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Productivity Improvement Through Cycle Time Reduction In A Gear Manufacturing Industry

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Abstract: In this work, Statistical process control (SPC) and Design of experiments (DOE) was used to reduce the cycle time of gear hobbing process. The roller lever shaft and gear shaft occupies about 35% production capacity of gear hobbing machine in a month. Statistical Process Control (SPC) analysis was done to identify how the process is performing against its specification limit. In order to increase the production without compromising the quality, the process parameters is should be enhanced to improve the quality. In this process, Hob tool, Feed rate, RPM and Hob material were considered as the most influencing input parameters. Cycle time was considered as a response variable. For experimentation Hob tool, Feed rate and RPM are used to found the best process parameter to get optimized cycle time. And finally it is observed that the feed rate is the dominating parameter to reduce the cycle time. The optimal parameter leads to decrease in processing time of gear hobbing in roller lever shaft by 26.29%.

Keywords: Time study, Value Stream mapping, Measurement System Analysis, Process Capability analysis, Design of Experiments.

1. INTRODUCTION

In today's growing world, the manufacturing companies are in a situation to improve their production quality. For that machining parameters plays a vital role to avoid the loss and also to reduce the cycle time [5]. So DOE analysis is used to manipulate most appropriate parameters. In order to perform DOE analysis, the stability of the process is very important criteria [1]. Control chart is a valid to tool to find weather the process is stable or instable. And also Process capability analysis is used to determine how a given process meets the specification limits [4]. In other words, it measures how well the process works. The amount of variation contributed by the measurement system is necessary for performing process capability analysis for that Measurement System analysis is used [7].

MSA is a straightforward way to assess the conformity of the measurement system and to minimize factors that contribute to the analysis of the actual differences arising from the measurement system. The primary purpose of the MSA is to verify the measurement system used to collect data before moving on to the analysis and performing mathematics tests [2]. Within this analysis, you will measure both the variability of the Process and the Appraiser (device) to detect variations of the Comprehensive System.

Capability analysis is used to compare the distribution of sample values to specification limits. One basic measure of process capability is a measure of values that fall within (or outside) the specification limits. Another one is the average values will fall within (or outside) the specification limits if the data is assumed to be normal distribution [2].

The design of Experiments (DOE) is defined as a branch of applied statistics relating to the planning, conduct, analysis and interpretation of controlled trials to assess items that control the value of a parameter or group of parameters. The DOE is a powerful data collection and analysis tool that can be used in a variety of testing situations. Allows multiple input items, determining their effect on the output you want (response) [3]. By using multiple inputs at the same time, the DOE can identify important combinations that can be missed when trying one feature at a time. All possible combinations can be investigated (full factorial) or part of a possible combination (fractional factorial) [8].

PROBLEM DEFINITION

In Gear manufacturing Industry, the time taken by the components Gear Shaft and Roller Lever shaft to finish its gear hobbing process is 70.52 minutes. These two components occupies about 35% production capacity of that particular machine in a month. So it affects the customer delivery requirements and also the internal capacity of the machine. And also the gear hobbing process does not provide sufficient stability with respect to keeping the parts produced within the tolerance range. When the Gear hobbing machine is operational, the dimensions is either within the tolerance range or is moved according to the tolerance limits. The problem also occurs when the machine tool is stopped (unexpected stop, cleaning, lunch break), and as a result it has cooled. After the restart of the machine tool, the dimensions deviates significantly; therefore the parts produced are not acceptable. This results in a loss of time and cost. There is therefore a need to reduce the cycle time and select the best mechanical parameters.

2. METHODOLOGY

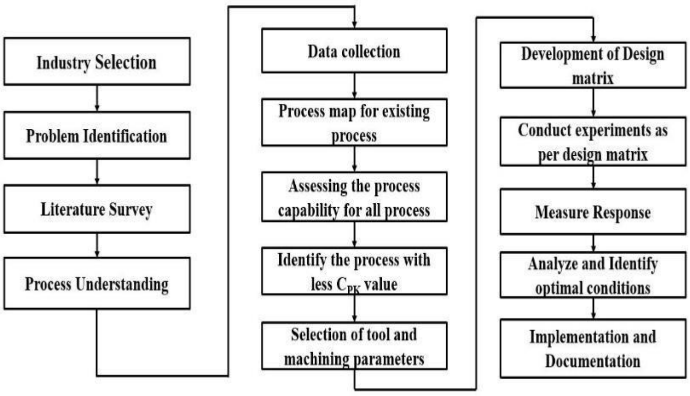


Fig 1. Methodology

DATA COLLECTION

In order to know the initial cycle time for gear shaft and roller lever shaft. The time study for both the components was performed. For performing time study all processing time including their material handling time, product removal and tool setting for all the process is collected and tabulated. In order to perform process capability analysis, measurement system analysis to be performed too check the measuring system. For performing MSA, 10 parts data are measured by 3 operators with 3 trials are observed and tabulated. For performing process capability analysis, the upper specification limit and lower specification limit for each process is collected and tabulated. And also the 30 sample data with 4 observations for each process is collected and tabulated. For performing DOE analysis, the various levels corresponding to the gear hobbing of roller lever shaft was collected. For various combination of levels their responses are collected and tabulated.

