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Performance Evaluation of the Manufacturing Process for the Proposed Design Modification of the Kingpin

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Abstract

The manufacturing process of a metallic kingpin plays an important role in determining its fatigue life. Several machining processes are carried out which induce different kinds of stresses in the material. In order to relieve these stresses heat treatment processes are carried out. This may lead to certain dimensional defects in the part. In order to ensure the quality of the manufactured part different quality control techniques are used. The goal of this paper is to evaluate the overall performance of the manufacturing process for a modified king pin design. For this purpose, the MSA and SPC techniques have been used find out the acceptability of the measuring system and the stability of the quality control process for the manufacturing of the proposed king pin design.

Keywords: *Lean Manufacturing, Measuring System Analysis (MSA), Metal, Process Flow Diagram (PFD), SPC*

1.0 Introduction

The kingpin, also known as cross pin, is the main pivot in the steering mechanism of a car or other vehicle. In a steering system, the kingpin's main function is to provide an axis for the steering wheels to spin, or steer, around. A King-Pin is a component that joins the front axle with the tyre. It supports the shock-absorber system as well. Its construction is intended to withstand severe jerks, lodgings, and abrupt impacts that go straight through the wheel. The vehicle's weight is supported by a stiff shaft when it comes to wheels[1]. The steering control for commercial vehicles must be of high quality as they carry heavy loads and travel long distances. Failure of kingpin has become very common in vehicles. This leads to loss in reliability over the vehicle and causes loss in the profitability of the company. Thus, the manufacturing process of the king pin becomes quite an important criterion for improving the life of the king and also provides better control of the overall steering mechanism.

The manufacturing process is essentially a complex activity involving a wide range of disciplines and levels of knowledge in people. A manufacturing endeavour needs to be open to various demands and developments. It covers many facets of workshop operations and imparts a fundamental understanding of the different engineering materials, tools, accessories, manufacturing procedures, fundamental machine instrument concepts, production criteria, characteristics and applications of various testing instruments, and calibrating or inspecting units to verify

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materials or goods designed in different production shops in commercial environments. Several manufacturing processes have been designed for the purpose better productivity and quality control of the complete process depending the needs of the consumers and the facilities present in the industry as well. The manufacturing process adopted by any industry is expected to enhance both the quantity as well as the quality of the parts while reducing the overall wastage in the process and maintaining its cost efficiency. Lean, also known as Lean Management, Lean Manufacturing (LM), Lean Enterprise, or Lean Production, is a collection of ideas, methods, and strategies that many businesses and organizations in the industrial sector choose to apply in order to reduce waste and increase overall customer value and production efficiency.

Lean aims to get rid of waste, or the parts of any process that don't bring value. A process will always have some waste unless it has undergone numerous lean cycles. When implemented effectively, lean can result in significant gains in productivity, cycle time, efficiency, material costs, and scrap, which can reduce expenses and boost competitiveness. And never forget that lean isn't just for manufacturing. It has the potential to enhance teamwork, inventory control, and even customer relations. The lean manufacturing process of the king pin also involves the documentation and quality control of the process. Certain tools and techniques have been developed for the proper documentation and a better quality control of the complete process like formation of PFDs, PFMEA exercise, Process plan charts, MSA charts and the SPC charts to keep a check on the overall performance output of the manufacturing process.

In this paper, the manufacturing process for a new proposed design of the king pin have been evaluated using the techniques of the lean manufacturing process. The goal is to evaluate the performance of the existing manufacturing techniques and measuring equipment's, so as to meet the standards for the new design specifications of the modified king pin. For this purpose, a Measuring System Analysis (MSA) of the measuring system and a Statistical Quality Control analysis of the production process have been carried out to check the capability and acceptability of the existing process.

2.0 Manufacturing of the King Pin

To trace the step by step development of king pin and maintain the machineries and equipments in good condition to avoid malfunctioning and defects, companies use various diagrams and charts. These documents help in proper organization and positioning of the workstations and technicians in accordance with the different manufacturing steps and also provide a guidance for meeting the quality demands of the product and the machineries. The main documents and processes that are viewed for setting up the production line are as follows:

- Process Flow Diagram (PFD)
- Process Failure Mode and Effect Analysis
- Control Plan

A Process Flow Diagram (PFD)[2], is a detailed flowchart that traces all the steps of the development of a product from being a raw material to its storage or dispatch. It has the key to developing and managing an industrial manufacturing process. A popular chart in chemical and process engineering is the Process Flow Diagram (PFD). It serves as an illustration of the continuous flow of chemicals and other equipment used in production. American industrial engineer Frank Gilbreth first proposed the idea of the process flow diagram in the 1920s. Process flow diagrams have gained popularity in the corporate world as well as in the field of industrial engineering during the ensuing decades. This process flow diagram example describes how a front axle cross pin is made in the manufacturing sector.

