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Application of Lean Six Sigma in Manufacturing of Precision Tools and Die: A Case Study

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Abstract

Tools and die represents small elements but are very important component of manufacturing system.One can say that these are the heart of manufacturing system.So consumers of tools and die always wish to use high quality of tools and die at low price .To fulfill this customers wish and demand tools and die manufacturer across the world are moving from old craft-mass production system to lean production. The LSS (lean six sigma) is a powerful tool and philosophy in manufacturing for production of high quality of products with minimum cost .The heat treatment is very important process in production of tools and die.Literature shows that 70% of the tools and die failure is because of heat treatment quality(hardness).The same problem were observed at a factory called TPU (Tool Production Unit) under the Ministry of Defense, Government of Nepal.So this study has been focused to improve heat treatment process and hardness quality.The standardization and optimization of hardening process and its parameters has been carried out using (VSM-DMAIC) approach of lean six sigma.The Standard Deviation,Process Capability and Process Capability Index of the Hardening process before standardization were 1.03,0.32 and (-0.34) and achieved 0.26,1.28 and 0.63 after standardization respectively.

Keywords

Lean Six Sigma, Value Stream Mapping, Quality Assurance and Management, Process Improvement, Precision Tools and Die

1. Introduction

1.1 Background

Tools and dies represents small elements but are the heart of manufacturing system [1].The low quality tools and dies have low durability and high failure rate which adds more cost for tooling in manufacturing and hence affect the performance of an organization[2].According to the research conducted at different part of world around 70 % of the tools and dies failure is because of the heat treatment quality (hardness)[1].Similar problem was observed at a factory called TPU (Tool Production Unit) under Ministry of Defense,Government of Nepal.At TPU the hardness of the products were not consistent and there is bending and distortions after heat treatment.So this research has been focused to improve heat treatment product quality and to optimize and standardize hardening process parameter which yields less hardening defects.The product quality can be enhanced by reducing the variability between the products and improving the process capability of the processes[3].

1.2 Lean Six Sigma

Lean Manufacturing or Lean Production is a systematic way of waste minimization in production practices without scarifying the productivity[4].Lean Manufacturing philosophy was driven by some core ideas such as customer value, elimination of non-value activities and wastage [5].The six sigma is the customer focused continuous improvement methodology that minimizes the defects and variation towards an achievement of 3.4 defects per million opportunities in product design, prototyping, production, administrative process and to other so many activities [6].The Lean Six Sigma combines the philosophies of “Lean Manufacturing” and “Six sigma” to reduce various kinds of wastage, reduce variations and improve quality of the products [7].The lean six sigma takes the advantages of both the lean and six sigma. Lean six sigma is a methodology that maximize the organization profitability by achieving fastest rate of improvement in customer satisfaction, cost, quality, process speed and invested capital [8].The combine effort Lean Six Sigma is required because lean cannot bring a process under statistical control, six sigma alone cannot dramatically improve process speed or reduce invested capital and both enable the reduction of cost of complexity [8].The methodological approach for lean six sigma implementation is given below figure[9].

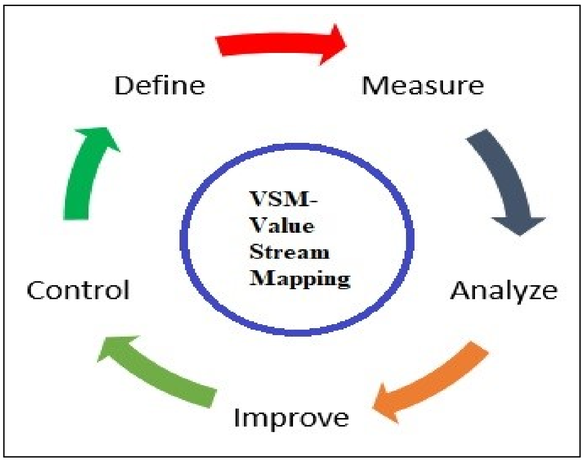

Figure 1: Lean Six Sigma Methodology

1.3 Research Methodology

The purposed research methodology for this research work is shown in below figure:

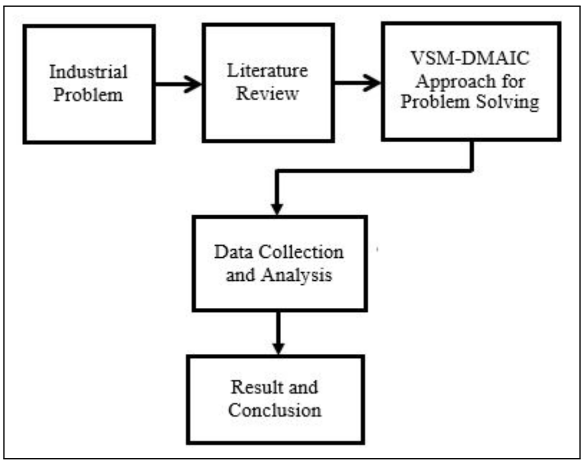

Figure 2: Research Methodology

2. Lean Six Sigma Project Execution

The VSM-DMAIC approach for problem solving has been used as methodology for lean six sigma project execution.The researcher[3][9] had used the same methodology for their researcher and there is significant improvement in many areas.

2.1 VSM (Value Stream Mapping)

Value stream mapping is a lean manufacturing tools which helps to clearly map the current status of the manufacturing process and to design new approach, which have less wastage(non-value adding activities) as compare to previous status [10]. The general production flow layout at TPU(Tool production Unit) is given below:

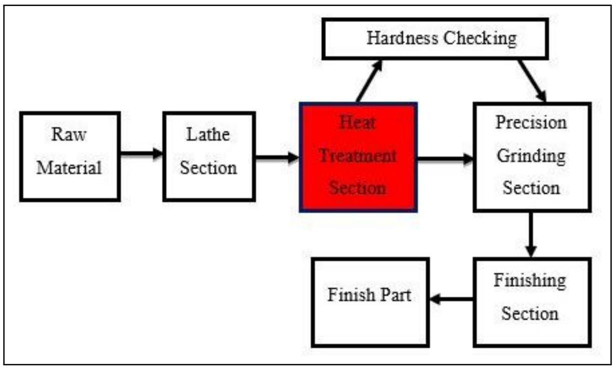

Figure 3: Production Flow Layout at TPU

At tool production unit there are currently 78 items of tools and die manufactured.This items are not always fixed, may be change with time.Among 78 items there are 47 items of precision type and 31 items are of non-precision type. The boundary to differentiate precision and non-precision item is precision accuracy. The precision items has a precision accuracy of less than or equal to 50 micrometer while non-precision item has a precision accuracy of greater than 50 micrometer.The precision item manufactured at TPU can be categories into six category. The product category and their variety can be seen in below figure:

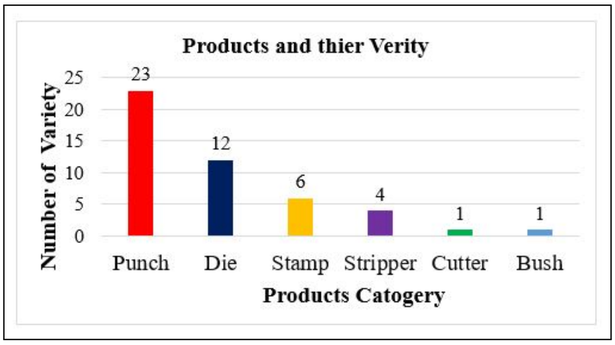

Figure 4: Product Category and their Variety

As per the product specification sheet, the quality defining parameters for the precision products are:

1. Geometric Dimensions and Tolerances(as per the product specification)
2. Hardness (as per the product specification)
3. Surface Finishing (as per the product specification)
4. Defect Free (such as cracks, bends, scratches etc.)

