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Process Capability Improvement of HSS Drill Bit Manufacturing Process

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Abstract: Statistical process control is very good quality inspecting tool to improve quality of products to manufacture and scores on customer satisfaction. Process capability is one of the best statistical process control technique. This research work elaborates calculation of process capability index C_p and process performance capability index C_{pk} values for manufacturing process of drill bits. based on C_p and C_{pk} values capable and non-capable parameters are identified. For non-capable parameters cause and effect diagram is used to identify the root causes affecting to process capability. corrective actions have been taken to bring the non-capable parameter's process capability up the standard level by iterations. By using this approach, we improve C_p values for point angle 0.94 to 1.47, for chip breaker angle 0.65 to 1.47, for web after notch 0.83 to 1.23 and C_{pk} values for point angle 0.72 to 1.33, chip breaker angle 0.32 to 1.33, web after notch 0.26 to 0.75.

I. INTRODUCTION

Drilling is one of important process in industry. Drilling is done by various types drill bits. HSS twist drill bits are one of most commonly used. This paper investigates the define-measure-analyze-improve-control approach to improve the process capability of HSS drill bits manufacturing process by reducing the variations of specifications of critical parameters from a nominal value. Process mapping and identifying critical parameters is carried out in the definition phase, while estimation of process capability indices is carried out in the measure phase. The cause-effect-diagram of investigation to test for the differences between the manufacturing data is employed in the analysis phase. Statistical process control study forms the basic tool for obtaining the required process capability confidence levels. The various process capability indices are defined as follows:

$$C_P = \frac{USL-LSL}{6\sigma} \tag{1}$$

$$C_{pkU} = \frac{USL-\mu}{3\sigma} \tag{2}$$

$$C_{PL} = \frac{\mu-LSL}{3\sigma} \tag{3}$$

$$C_{pk} = \min\{\frac{USL-\mu}{3\sigma}, \frac{USL-\mu}{3\sigma}\} \tag{4}$$

where LSL and USL are the lower and higher specification limits, μ = process mean, and σ = standard deviation represent the process potential capability index, and C_{pk} represent the process performance capability index. C_p gives an indication of the dispersion of the product specification values within the specified tolerance zone during the manufacturing process. Similarly, the index C_{pk} denotes for the centering of the manufacturing process with respect to the mean of the specified dimensional tolerance zone of the product. C_{pk} gives us an idea on whether the manufacturing process is performing at the middle of the tolerance zone or nearer the upper or lower tolerance limits. If the manufacturing process is nearer the lower limit, then the process performance capability index is given by C_{pkl}, and if the manufacturing process is nearer the upper limit, then the process performance capability index is given by C_{pku}. As a measure of precautionary safety, the minimum value between the two is taken as the value of C_{pk}.[2]
C_p relates the process capability to the dimensional range and not relate the location of process with respect to the dimensions. Values of C_p index exceeding 1.33 specify that process is adequate to meet the dimensional range. Values of C_p index between 1.33 and 1.00 specify that process is adequate to meet dimensional range but require close control. Values of C_p index below 1.00 specify process is not capable of meeting dimensional range.

C_{pk} considers process average and evaluates the process spread with respect to where the process is actually located. The value of C_{pk} index relative to C_p is a measurement of how off-center manufacturing process is operating. It assumes process output is approximately normally distributed. If the characteristic or process variation is centered between its specification limits, the calculated value for C_{pk} is equal to the calculated value for C_p. But as soon as the process variation moves off the specification center, it is penalized in proportion to how far it's offset. C_{pk} is very useful and very widely used. Generally, a C_p greater than 1.33 indicates that a process is capable in the short term. Values less than 1.33 tells that the variation is either too wide compared to the specification or that the location of the variation is offset from the center of the specification.

II. LITERATURE REVIEW

The literature survey of process capability improvements using the define-measure-analyze-improve control approach is discussed in this section. M. Mahajan emphasized in his book "statistical quality control" about basics of process capability and how to relate it with accuracy of process manufacturing of product. Singh (2011) investigated the process capability of polyjet printing for plastic components. In his observation, he traveled the improvement journey of the process of critical dimensions and their Cpk value attainment greater than 1.33, which is considered to be an industrial benchmark. Sharma and Rao (2013) calculate process capability for connecting rod and find out the causes for the reduction of process capability by define-measure-analyze-improve control concept with cause and effect fishbone diagram. Yerriswamy Wooluru (2014) proposed case study on process performance of boring operation in which states the concept, methodology and critical assumptions by using Minitab software. Andrew A. Erameh (2016) determine the process capability of centre lathe turning operation for varying spindle speed and feed rate of lathe. Dhanraj Patel (2015) published a review paper on drilling tool life in which he discusses the effects of various parameters on drilling tool life and also the geometrical parameters of drill bit and their significance.

III. METHODOLOGY

A. Definition Phase

HSS drill bits are used to drill hole in metal, wood and plastic. Depending on hardness of material and size of hole different drill bits are chosen. There are different sizes drill bits which are manufacture in industry are 1/2 inch,1/4 inch, 3/8 inch, 5/16 inch. All the manufacturing procedures are same for all sizes.1/4 inch size drill bit consider for process capability analysis.