TIME STUDY

Time study is a systematic process of directly monitoring and evaluating a person's work using a time tool to determine the time required to complete a task is a suitable task when working at a specified level of performance. It follows the basic procedure for systematic evaluation of work for:

- Job analysis into smaller elements that can be easily measured
- Measurement of these components as well
- Synthesis from those measured components to arrive at the time of complete work.

Several sets of readings are taken to achieve the correct result. This obtained average is multiplied by a rating factor also called the 'Rating Factor', which is generally considered to be 90-120% to determine the time required by the normal employee. Average time multiplication is the so-called “Normal Time”. Other allowances such as a personal allowances (20%), a fatigue allowances (5%), a preparation allowances (5%) are added at regular intervals to get standard time. Standard time is the basis for salary calculations and incentives.

The time study for each and every process is done with its Tool setting, material handling time, Processing time, Product removal, Inspection and Cleaning. The time study data for Gear hobbing of Gear shaft is shown below:

Table 1. Normal time of gear hobbing process

Task name	**Observed time(sec)**				**Normal time (sec)**
	1	***2***	***3***	***4***	
Tool setting	2832	2840	2845	2827	2836.0
Material handling	55	54.8	55	55.2	55.0
Processing time	840	840	840	840	840.0
Product removal	65	65.8	64.9	65	65.2
Inspection	9	9.2	9.5	8.9	9.2
Cleaning	16	16.8	15.9	15	15.9

After obtaining Normal time, its rating and allowances are added to get a standard time. The allowances used are:

- Relaxation allowance = 4%
- Contingency allowances = 6%
- Personal allowances = 5%
- Special allowances = 9%

The rating factor for each element of process is given based on the type of work (automated or manually controlled). After incorporating rating and allowances. The standard time for the process is calculated. The standard time for the process is:

Table 2. Standard time of gear hobbing process

Task	**Rating**	**Limit**	**Basic time (sec)**	**Standard time (sec)**
1	85	680.64	2410.6	3091.24
2	90	13.2	49.50	62.70
3	100	201.6	840.00	1041.60
4	90	15.642	58.66	74.30
5	85	2.196	7.78	9.97
6	85	3.822	13.54	17.36

The standard time for every process of gear shaft and roller lever shaft is calculated as like above procedure. The standard time obtained for the every process of gear shaft is shown below:

Table 3. Standard time obtained for gear shaft

Gear shaft			
Process	***Set time (min)***	***Run time (min)***	***Cycle time (min)***
Sawing	7.01	12.66	19.67
Quenching	0	159.42	159.42
Turning 1	95.54	23.64	119.18
Turning 2	95.67	20.95	116.62
Gear cutting	51.52	20.1	71.62
Gear deburring	11.93	1.17	14.05
Drilling & tapping	29.73	7.85	37.58
Cylindrical grinding	16.1	20.41	36.51
Zinc phosphating	0	72.23	72.23
Engraving	9.255	0.855	10.11
Move to inventory	0	2.1	2.1
Final inspection	0	1.38	1.38
F G stock receipt	0	0.55	0.55

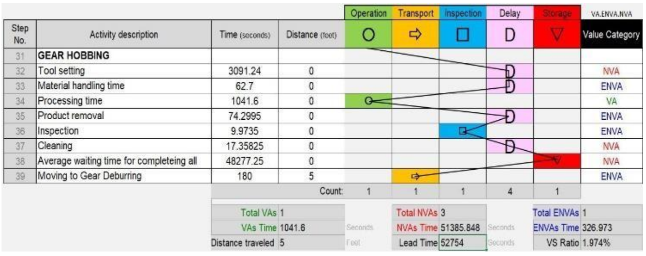
The standard time for all process of roller lever shaft is also tabulated.

PROCESS CHART FOR PROCESS MAPPING

In order to understand the flow of process in an industry, process chart is very useful. Through which we can calculate value added, Non-value added and essential value added time. Value Added activities must meet the following three criteria: Work that the customer is willing to pay for, Work that converts product and Work that is done for the first time. Non Value-added activities include work that consuming resources, but not added value to a product or service. Necessary Non Value added activities are too complex to identify. These are activities that do not add value to a product or service, but are currently required.

In order to differentiate time between value added, Non value added and Essential non value added activities, Process flow chart is used. Through which Total value added time, Total value added activities, Total essential non value added activities, Non value added time, Essential non value added time, Lead time, Distance travelled and Value added ratio are calculated.