As reported by the senior production supervisors and customer there was problem at heat treatment section.The different heat treatment operations performed at TPU to the products are:

1. Stress Relieving
2. Hardening(Quenching)(Water and Oil Bath)
3. Annealing
4. Tempering
5. Normalizing

The quenching is compulsory for all the products and other heat treatment process are optional and depends upon the requirement.The hardening is performed to increase the hardness of the products.There is two major problems at heat treatment section specifically in hardening are:

1. In-Consistent Hardness (Variations in Hardness)
2. Bending and Distortion during hardening

These problems collectively can be termed as Hardening or Quenching Defects.To quantify the problem the hardness of the 10 lots,5 samples from each lot has been checked which is given in below table number 1. The X-bar and R-bar control charts for this data is shown in below figure number 5 and 6 respectively.

Table 1: Sample Hardness(in HRC) Data from Hardening Section

S.N.	X1	X2	X3	X4	X5	X-bar	Range
1	66	62	63	66	64	64.20	4
2	59	63	63	65	64	62.80	6
3	60	64	63	64	64	63.00	4
4	59	65	63	62	63	62.40	6
5	60	59	64	60	66	61.80	7
6	63	62	60	62	59	61.20	4
7	66	64	65	61	66	64.40	5
8	63	65	62	63	66	63.80	4
9	65	60	64	66	63	63.60	6
10	58	66	66	64	63	63.40	8

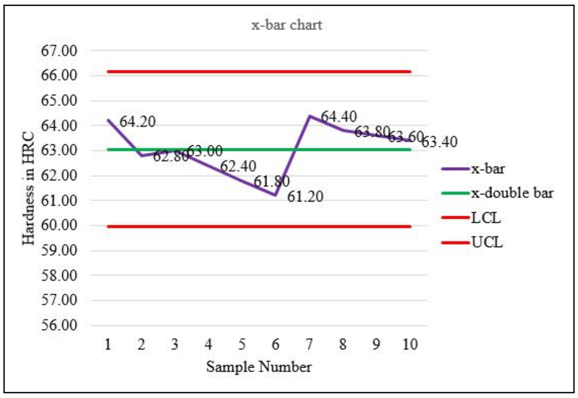

Figure 5: X-bar Control Chart before Standardization

X-bar control chart shows that the process is under the control as all the data are within the specified limit, but the values are not aligned to the mean line so it needs to be improved.

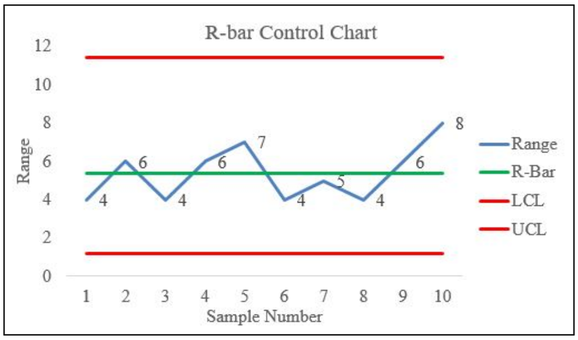

Figure 6: R-bar Control Chart before Standardization

R-bar control chart also shows that the process is under control but the values are not aligned to the mean line, there is large variations so this also needs to be improved.

2.2 Define

To clearly visualize the problem and accordingly to take the corrective actions the problem needs to be define.From the value stream mapping the problem has been clearly defined as:

- The hardness of the products as seen in table number 1 is not consistent so this needs to be improved.i.e.The hardness quality needs to be improved.
- There is hardening defects so to minimize hardening defects the hardening process and its parameter needs to be optimize and standardize.

Keeping in mind above two stated and clearly defined goals various activities has been carried out.

2.3 Measure

The hardness of the few products were measured. The measured data has been tabulated in table number 1.If we calculate the standard deviation of this data it will be 1.033 process capability will be 0.32 which is less than one so process is not capable and also process capability index Cpk will be (-0.34) which is negative this also indicates that process is not capable.The specification limits is (60-62) HRC.
The formula for calculating Standard deviation is given below[11].

$$S = \left[\sum_{i=1}^{n} (X_i - \bar{X})^2 / \left(n-1\right)\right]^{1/2}$$

The formula for calculating process capability Cp and process capability index Cpk is given below[12]:

$$C_p = \frac{USL-LSL}{6*\sigma}$$
$$C_{pk} = minimum\left[\frac{USL-Mean}{3*\sigma}, \frac{Mean-LSL}{3*\sigma}\right]$$
$$C_p = Process\ Capability$$
$$C_{pk} = Process\ Capability\ Index$$
$$USL = Upper\ Specification\ Limit$$
$$LSL = Lower\ Specification\ Limit$$