Figure 1 shows the anatomy of all the geometrical parameters associated with twist drill bit. Out of these parameters shown in figure 1, we have selected drill diameter, point angle, chip breaker angle, lip angle and web after notch consider as critical parameters to study process capability as they predominate drilling accuracy and tool life.

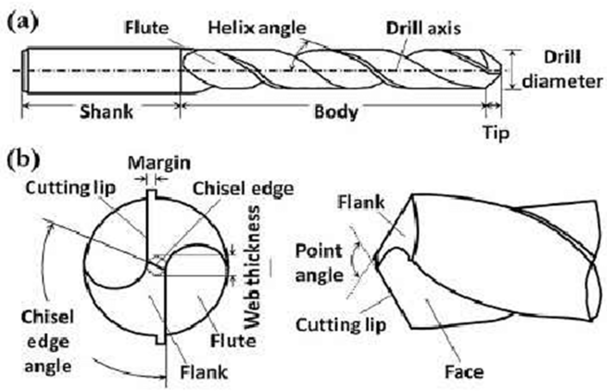

Figure 1: Drill bit anatomy.

B. Process Mapping

Raw material for drill bit is HSS heat-treated blanked is used. The blanked rod size has been used of 6.6 mm in diameter and 116 mm in length. Various machining operations are performed on blanked material by cnc machines to convert into finished product. initially rough centerless grinding has been used to up to its diameter to 6.37±0.2 mm. Then flute grinding is performed during which core diameter, land width, flute length and web taper operations are generated. Flute grinding is followed clearance grinding by margin grinding, margin length, clearance diameter and margin width are produced on drill bit. the drill bit is finished by centerless grinding by up to its diameter to 6.3535±0.05mm.

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Figure 2 represents the sequential flow of processes undergoing in industry for manufacturing of drill bits.

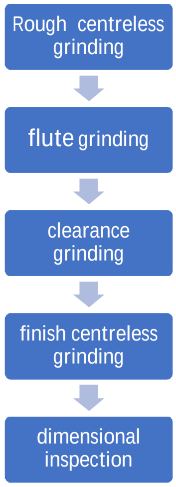

Figure 2: Process flow chart for drill bit manufacturing.

Figure 3 indicates the industrial machines arrangement on shop floor.

Figure 3: Machine arrangement on shop floor.

C. Measurement Phase

In this phase, measurement of critical parameter's size is carried out. Sample size of 30 drill bits is used. Drill bit diameter is measure by digital caliper and other critical parameters point angle, lip angle, web after notch and chip relief angle are measure on KETOTEK CT12000-D machine. This process is followed up to 4 iterations. In each iteration corrective actions for improving process capability are taken.

Figure 4 demonstrates the samples of 30 consecutive drill bits of size ¼ inch taken under study of process capability.

Figure 4: Drill bit samples.

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Figure 5 shows the digital Vernier caliper by which we measured the drill diameter of drill bits.

Figure 5: Digital caliper.

Figure 6 indicates the KETOTEK CT 12000 instrument by which we can measures our point angle, lip angle, chip breaker angle and web for notch.

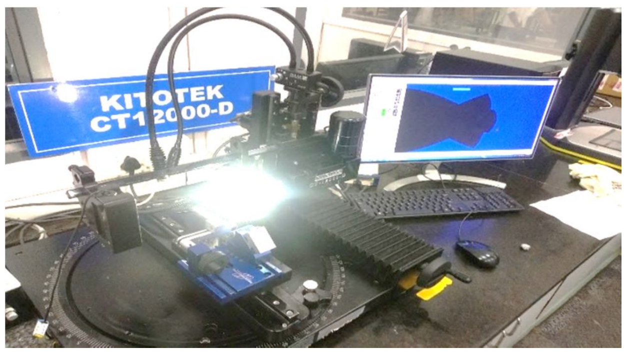

Figure 6: KETOTEK CT 12000

D. Cause & Effect Analysis

The process capability of critical parameters of drill bits in first iteration shows that process for drill diameter and lip angle is only capable and acceptable. But for point angle, chip breaker angle and web after notch are not capable. So, we found root causes for this with the help cause and effect diagram. Also differentiate common causes and special causes involved for lowering process capability. Main causes affecting process capability observed are improper dressing of grinding wheel and frequency of dressing of consecutive dressing, the loosening of screw of pallet head where raw material is fitted. Special cause such as sagging of belt of motor which is connected to grinding wheel is detected. We eliminated these causes and necessary actions are taken in four iterations so as to improve process capability.