The process flow chart for gear hobbing process of gear shaft along with value added, Non value added and essential non value added time are shown below:



Step No.	Activity description	Time (seconds)	Distance (feet)	Operation ○	Transport ⇨	Inspection □	Delay D	Storage ▽	VA.ENVA.NVA Value Category
31	**GEAR HOBBING**								
32	Tool setting	3091.24	0				D		NVA
33	Material handling time	62.7	0				D		ENVA
34	Processing time	1041.6	0	○					VA
35	Product removal	74.2995	0				D		ENVA
36	Inspection	9.9735	0			□			ENVA
37	Cleaning	17.35825	0				D		NVA
38	Average waiting time for completeing all	48277.25	0					▽	NVA
39	Moving to Gear Deburring	180	5		⇨				ENVA
			Count:	1	1	1	4	1	

Total VAs 1
VAs Time 1041.6 Seconds
Distance traveled 5 Feet
Total NVAs 3
NVAs Time 51385.848 Seconds
Lead Time 52754 Seconds
Total ENVAs 1
ENVAs Time 326.973
VS Ratio 1.974%

Fig.9. Process flow chart for Gear hobbing of gear shaft

Likewise, VA, NVA, ENVA activities for all the process of gear shaft and roller lever shaft is calculated. Process chart observations for the gear shaft is shown below:

Table 4. Process chart observations for gear shaft

Process chart observations for gear shaft				
Operation	**VA time**	**NVA time**	**ENVA time**	**VAS ratio**
Sawing	11.79	510.01	10.8	2.21
Quenching	147.4	0	24.87	85.54
Turning 1	21.7	1036.79	1.64	2.05
Turning 2	19.1	598.95	1357	3.02
Gear hobbing	17.36	856.43	5.45	1.94
Gear deburring	1.5	98.13	4.69	1.44
Drilling	5.58	349.37	17.27	1.49
Cylindrical grinding	19.27	858.96	15.22	2.16
Zinc phosphating	57.04	0	19.18	74.83
Engraving	0.29	9.255	0.45	2.945

After finding the Non value added and essential non value time for each process it is tabulated for both gear shaft and roller lever shaft. In order to reduce the non-value added and essential non-value added activity time the line improvements that can be made is tabulated. The concern and action plan suggested for the gear hobbing process of gear shaft is shown below:

Table 5. Concern and action plan for gear hobbing

Concern	**Action plan**
Run out occur due to tool wear	Periodic check of run out with Dial gauge
Wait time for reloading is high	Automate it
Waiting for air gun to cleaning	Provide separate air gun for each machine
Manual removal of work piece from the machine	Provide semi-automatic material handling system to eliminate it

VALUE STREAM MAPPING

Value stream mapping (VSM) is defined as a lean tool that uses a flow chart that records all the steps in this process. Many lean experts see VSM as a tool for identifying waste, reducing process cycle times, and improving process. It is used to analyse the current state and to design the future of a series of events that take a product or service from the beginning of a process to reach customers. VSM is a visual tool that shows all the hypercritical steps in a particular process and easily calculate the time and volume taken in each step. Value streaming maps show the flow of both information and information as the process progresses in a forward and reverse direction. The flow chart obtained to find the cycle time of gear shaft is shown below:

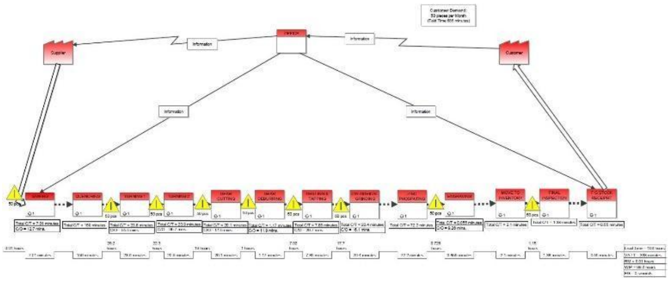


Fig.2. VSM for Gear shaft

Here Value stream mapping is mostly used to find the cycle time of the gear shaft and roller lever shaft. And also VSM is used to find the Value Added Time, Work in progress and Takt time of Gear shaft and Roller lever shaft. The Value Added Time, Work in progress and Takt time obtained for both gear shaft and roller lever shaft is shown below:

Table 6. VSM results

VSM Results		
Parameters	***Gear shaft***	***Roller lever shaft***
Cycle time	106 hours	205 hours
Value added time	338 minutes	349 minutes
Work in progress	99.6 hours	200 hours
Takt time	686 minutes	386 minutes

AN OVERVIEW OF THE CURRENT STATE OF THE PRODUCTION PROCESS

An overview of the current situation is important step that gives us feedback on the quality of production process. In our case the production process they contain the processing and measurement process. If we recognize that the quality of the components produced is not sufficient provinces, the production process consists of:

1. Part is acceptable, but moderate the system does not show a direct result, so the product is received as unacceptable.
2. The machining process is not enough, which is results in unacceptable product.

Therefore, the process of measuring and operating the equipment should be updated to determine the current status of production process.

The measurement process is analysed using Measurement System Analysis (MSA), while SPC (Statistical Process Control) and DOE (Design for experiment) are used to check the machining process.