2.4 Analyze

The root cause analysis has been carried out, which is shown in below figure:

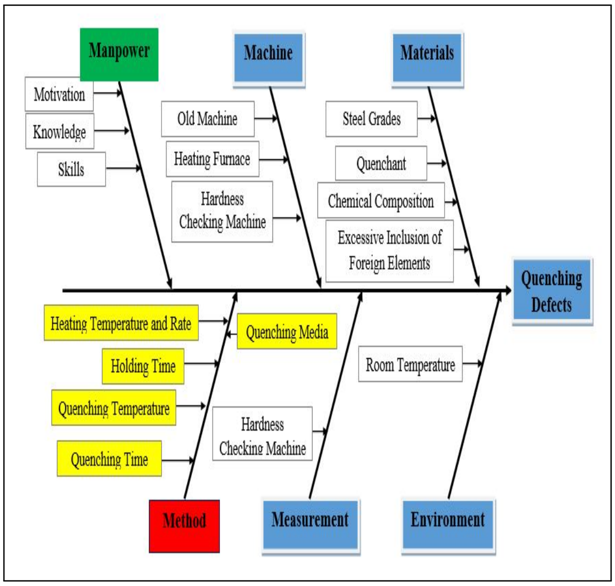

Figure 7: Ishikawa Diagram for Quenching Defects

The major cause are concern to the method of heat treatment which is shown in above cause and effect diagram so this need to be improve.
The current process parameter for hardening are:

- Heating Temperature: 900 degree centigrade
- Holding time: Not Fixed
- Quenching duration: Not Fixed
- Quenchant:Oil and Water
- Quenchant Temperature: Ambient Temperature

The heating temperature here is taken based on hit and trial method and other parameter like holding time, quenching duration are based on operator opinion and are not fixed. According to [13][14] the hardening process parameter have a direct impact on hardening defects so to minimize hardening defects the hardening method and its process parameters needs to optimize and standardize.

2.5 Improve

To improve hardening process first the materials to be heat treated must be well known. The material(Steel Grade) used for all precision product is 100Cr6. The chemical composition of 100Cr6 grade has been checked using digital metal analyzer and the result found as tabulated below number 2.From the table the content of carbon in 100Cr6 is 1.050% which is also confirm by the literature[15].

Table 2: Chemical composition of 100Cr6 steel in percentage by weight

Fe	C	Si	Mn	Co	Cr
96.400	1.050	0.230	0.346	0.006	1.460
Mo	Ni	V	W	P	S
0.089	0.039	0.006	0.025	0.021	0.035

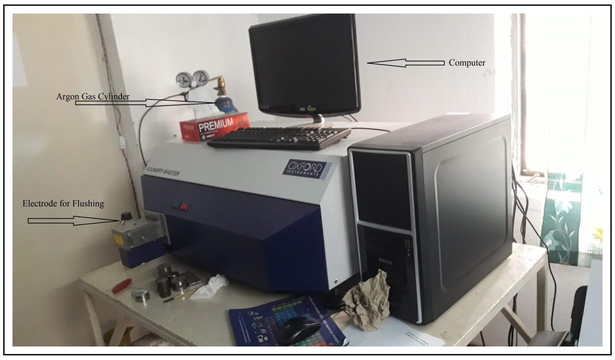

Figure 8: Digital Metal Analyzer(Spectrometer)