Figure 7 represents the cause-effect diagram in which all the factors associated with process capability of drill bit. These factors are sub group in material, methods, machines and personal which shown fishbone like structure

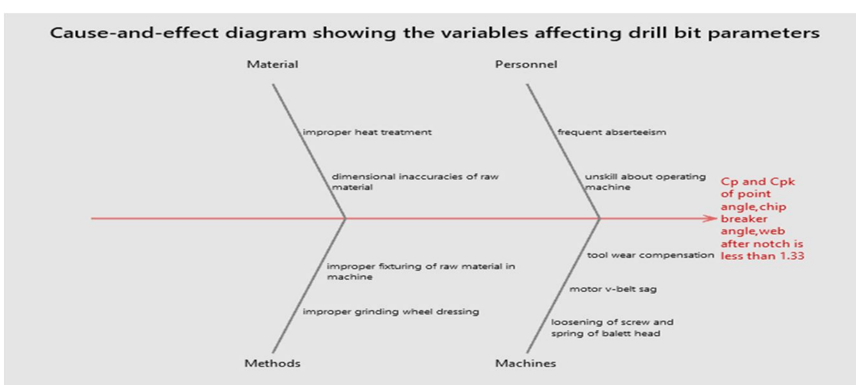

Figure 7: Cause-effect fishbone diagram.

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E. Data collection

For this analysis, Data has been collected in form of samples of finished drill bits. This data collection has been performed in four iterations in span of 6 weeks. Then this data has been arranged in tables for all four iterations. In this four sets of 30 samples of consecutive drill bits has been used.

Table 1 shows all the measure data for all 5 critical parameters of 30 samples taken for iteration 1 and the specification range for all that parameters. For next 3 iterations we only collect the measure data for parameters point angle, chip breaker angle and web after notch.

Sample No.	Drill Diameter (6.317 to 6.350)	Point angle (130 to 140)	Chip breaker angle (155 to 165)	web after notch (0.05 to 0.35)	Lip Angle (5 to 19)
1	6.337	132	165	0.33	13
2	6.335	130	158	0.37	14
3	6.333	131	165	0.34	14
4	6.334	132	165	0.32	13
5	6.338	137	161	0.35	13
6	6.330	137	165	0.25	13
7	6.336	138	162	0.25	15
8	6.340	137	160	0.40	14
9	6.332	137	165	0.28	14
10	6.330	130	161	0.31	13
11	6.340	133	162	0.30	14
12	6.329	133	162	0.24	14
13	6.332	136	160	0.31	15
14	6.340	132	161	0.24	13
15	6.342	131	160	0.23	13
16	6.338	134	165	0.24	16
17	6.341	134	164	0.16	12
18	6.335	132	163	0.37	13
19	6.340	136	164	0.22	13
20	6.338	136	164	0.30	11
21	6.340	135	158	0.37	13
22	6.335	132	164	0.26	10
23	6.333	132	160	0.29	14
24	6.336	132	165	0.35	14
25	6.332	138	160	0.32	12
26	6.331	131	165	0.43	14
27	6.332	133	163	0.33	13
28	6.331	133	164	0.26	13
29	6.338	133	163	0.35	12
30	6.334	132	163	0.31	13

Table 1. Data collection for iteration 1

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Table 2 shows measured data of point angle for 30 consecutive samples of drill bit for iteration 2, iteration 3 and iteration 4 respectively.

Sample No.	Point angle iteration 2	Point angle iteration 3	Point angle iteration 4
1	132	132	135
2	130	130	137
3	131	131	135
4	132	132	138
5	137	137	135
6	135	135	135
7	138	138	138
8	137	137	137
9	137	137	137
10	134	134	134
11	133	133	133
12	133	133	133
13	136	136	136
14	132	132	132
15	131	131	134
16	134	134	134
17	134	134	134
18	132	132	136
19	136	136	136
20	136	136	136
21	135	135	135
22	132	132	132
23	132	132	132
24	132	132	132
25	138	134	134
26	131	134	134
27	133	133	133
28	133	133	133
29	133	133	133
30	132	132	132

Table 2. Data collection for point angle

Table 3 shows measured data of chip breaker angle for 30 consecutive samples of drill bits for iteration 2, iteration 3, iteration 4 respectively.

Sample No.	Chip breaker angle iteration 2	Chip breaker angle iteration 3	Chip breaker angle iteration 4
1	160	160	158
2	162	159	163
3	163	161	161
4	165	160	160
5	161	161	161
6	162	162	164
7	162	162	162
8	163	160	160
9	164	162	162
10	160	161	161
11	162	160	160
12	158	162	162
13	161	160	160
14	161	161	161
15	159	160	160
16	165	162	162
17	160	162	162
18	158	162	162
19	164	159	159
20	160	164	159
21	163	158	158
22	164	164	157
23	164	160	160
24	165	159	159
25	160	160	160
26	165	160	160
27	165	163	161
28	164	161	161
29	163	163	159
30	165	159	159

Table 3. Data collection for chip breaker angle

Table 3 shows measured data of web after notch for 30 consecutive samples of drill bits for iteration 2, iteration 3, iteration 4 respectively.

