**	27.56	**29**	27.57
10	27.57	**20**	27.57	**30**	27.55

Table 11: Data after improvement for washer "E"

Part Name	Washer E	**Punch O.D.**	27.59	**Mean**	27.56
		Die I.D.	27.89	**Std. Dev.**	0.0099
Ctq	27.50	**Clearance**	0.15	**Cp**	2.22
Usl	27.63	**Sheet Thickness**	2	**Cpku**	2.51
Lsl	27.5	**% Clearance**	5	**Cpkl**	1.91
		Shrinkage Mean	.028	**Cpk**	1.91

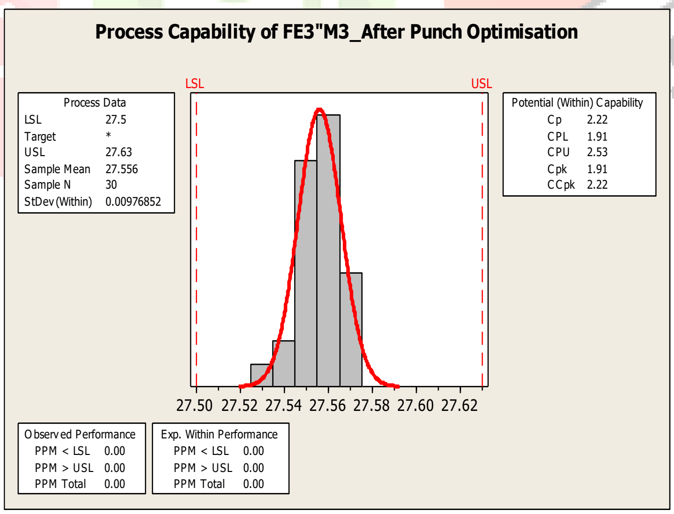

Figure 6: Process Capability Analysis For Washer "E" after Punch Optimization

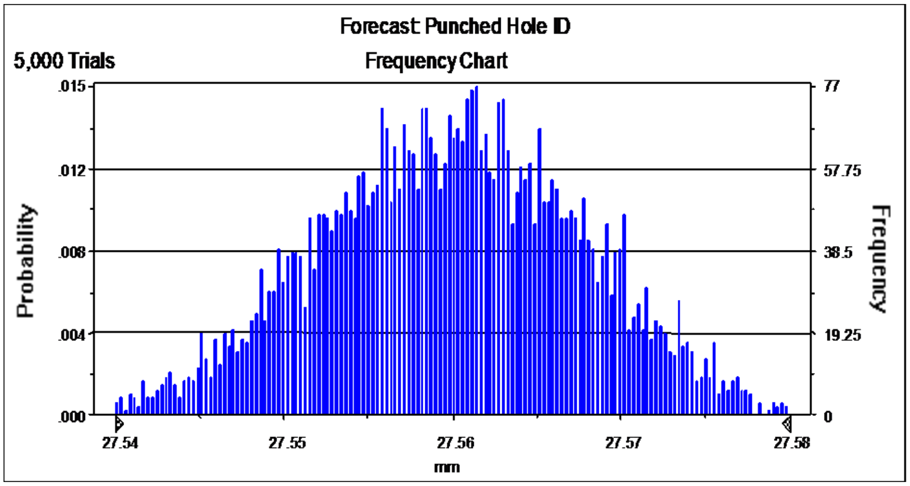

Figure 6:Minitab simulations Output For Modification of Punch OD

Simulated probability plots is given in Figure 6 in which 5000 trial were conducted, it is clear from the Figure 6. that the process is about the mean and vary in between 27.54 to 27.58 only.

6.0 CONCLUSION

1. Elastic recovery or shrinkage allowance is important parameter in punching for which there is hardly any published literature. 2x2 factorial design was used to obtain a mathematical shrinkage model as a function of sheet thickness and punched hole dimension as follows:

$$Yc = -0.0508 + 0.0078 * T + 0.0023 * H$$

Clearances between die and punch for SS304 were not appropriately chosen by design office. Clearances for different material were searched from published literature and implemented accordingly.

2. Improved process for the manufacturing of punch was introduced to obtain the specified tolerances and clearance.
3. Standard quality analysis control methods(DMAIC) were sued to Identify the problem area and solution for thereof.
4. Six Sigma level was obtained.

The major conclusions for obtaining C_p>2.0 the following should be considered:

- To get a mean of desired hole dimension, standard pillar bush set is strongly recommended.
- The punch diameter should be designed on the basis of targeted mean value and elastic recovery as given by equation 3.4.
- The clearance Should be 7.5 percent per side of thickness of sheet for SS304.
- The number of operations between two regrinding should be monitored and maintained up to about 800 components and after the 40,000 components the punch should be replaced.

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