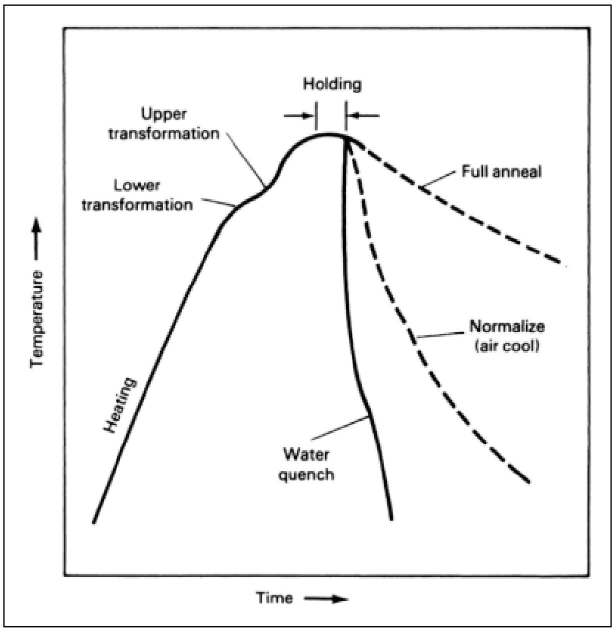

Figure 9: Heat Treatment(Hardening) Process

The different process parameters for the hardening operations which needs to be optimize and standardize are:

- Heating Temperature and Rate
- Holding Time
- Quenching Time(duration)
- Quenching Media
- Quenching Temperature

To have less quenching defects the quenching process parameter must be optimized and standardized to as below[13]:

- Lowest Heating Temperature (Austenitizing Temperature)
- Lowest Holding Time
- Lowest Quenching Time(duration)

The lower critical temperature for 100Cr6 Steel is 750 degree centigrade and the upper critical temperature is 790 degree centigrade[16]. In hardening the material is heated to its above critical temperature(austenitizing temperature),hold at this for certain duration of time then rapid cooling (quenching) near to martensite transformation temperature to form martensite micro structure.The general curve heating and cooling cycle is given in below figure number 9.

2.5.1 Optimization of Heating Temperature and Heating Rate

At TPU heating furnace has constant heat output rate so heating rate cannot be optimize with current furnace.Only heating temperature can be optimized.To optimize heating temperature the sample were prepared for experiment.The diameter of sample is 18 mm and length approximately 30 mm.Based on the general thumb he approximate holding time per inch diameter is 30 minute[17] so for 18 mm diameter approximately 20 minute were taken.

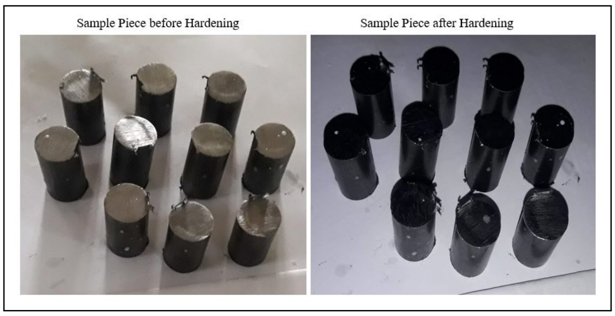

Figure 10: Samples of 100Cr6 for Experiment

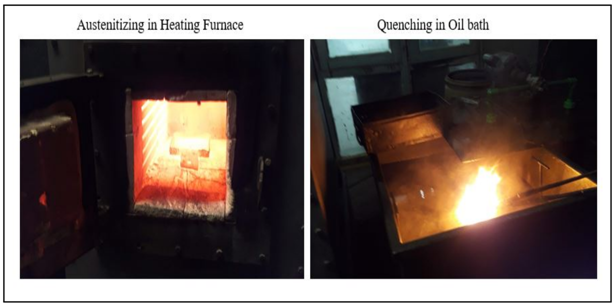

Figure 11: Heating and Quenching of Samples

Number of Experiment were conducted at different heating temperatures. The result obtained is shown in below chart(figure number 12).