Sample No.	Web after notch iteration 2	Web for notch iteration 3	Web after notch iteration 4
1	0.25	0.23	0.28
2	0.35	0.24	0.30
3	0.28	0.16	0.32
4	0.31	0.33	0.32
5	0.30	0.22	0.29
6	0.24	0.30	0.25
7	0.31	0.26	0.25
8	0.24	0.26	0.16
9	0.23	0.29	0.28
10	0.24	0.21	0.31
11	0.16	0.32	0.30
12	0.37	0.29	0.24
13	0.22	0.33	0.31
14	0.30	0.26	0.24
15	0.37	0.30	0.23
16	0.26	0.31	0.24
17	0.29	0.23	0.16
18	0.35	0.24	0.27
19	0.32	0.16	0.22
20	0.36	0.33	0.21
21	0.33	0.22	0.26
22	0.26	0.30	0.26
23	0.35	0.26	0.29
24	0.31	0.26	0.21
25	0.25	0.29	0.32
26	0.35	0.21	0.29
27	0.28	0.32	0.26
28	0.31	0.29	0.26
29	0.30	0.33	0.30
30	0.24	0.26	0.20

Table 4. Data collection for web after notch

F. Calculation of C_p & C_{pk}

Calculations of C_p and C_{pk} are calculated from the collected data in Minitab 19 software for each iteration and the for each parameter normal distribution over histogram is estimated.

1) *Iteration 1:* The first set of statistical process capability study of drill bit composed of raw data of critical parameters, which depicted transparent picture of the existing problems of manufacturing processes. hence it has been observed that first iteration process is capable for only two parameters, drill diameter (C_p 1.49, C_{pk} 1.32) and lip angle (C_p 2.12, C_{pk} 1.74). the other 3 parameters point angle (C_p 0.94, C_{pk} 0.68), chip breaker angle (C_p 0.65, C_{pk} 0.32) and web after notch (C_p 0.83, C_{pk} o.26) are not capable as both C_p and C_{pk} indices are below 1.33.

Figure 8 shows the histogram with normal distribution curve obtain for drill diameter in iteration 1. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution is very close i.e. tending mean specification of 6.335 (required for quality product). Process capability index C_p and C_{pk} are 1.49 and 1.32 respectively describes that the process is capable to produce accurate results.

Figure 9 shows the histogram with normal distribution curve for lip angle in iteration 1. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution is very close i.e. tending mean specification of 13.2667 (required for quality product). Process capability index C_p and C_{pk} are 2.12 and 1.74 respectively describes that the process is capable to produce accurate results.

Figure 10 shows the histogram with normal distribution curve for point angle in iteration 1. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings tending lower specification. Process capability index C_p and C_{pk} are 0.94 and 0.64 respectively describes that the process is not capable to produce accurate results.

Figure 11 shows the histogram with normal distribution curve for chip breaker angle in iteration 1. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings tending higher specification. Process capability index C_p and C_{pk} are 0.65 and 0.32 respectively describes that the process is highly not capable to produce accurate results.

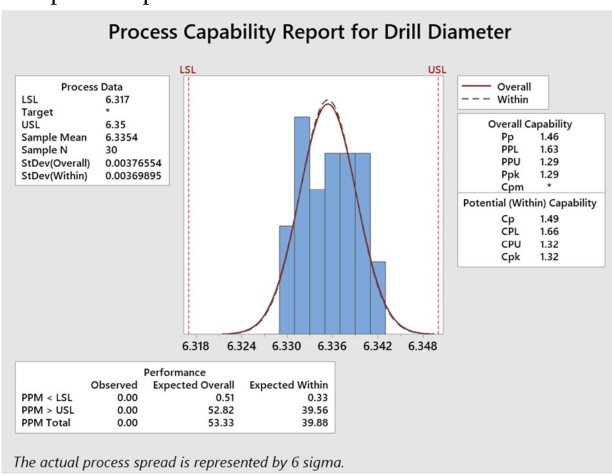

Figure 8: Histogram for drill diameter iteration 1.