MEASUREMENT SYSTEM ANALYSIS

The MSA is defined as an experimental and mathematical method to work out the quantity of variance that exists within the measurement process. Variation of the measurement process can directly contribute to our entire process. The MSA is used to validate a performance of measurement system by checking system accuracy, accuracy and stability. A measurement system is defined as a system of related measures that enables the number of specific characteristics to be measured. An effective MSA process can help make sure that the info collected is accurate and therefore the data collection system is acceptable for the method.

The following criteria's have been used for performing Measurement system Analyse:

- Appraiser = 3
- Parts = 10
- Measurement for each parts = 3

The results of MSA analyse consists of %Study Variation and %Contribution with certain limits are:

If the Total Gauge R&R offer in the% Study Var column is:

- Less than 10% - measuring system is acceptable.
- Between 10% and 30% - the measuring system is acceptable depending on the system, cost of the measurement device, repair costs, or other items.
- More than 30% - the measuring system is unacceptable and should be enhanced

If you look at the% Contribution column, the corresponding levels are:

- Less than 1% - measuring system acceptable.
- Between 1% and 9% - the measurement system is acceptable depending on the system, cost of the measurement device, repair costs, or other items.
- Bigger than 9% - the measuring system is unacceptable and should be improved.

Here Digital Outer Diameter Micrometer is used for measuring MOP values, Turning 1 and Turning 2 Dimensions for both components. Bore micrometer is used for measuring drilling dimensions. The part number and part name taken for assessing Digital outer diameter micrometer along with its dimensions and parameters are shown below:

Table 7. Part taken for OD micrometer

Part name	SPUR GEAR 29T
Part number	5E1401431
LSL	33.705mm

USL	33.730mm
Tolerance	25 microns

The data collected for performing MSA for OD micrometer is shown below. The measurement values obtained for 3 trials with 10 Parts for operator A is shown below:

Table 8. Trial values obtained for 10 parts of operator A

	Part										
Operator	**Trial**	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
A	1	33.708	33.728	33.72	33.716	33.713	33.722	33.712	33.719	33.715	33.71
	2	33.709	33.729	33.721	33.715	33.714	33.723	33.713	33.72	33.716	33.709
	3	33.709	33.728	33.721	33.716	33.714	33.722	33.712	33.72	33.715	33.71

The measurement values obtained for 3 trials with 10 Parts for operator B is shown below:

Table 9. Trial values obtained for 10 parts of operator B

	Part										
Operator	**Trial**	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
B	1	33.708	33.727	33.72	33.716	33.712	33.72	33.714	33.72	33.716	33.71
	2	33.709	33.728	33.721	33.715	33.713	33.72	33.713	33.721	33.715	33.709
	3	33.708	33.728	33.721	33.715	33.714	33.72	33.712	33.72	33.715	33.71

The measurement values obtained for 3 trials with 10 Parts for operator C is shown below:

Table 10. Trial values obtained for 10 parts of operator C

	Part										
Operator	**Trial**	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
C	1	33.708	33.727	33.719	33.716	33.713	33.722	33.714	33.719	33.715	33.71
	2	33.708	33.728	33.72	33.715	33.714	33.722	33.712	33.72	33.716	33.708
	3	33.709	33.728	33.72	33.713	33.713	33.723	33.714	33.72	33.716	33.709

The graphs obtained from the above study are Range chart to check the consistency of each appraiser, Run chart to assess difference in measurements between operators and parts and Bias chart to check the measurement value with reference value. The Range chart obtained for OD micrometer is:

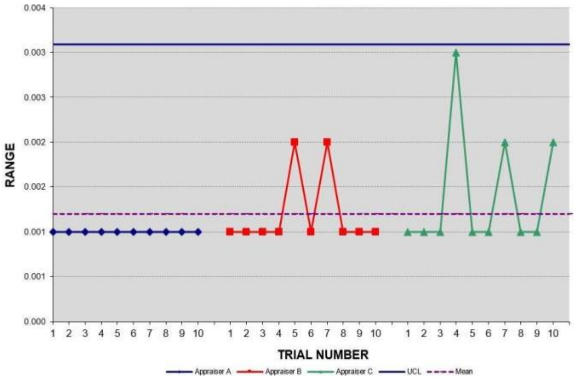


Fig.3. Range chart for OD micrometer

From the Range chart, it is observed that the process variation is in control with the specification limits. And also it is observed that the most of the parts are aligned with centre line without any variation. The Gauge run chart obtained for OD micrometer is:

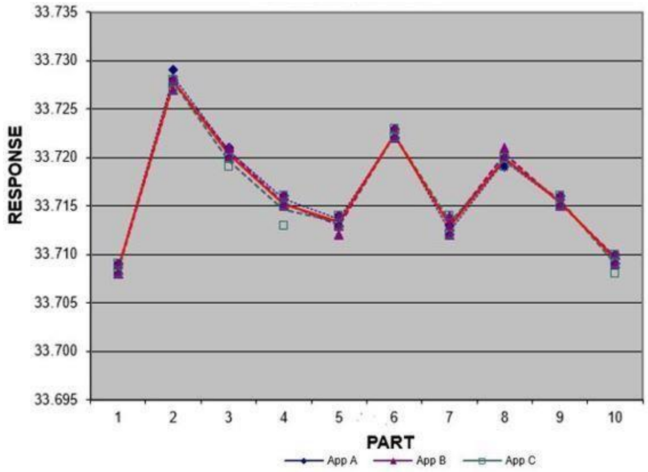


Fig.4. Gauge run chart for OD micrometer

From the run chart, it is able to understand the trend or pattern of the process to the particular period of the time. For this process, response is linearly increasing for the particular period of time and then linearly decreasing for the particular period of time. And this type of pattern is continued for all parts. The bias chart obtained for OD micrometer is:

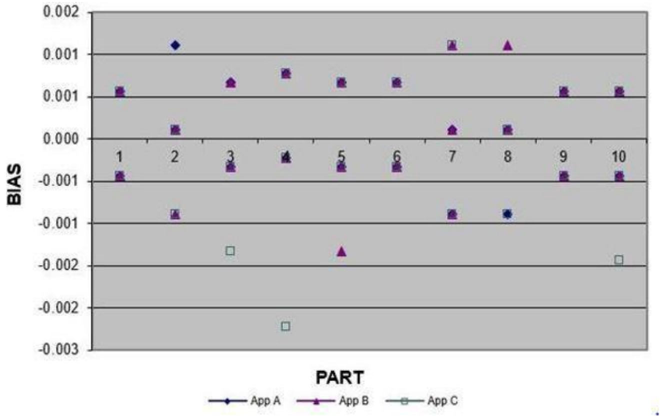


Fig.5. Bias chart for OD micrometer

From the bias chart, it is able to understand how the process accurately measured with its reference value and also their deviation from the mean value. Here most of the parts are measured with a deviation of 2 or 1 micron in between the appraisers. The part to part variation graph obtained for OD micrometer is shown below:

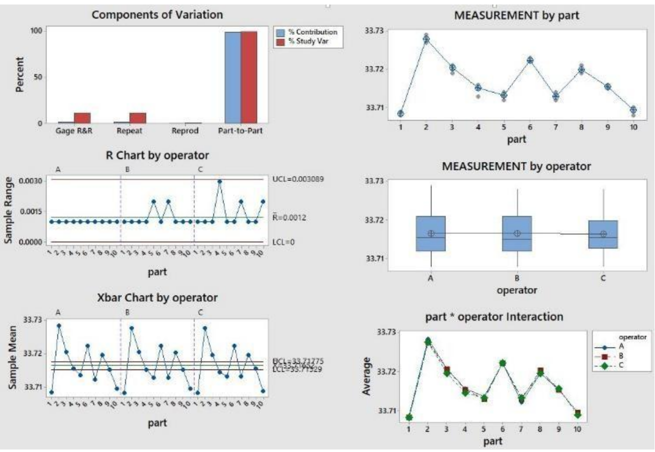


Fig.6. Part to Part variation for OD micrometer

Part to part variation graph indicates the variation in average measurements made by different appraiser with same parts. In this graph shows the high part to part variation indicates that the each appraiser are measuring the same parts with less deviation. From the R chart by operator it is able to understand that the appraiser C have the largest difference in measurement between appraiser B and A. Where the appraiser B have the smallest difference in measurement between appraiser A. In MSA if X bar chart by operator have tighter the limits and more points outside the limits means the system is acceptable. So the system is acceptable here also. The results obtained from the MSA is shown below

Table 11. MSA results for OD micrometer

Source	**% Contribution**	**%Variance**
Total Gage R&R	1.24	11.16
Repeatability	1.24	11.16
Reproducibility	0	0
Operator	0	0
Part to Part	98.76	99.38
Total Variation	100	100

The % Contribution and %variance of OD micrometer concludes that OD micrometer is acceptable for this application. But it can be eliminated based on cost of repair or other factor. And similar procedure is done for bore micrometer to calculate %Contribution and %variance.

PROCESS CAPABILITY ANALYSIS

After analysing the measurement system used to control of machined components, and found to be suitable, the efficiency of the process was analysed. SPC is a method that determines the capability and robustness of the process based on the data obtained. This method provides feedback on past and current process status. Based on the current situation we can predict how the process will behave in the future. In this way we can prevent process corruption, which leads to the production of unacceptable products and consequently increases costs. Process Capability analysis is a set of tools used to determine how a given process meets the specification limits. In other words, it measures how well the process works. Process capability indices are often used to describe process capability. C_p represents a process capability, and is an easy way to measure the capability of process process. C_{pk} represents the process capability index and refers to the specific process it has for achieving the output within a specific specification.

- If C_{pk} 1.33 indicates that the process is capable and meets specification limits.
- If C_{pk} 1.33 indicates that the process is less capable and it is too wide compared to the specification value.