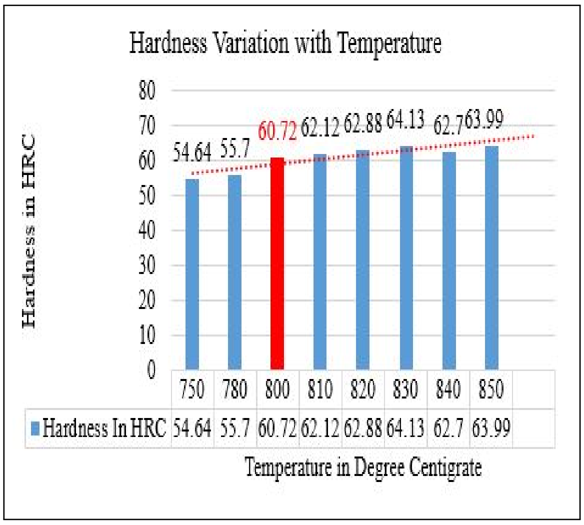

Figure 12: Hardness Variation with Heating Temperature

From the above chart the hardness increases as the temperature increase. As per the product specification sheet the required hardness is (60-62) HRC which best obtained at minimum heating temperature that is at 800 degree centigrade and this temperature is above the upper critical temperature of material so it can be taken as standardized temperature.

2.5.2 Optimizing the holding Time

To have less hardening defects it is always preferred to have low holding time [17]. So number of experiments has been conducted to optimize holding time. The hardness variations with holding time has been shown in chart (figure number 13).

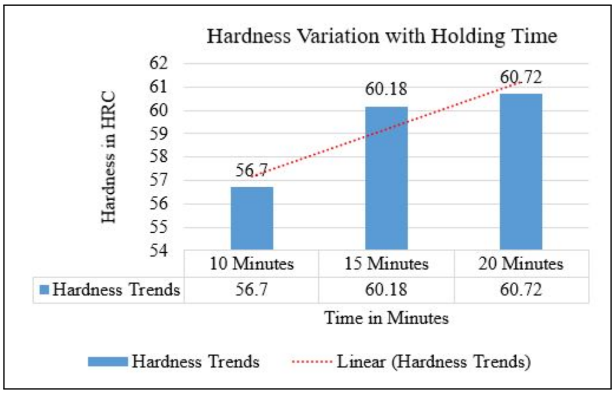

Figure 13: Hardness Variation with Holding Time at Constant Temperature

The minimum holding time at which the best result obtained is (15-20) minutes so this is taken as standardized and optimized holding time.Here the interval of time is preferred because the operator may not always strict to exact timing.

2.5.3 Quenching Media

The quenching media here used is oil bath and water.The rate of heat drop during quenching in water is more than oil bath because of this reason when the water has been used as quenching then it will have more hardening defects[17]. So oil bath has been preferred for quenching of all the parts except internal quenching.

2.5.4 Quenching Duration

The quenching duration have direct impact on hardness obtained.To optimize this number of experiment has been conducted at different quenching duration which is shown below chart(figure number 14).

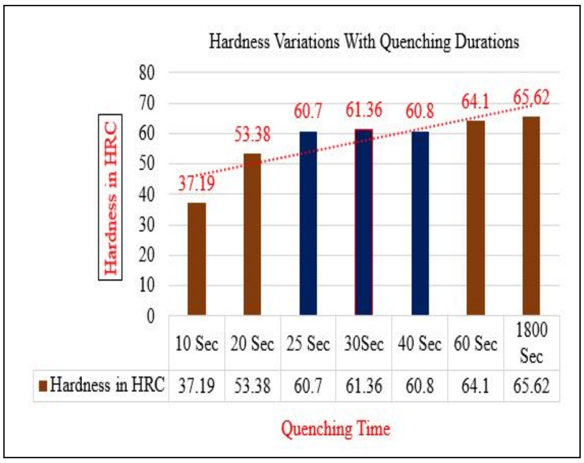

Figure 14: Hardness Variation with Quenching Time(Oil Bath at Room Temperature)

With increase in quenching duration hardness increases.In above figure the best minimum quenching duration at which we have best result is (25-40) second. So this has been taken as standardized and optimized quenching duration.

2.5.5 Testing on New Process Parameter

Based on new process parameter number of experiments has been conducted, the result is tabulated in table number 3. The standard deviation from the mean of the data in table 3 is 0.26, process capability Cp is 1.28 and process capability index Cpk is 0.63 by taking USL and LSL (60-62)HRC.