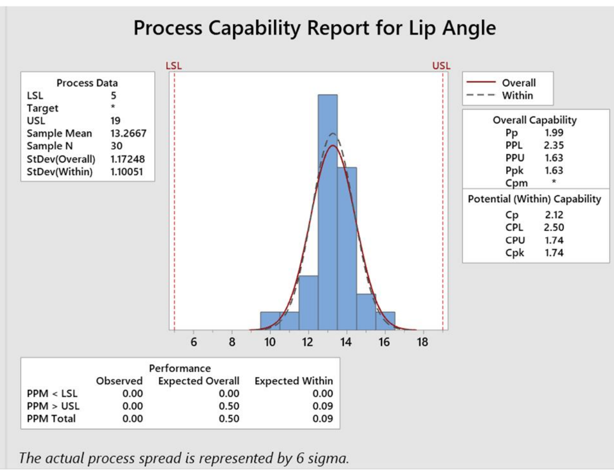

Figure 9: Histogram for lip angle iteration 1

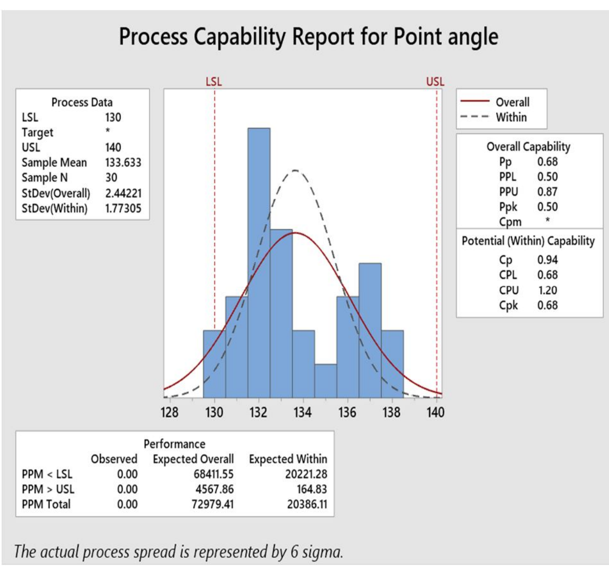

Figure 10: Histogram for point angle iteration 1

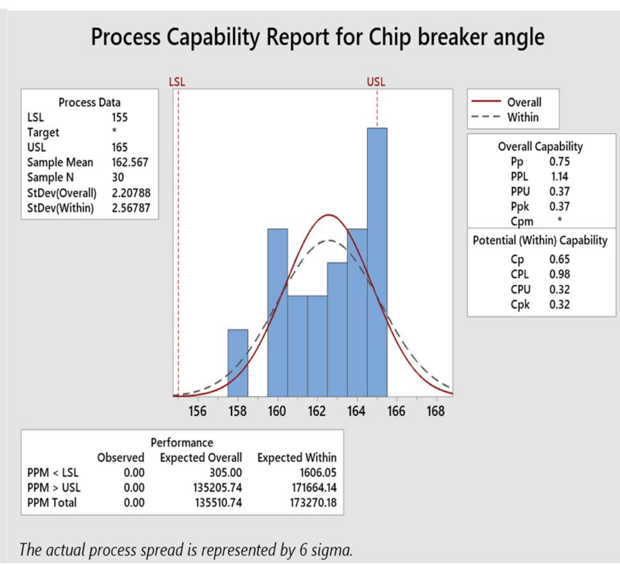

Figure 11: Histogram for chip breaker angle iteration 1

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Figure 12 shows the histogram with normal distribution curve for web after notch in iteration 1. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings tending higher specification and some readings crossed higher specification limit. Process capability index C_p and C_{pk} are 0.83 and 0.26 respectively describes that the process is not capable to produce accurate results.

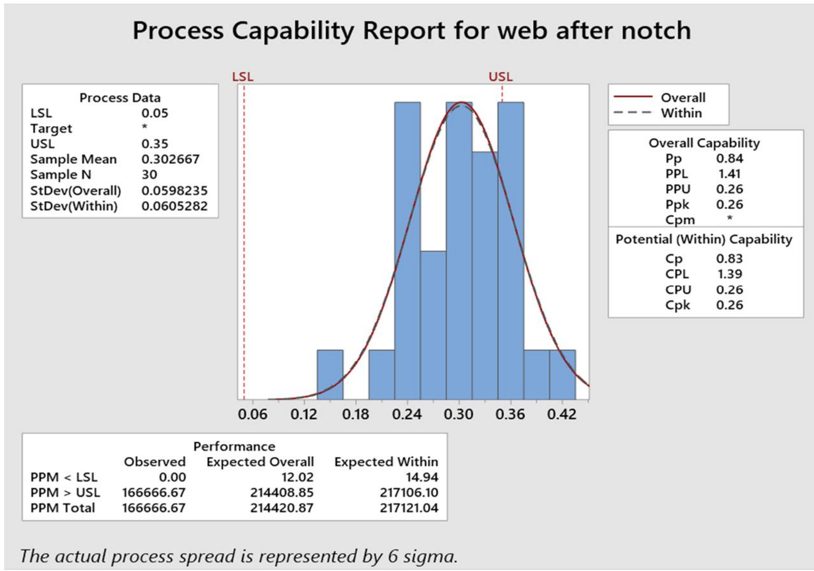
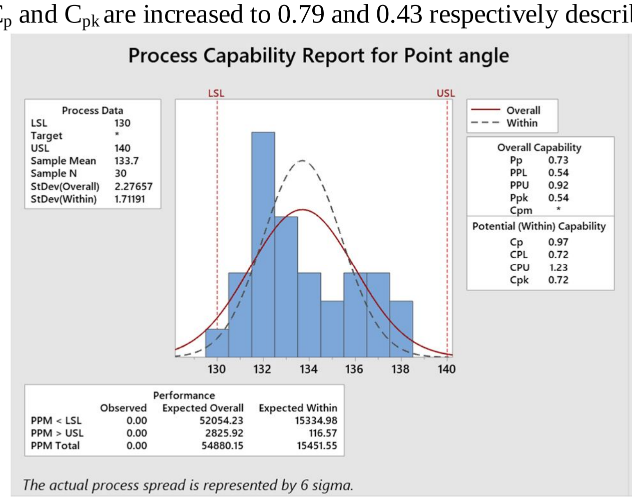


Figure 12: Histogram for web after notch iteration 1

2) *Iteration 2:* For first iteration grinding wheel dressing was done after 10 consecutive tools but in this iteration, it reduces to 9 consecutive tools. From set of data we get process capability for point angle (C_p 0.97, C_{pk} 0.72), chip breaker angle (C_p 0.79, C_{pk} 0.43), web for notch (C_p 0.94, C_{pk} 0.32). though this is still not capable as both C_p and C_{pk} are less than 1.33 for all 3 parameters but shows the positive sign in improving process capability

Figure 13 shows the histogram with normal distribution curve for point angle in iteration 2. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings tending lower specification though better distribution between specification limits as of iteration 1. Process capability index C_p and C_{pk} are increased to 0.97 and 0.72 respectively describes that the process is not capable to produce accurate results.