Here the process capability analysis is performed for Turning 1, Turning 2, Gear hobbing, cylindrical grinding, drilling and Zinc phosphating for both Gear shaft and Roller lever shaft. The upper and lower specification limit for all the process is shown below:

Table 12. Specification limit for all process

Process	**Specification limit**	**Gear shaft**	**Roller lever shaft**
Turning 1	LSL	44.936	44.936
	USL	44.975	44.975
Turning 2	LSL	44.936	44.936
	USL	44.975	44.975
Gear hobbing	LSL	48.885	48.885
	USL	48.918	48.918
Drilling	LSL	5	5
	USL	5.075	5.075
Cylindrical grinding	LSL	44.636	44.636
	USL	44.675	44.675
Zinc phosphating	LSL	44.648	44.648
	USL	44.687	44.687

The data for each process is collected as per the specification limit for both the components. In order to perform process capability analysis, the data is collected with a sample size of 30 along with the 4 observations. The data collected for the MOP of gear shaft is shown below:

MOP data for gear shaft				
Subgroup number	***X1***	***X2***	***X3***	***X4***
1	48.912	48.913	48.914	48.911
2	48.894	48.898	48.896	48.899
3	48.892	48.897	48.914	48.887
4	48.895	48.899	48.896	48.894
5	48.887	48.889	48.887	48.885
6	48.886	48.899	48.905	48.904
7	48.887	48.892	48.897	48.886
8	48.906	48.903	48.897	48.894
9	48.906	48.904	48.904	48.9

10	48.905	48.904	48.901	48.905
11	48.887	48.895	48.899	48.902
12	48.911	48.918	48.907	48.902
13	48.889	48.893	48.899	48.897
14	48.905	48.907	48.913	48.901
15	48.911	48.904	48.917	48.9
16	48.887	48.895	48.886	48.897
17	48.904	48.91	48.916	48.904
18	48.887	48.893	48.897	48.896
19	48.906	48.901	48.897	48.893
20	48.89	48.897	48.899	48.893
21	48.907	48.911	48.914	48.916
22	48.895	48.899	48.891	48.898
23	48.887	48.89	48.914	48.886

Table 13. MOP data for gear shaft

MOP data for gear shaftx				
Subgroup number	***X1***	***X2***	***X3***	***X4***
24	48.892	48.899	48.896	48.894
25	48.887	48.907	48.901	48.909
26	48.911	48.917	48.906	48.901
27	48.894	48.89	48.891	48.886
28	48.887	48.893	48.895	48.899
29	48.901	48.907	48.911	48.913
30	48.916	48.904	48.909	48.904

Likewise, sample data along with 4 observations is collected for all the process and it is tabulated. After Control chart is made with the help of excel. Here Xbar chart and R chart is formed using excel.

From the X-chart, we can determine if a product is within the limits of tolerance or predict when a product will no longer be suitable. If the measure is above or below the control limit, it is marked in red. The R-chart tells you whether the variations in product properties are kept within acceptable limits. The lower control limit remains zero because the distance between the two measurements is determined by the absolute value. The Xbar chart and R chart obtained for the MOP value of gear shaft is shown below:

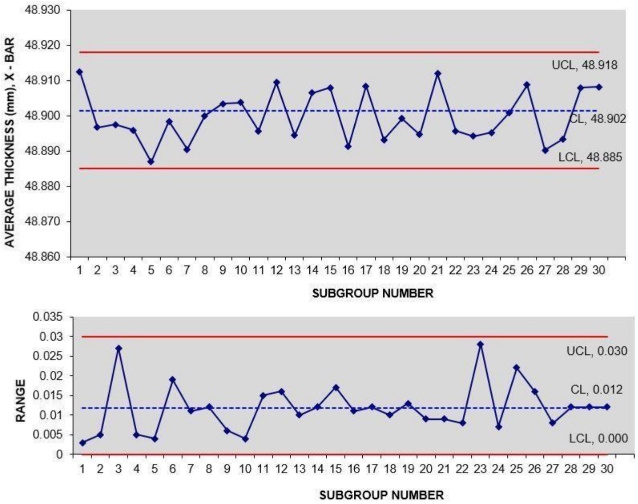
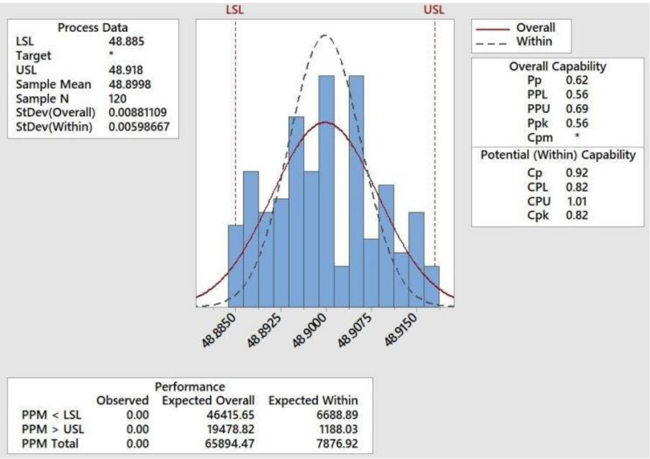