Table 3: Hardness after Standardization

S.N.	X1	X2	X3	X4	X5	Ave.	Range
1	61.7	61.1	61.2	61.3	61.5	61.4	0.6
2	61.6	62.0	61.3	61.5	61.4	61.6	0.7
3	61.1	61.2	61.7	61.9	61.6	61.5	0.8
4	61.8	61.1	61.2	60.9	61.0	61.2	0.9
5	61.8	62.0	62.1	61.7	61.9	61.9	0.4

- Initially the standard deviation was 1.03, now it is 0.26.The standard deviation has been decreased by 74.76 %.
- Initially the process capability was 0.32 but now it is 1.28 this has been improved by 300 %
- Initially the process capability index was (-0.34) but now it is 0.63 the process capability index has been improved by 285.29 %.

2.6 Control

The new process parameter has been adapted. Based on new process parameter the number of experiments has been conducted and the result is tabulated in table 3.The control charts based on the new parameters has been given below.

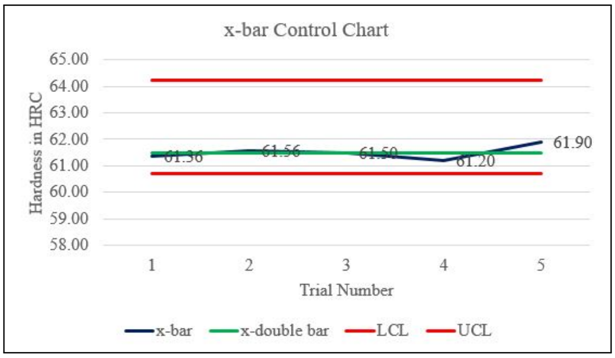

Figure 15: X-bar Control Chart after Standardization

In above X-control chart all the values are within the limit and very precisely coincides with the mean line so the process is under control.

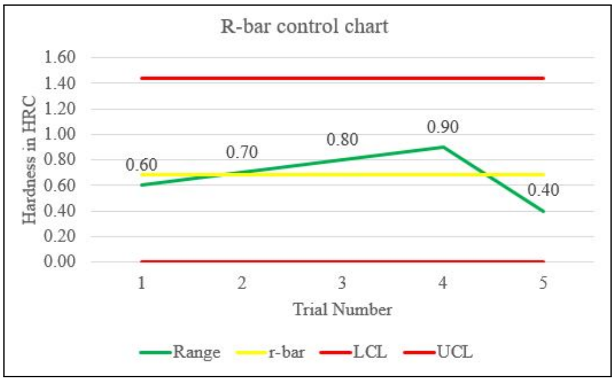

Figure 16: R-bar Control Chart after Standardization

From above R-bar control chart all the values are within the specified limit and hence the process is under the control.

3. Result and Conclusion

3.1 Result

After this study the new process parameter of the hardening process has been developed which is given below

- Heating Temperature: 800 Degree Centigrade
- Holding Time: (15-20) Minutes for All items less than 20 Diameter
- Quenching Duration: (25-40) Second
- Quenching Media: Oil bath at room temperature and water for internal quenching

3.2 Conclusion

The process has been standardized and new process parameter has been adapted.On new process parameter the product hardness is withing the specified limit so the hardness quality of the product is assured.

The similar work has been carried out [3] [18] there is significant reduction in standard deviation and improvement in process capability index.In the research [3] the standard deviation is decreased by 22.12% from 2.17 to 1.69 and the process capability index was improved by 78.78% from 1.65 to 2.95 and in [18] the standard deviation is decreased by 91.45% from 0.069 to 0.0059 and process capability index improved by 1075% from 0.12 to 1.41. So this study also relates with the previous similar kinds of work performed by different researcher.

3.3 Recommendation and Future Work

The following recommendation has been given from this work.

- The standardization and optimization of the hardening process has been carried out using experimental approach only.To have more accurate and reliable result the simulation and mathematical modeling approach may be used as further future research work.
- This work have not focused on the economic benefits that the organization would gain after applying lean six sigma so further research may be carry out to investigate the economic benefits that the organization may gain.
- This work have not included the change in product durability after improving the quality of the products so further research may be carry out to investigate the impact on the durability of tools and die after improving quality using lean six sigma.

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