Figure 14 shows the histogram with normal distribution curve for chip breaker angle in iteration 2. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings tending higher specification though better distribution between specification limits as of iteration 1. Process capability index C_p and C_{pk} are increased to 0.79 and 0.43 respectively describes that the process is not capable to produce accurate results.



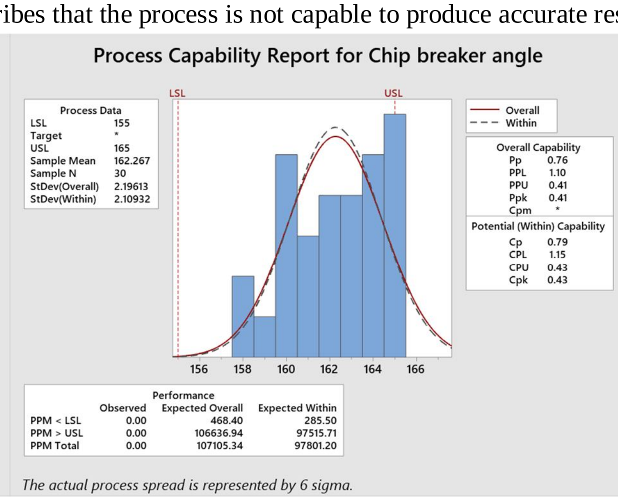


Figure 13: Histogram for point angle iteration 2

Figure 14: Histogram for chip breaker angle iteration 2

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Figure 15 shows the histogram with normal distribution curve obtain for web after notch in iteration 2. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings tending higher specification though better distribution between specification limits as of iteration 1 and also less readings on highest limit. Process capability index C_p and C_{pk} are increased to 0.94 and 0.32 respectively describes that the process is not capable to produce accurate results.

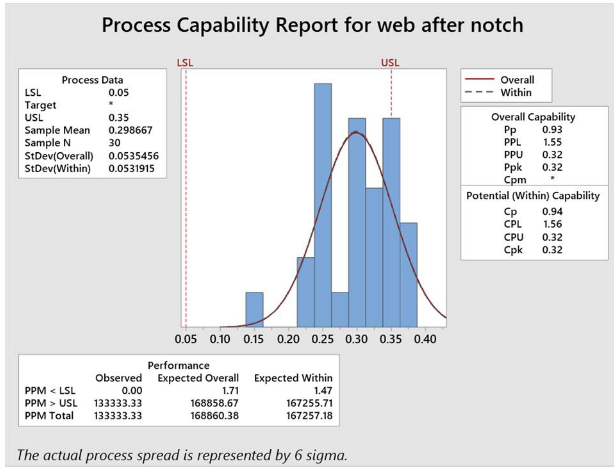
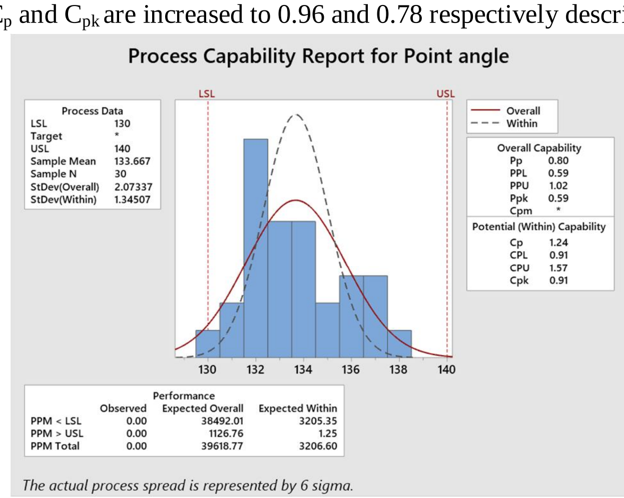


Figure 15: Histogram for web after notch iteration 2

3) *Iteration 3:* From iteration 2, it was found that successive increase in process capability by lowering grinding frequency from 10 to 9. In this iteration the grinding dressing frequency reduced up to 8 consecutive tools and also tightening the loose screw of ballet head after consecutive 20 tools, By this the process capability of point angle (C_p 1.24, C_{pk} 0.91), chip breaker angle (C_p 0.96, C_{pk} 0.78), web after notch (C_p 0.94, C_{pk} 0.48).so it resulted noticeable increase in process capability but still not capable as both C_p and C_{pk} are less than 1.33.

Figure 16 shows the histogram with normal distribution curve for point angle in iteration 3. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings shifts toward mean specification and better distribution between specification limits as of iteration 2. Process capability index C_p and C_{pk} are increased to 1.24 and 0.91 respectively describes that still the process is not capable to produce accurate results.