Fig.7. Xbar and R chart for MOP of gear shaft

Similarly, Xbar and R chart is made for all the process to check whether the process is in control or not. The process capability and capability index is calculated by using the Minitab software. It can be determined by feeding the specification limit in the software. Along with feeding the MOP data in the Minitab worksheet. The Minitab shows the result as a histogram. From the histogram we can understand the relative frequency of occurrence of the various data values, Reveals the centring, spread, and shape of the data and also helps to indicate if there has been a change in the process. The collected data will form a normal or bell shaped curve. Any significant change or abnormality indicate that there is something going on in the process which is causing quality problem. The process capability histogram obtained for the MOP value of gear shaft is shown below:



Process Data

LSL	48.885
Target	*
USL	48.918
Sample Mean	48.8998
Sample N	120
StDev(Overall)	0.00881109
StDev(Within)	0.00598667

Overall Capability

Pp	0.62
PPL	0.56
PPU	0.69
Ppk	0.56
Cpm	*

Potential (Within) Capability

Cp	0.92
CPL	0.82
CPU	1.01
Cpk	0.82

Performance

	Observed	Expected Overall	Expected Within
PPM < LSL	0.00	46415.65	6688.89
PPM > USL	0.00	19478.82	1188.03
PPM Total	0.00	65894.47	7876.92

Fig.8. Process capability graph obtained for MOP value

Fig.8. Process capability graph obtained for MOP value

The C_p and C_{pk} value obtained for MOP value of gear shaft is shown below:

Table 14. Process capability results for MOP data of gear shaft

CP	0.92
CPL	0.82
CPU	1
CPK	0.82

The process capability results obtained for all process of both the components is shown below:

Table 15. Process capability results

Process capability values		
Process	**Gear shaft**	**Roller lever shaft**
Gear hobbing	0.82	0.77
turning 1	1.02	0.97
Turning 2	1.04	1.14
Drilling	1.18	1.13
Cylindrical grinding	0.89	1.04
Zinc phosphating	0.98	0.98

From the results it is absorbed that the capability level of all the process is below the 1.18. So the machining process needs to be improved and also to enhance the productivity by reducing non-value added time.

DESIGN OF EXPERIMENTS

The design of experiments (DOE) is defined as a branch of applied statistics relating to the planning, conduct, analysis and interpretation of controlled trials to assess items that control the value of a parameter or group of parameters. The DOE is a data collection and analysis tool that can be used in a variety of testing situations. Allows multiple input items, determining their effect on the output you want (response). By using multiple inputs at the same time, the

DOE can identify important combinations that can be missed when trying one feature at a time(one factorial). All possible combinations can be investigated (full factorial) or part of a possible combination (fractional factorial).

Factors

Factors are inputs to the process and it may be controllable or uncontrollable variables. The factors that are selected for performing design of experiments are:

- Hob material
- Feed rate
- RPM

Gear Hobbing Tool

To achieve high production and low manufacturing cost, the RPM and feed rate in gear manufacturing industry is to be improved. Therefore the gear hobbing tool require the good manufacturability and toughness. In order to provide certain characteristics, the gear hobbing tool such as ASP2052, PS (gear shaving type) and PG (gear grinding type are selected to perform the experiments.

Response Variable

The response variable selected for the reduction of cycle time is “Smaller the better”.

Levels

Levels represent settings of each factor in the study. Levels that are selected to perform the experiments are:

Table 16. Levels for conducting experiments

Hob type	**Feed rate (mm/rev)**	**RPM**
ASP2052	0.8	350
PS(gear shaving type)	1	400
PG(gear grinding type)	1.2	450

Responses

Response is output of the experiment. The response selected for experiment is processing time. The various response obtained for various levels of experiments of hob tool of ASP2052 is shown below:

Table 17. Response obtained for ASP2052

Hob material	**Feed rate (mm/rev)**	**RPM**	**R 1**	**R 2**	**R 3**
ASP2052	0.8	350	19.24	19.26	19.25
ASP2052	0.8	400	18.54	18.45	18.46
ASP2052	0.8	450	17.25	17.21	17.24

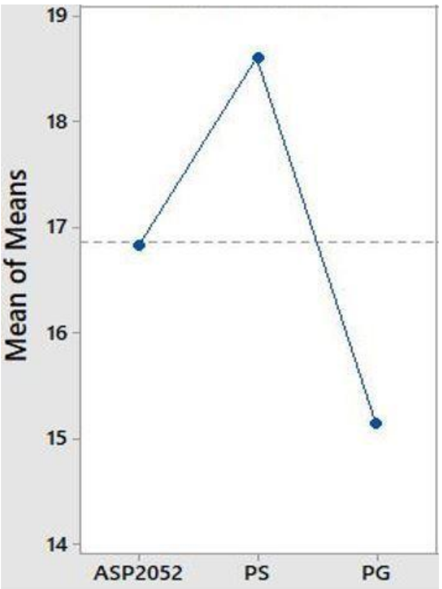
ASP2052	1	350	18.04	18.07	18.12
ASP2052	1	400	17.23	17.36	17.21
ASP2052	1	450	16.12	16.18	16.14
ASP2052	1.2	350	16.01	15.57	15.54
ASP2052	1.2	400	15.02	15.04	15.04
ASP2052	1.2	450	14.32	14.33	14.32

Likewise, responses for PS and PG type of tool is obtained and tabulated.