Figure 17 shows the histogram with normal distribution curve for chip breaker angle in iteration 3. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings shifts toward mean specification and better distribution between specification limits as of iteration 2. Process capability index C_p and C_{pk} are increased to 0.96 and 0.78 respectively describes that still the process is not capable to produce accurate results.



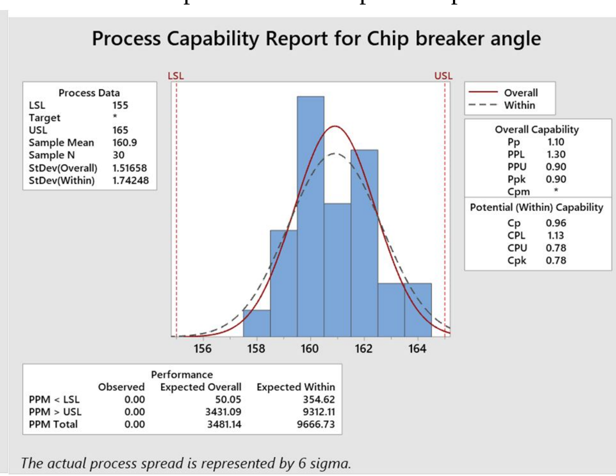


Figure 16: Histogram for point angle iteration 3

Figure 17: Histogram for chip breaker angle iteration

Figure 18 shows the histogram with normal distribution curve for web after notch in iteration 3. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings shifts toward mean specification and better distribution between specification limits as of iteration 2. Process capability index C_p and C_{pk} are increased to 1.09 and 0.48 respectively describes that still the process is not capable to produce accurate results.

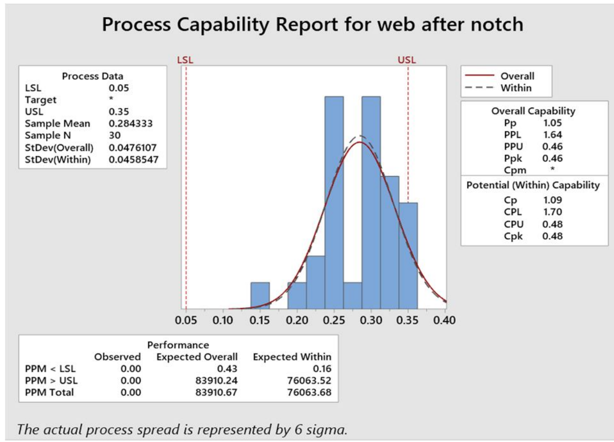
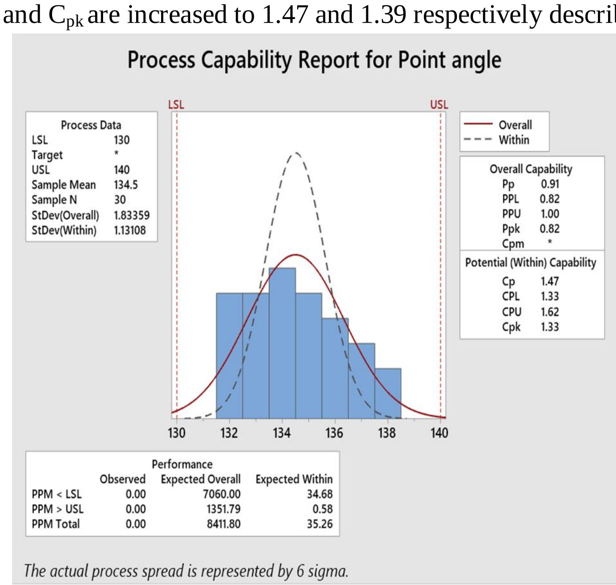


Figure 18: Histogram for web after notch iteration 3

4) *Iteration 4:* This iteration tackles with grinding wheel dressing frequency effect, with reducing dressing frequency process capability increases but it then increases grinding wheel wear out cost. in this iteration the frequency of grinding wheel dressing reduced to 7 consecutive tools and tightening of ballet head screw after 15 consecutive tools. If ballet head screw spring is broken, then it is being replaced with new one. This achieved process capability for point angle (C_p 1.47, C_{pk} 1.33), chip breaker angle (C_p 1.47, C_{pk} 1.39), web after notch (C_p 1.26, C_{pk} 0.75) which are acceptable values of process capabilities.

Figure 19 shows the histogram with normal distribution curve for point angle in iteration 4. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings shifts toward mean specification and better distribution between specification limits as of iteration 3. Process capability index C_p and C_{pk} are increased to 1.47 and 1.33 respectively describes that the process is capable to produce accurate results.

Figure 20 shows the histogram with normal distribution curve for chip breaker angle in iteration 4. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings shifts toward mean specification and better distribution between specification limits as of iteration 3. Process capability index C_p and C_{pk} are increased to 1.47 and 1.39 respectively describes that the process is capable to produce accurate results.



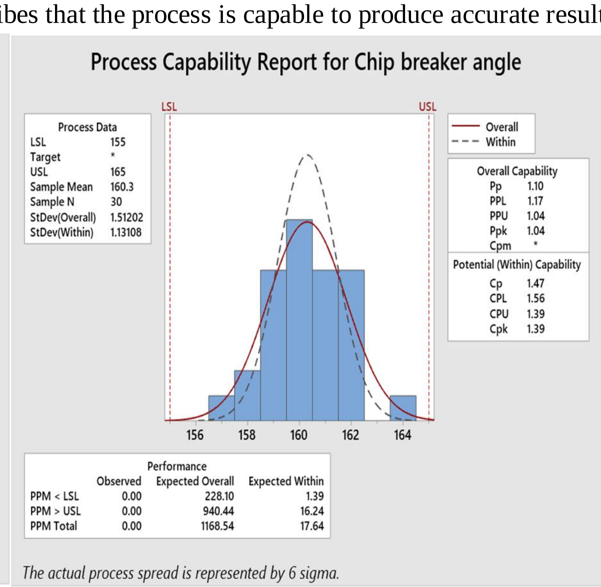


Figure 19: Histogram for point angle iteration 4

Figure20: Histogram for chip breaker angle iteration 3

Figure 21 shows the histogram with normal distribution curve obtain for web after notch in iteration 4. Experimental values of 30 samples are forming correlation shown in above graph. The normal distribution graph & histogram distribution graph shows that readings shifts toward mean specification and better distribution between specification limits as of iteration 3. Process capability index C_p and C_{pk} are increased to 1.26 and 0.75 respectively describes that still the process is not capable to produce accurate results. But we succeed in avoiding specimen to cross specification limits.

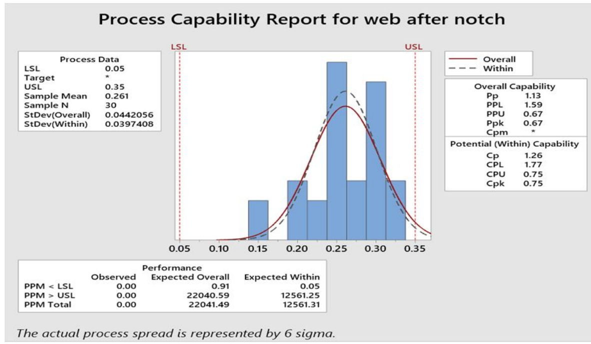


Figure 21: Histogram for web after notch iteration 4

IV. RESULTS AND DISCUSSION

A. After carrying out iteration 1, C_p and C_{pk} indices for drill diameter (C_p 1.49, C_{pk} 1.32) and lip angle (C_p 2.12, C_{pk} 1.74). the other 3 parameters point angle (C_p 0.94, C_{pk} 0.68), chip breaker angle (C_p 0.65, C_{pk} 0.32) and web after notch (C_p 0.83, C_{pk} o.26).

B. When is performed iteration 2, dressing frequency of grinding wheel has been reduced to 9. C_p and C_{pk} indices for non-capable parameters point angle (C_p 0.97, C_{pk} 0.72), chip breaker angle (C_p 0.79, C_{pk} 0.43), web for notch (C_p 0.94, C_{pk} 0.32). Still these parameters non-capable as Cp and Cpk values are less than 1.33.

C. Execution of iteration 3, dressing frequency of grinding wheel has been reduced to 8 and also with that the tightening of pallet head is done after consecutive 20 drill bits. This leads C_p and C_{pk} indices to point angle (C_p 1.24, C_{pk} 0.91), chip breaker angle (C_p 0.96, C_{pk} 0.78), web after notch (C_p 0.94, C_{pk} 0.48).

D. Iteration 4 gives dressing frequency of grinding wheel has been set to 7 and the tightening of pallet head is done after consecutive 15 drill bits. As this results in the values C_p and C_{pk} indices for point angle (C_p 1.47, C_{pk} 1.33), chip breaker angle (C_p 1.47, C_{pk} 1.39), web after notch (C_p 1.26, C_{pk} 0.75).

E. As corrective measures taken in successive iterations, when iteration 4 is performed parameter point angle and chip breaker angle converted into capable parameter. For parameter web after notch drill bits produced are between specification limit.

V. CONCLUSION

Process capability studies is one of statistical process control tool to be useful for eliminating the special causes of errors and making the process more capable manufacturing process by improving the C_p and C_{pk} values of the critical parameters under study. The cause-and-effect diagram formed for enlisting the causes behind occurrence of poor performance of the process.

In this study, four iterations have been done with different dressing frequency & pallet head screw tightening frequency. Iteration 1 performed with dressing frequency of 10 drill bits & found that the drill diameter and lip angle are capable and do not require to pay attention. Iteration 2 done with dressing frequency of 9 drill bits, it has been found that the capability index of point angle, chip angle and web after notch have been improved marginally. The pallet head screw need to be tighten with certain frequency as it is contributing to the results. Iteration 3 done with dressing frequency of 8 drill bits and pallet head screw tightening frequency with 20. Point angle, chip angle & web after notch in iteration 3 improved drastically. Iteration 4 done with dressing frequency of 7 and pallet head screw tightening frequency with 15. Process capability index of point angle & chip breaker angle found capable with C_p & C_{pk} of 1.33. Web after notch tending towards the C_p of 1.33 & needs no furture improvement.

VI. ACKNOWLEDGEMENT

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