Optimal Parameters

By using taguchi analysis, the optimal parameters for each levels on cycle time is obtained. The results obtained from the taguchi analysis are shown below:

Fig.10. Hob type Vs Mean of Means



From the graph, it is observed that the effect of hob type based on cycle time is maximum for grinding type of tool and its effect is minimum for shaving type of tool. So grinding type of tool is optimum for reducing the cycle time. The graph obtained for mean of means and feed rate is shown below:

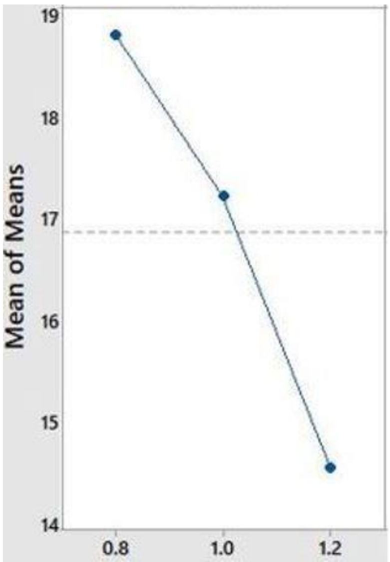


Fig.11. Feed rate Vs Mean of Means

From the graph, it is observed that the effect of feed rate on cycle time is maximum for feed rate of 1.2 mm/rev. And also the effect of feed rate on cycle time is increases as the feed rate increases. So the optimal feed rate is 1.2 mm/rev.

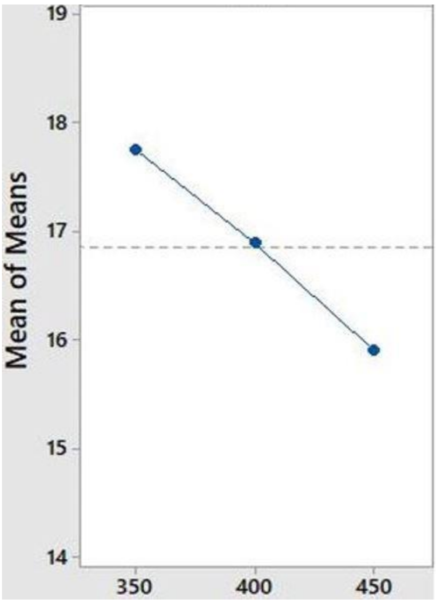


Fig.12. RPM Vs Mean of Means

From the graph it is understand, effect of RPM on cycle time is maximum for 450. And also the effect of RPM on cycle time is increases with increase in RPM. The Optimal RPM selected from the graph is 450.

3. RESULTS AND DISCUSSIONS

From the graphs obtained from the DOE analysis, it is observed that the various levels such as gear grinding type hob, 1.2 feed rate and 450 RPM are the optimal parameters. The total time for processing of gear hobbing of roller lever shaft is 70.52 minutes, by selecting the best machining parameter the processing time of gear hobbing process is reduced into 51.7 minutes. And also the overall value added time of all process is reduced from 349 minutes to 337 minutes.

The optimal parameter leads to decrease in processing time of gear hobbing in roller lever shaft by 26.29%. From the process capability analysis, the process with less process capability index is 0.77 for gear hobbing of roller lever shaft. For performing process capability analysis, the measuring system was checked with MSA analysis, the %Variance and

%Contribution obtained for both the OD digital micrometer and Bore micrometer is between 10 – 30 % and 1 – 9 % respectively. In order to reduce the non-value added time, process chart is used to distinguish value and non-value added time. And also improvements are suggested to reduce the non-value added time.

4. CONCLUSION

In this work, the cycle time reduction of gear manufacturing process was studied. The problem of highest cycle time was analyzed. With the use of control chart and process capability analysis, stabilization and capability of process was analyzed. With the use of DOE analysis, the influence of process parameters on cycle time was analyzed. It was found that the feed rate has the maximum effect on cycle time. And also the optimal process parameter and their effect on cycle time was explained. With the use of Measurement system Analysis, the % Contribution and % Variance of Digital OD micrometer and Bore micrometer was checked.

From the various experiments with various levels the following conclusion are to be arrived:

- Feed rate is the most important parameter that shows the effect on cycle time.
- Hob type is the second important parameter that shows effect on cycle time
- RPM is the less important parameter that shows effect on cycle time.

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