The mentioned details in the flowchart, are the steps in order of the operations and tests performed for the complete manufacturing of the cross pin. Industries usually layout their machines and workstations according to the order of different operations being performed on the product for the smooth flow of the raw material from the receiving end to the departure end. Thus, a PFD of the product being manufactured helps the engineers design the industrial layout of various processes in order and decide the position of machines or workstations.

In order to ensure that the manufacturing process detailed in the PFD runs smoothly with no or little failure risk, a Process Failure Mode and Effect Analysis (PFMEA)[3] exercise is carried out to determine the possible

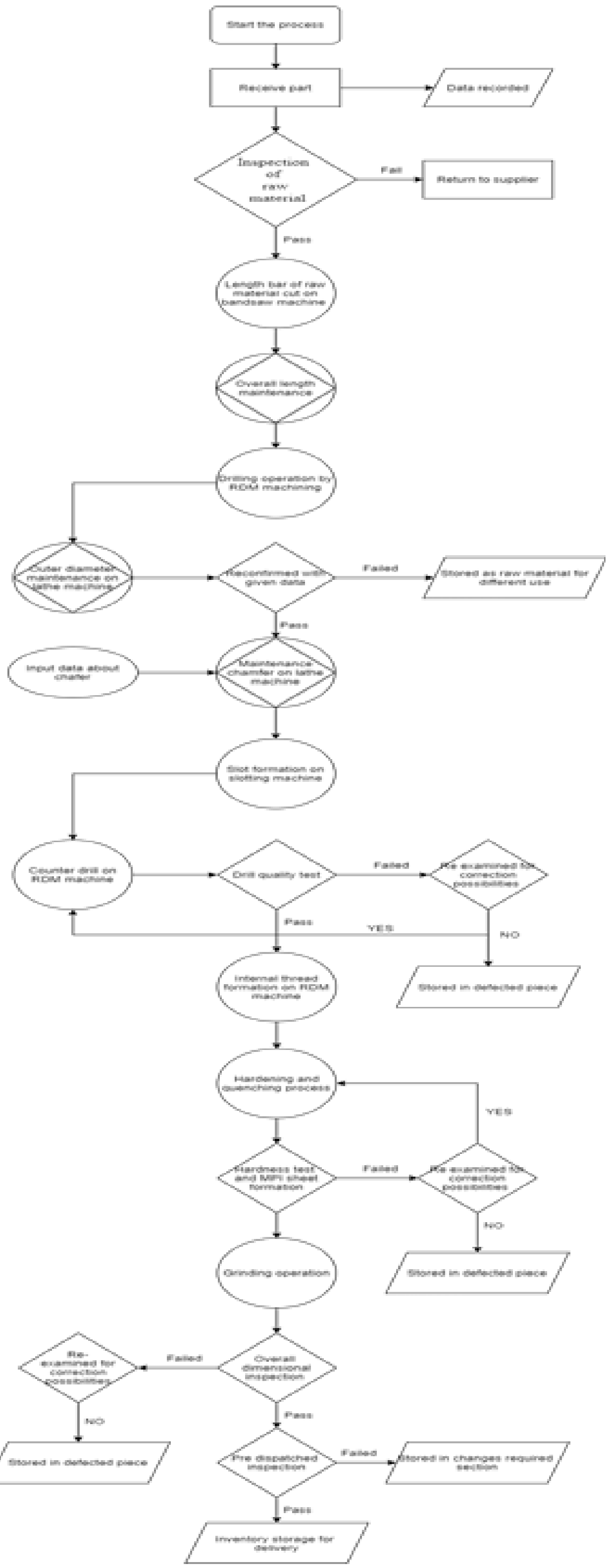

Figure 1. PFD of King Pin

causes and modes of failure in the overall manufacturing process of the product, either through the machines or the equipment's being used along the assembly line, and the steps to avoid these errors and failures are detailed even before they occur. The goal of this activity is to avoid issues. This raises consumer satisfaction and enhances safety even more. By identifying system, process, and product improvements early in the development cycle, PFMEA lowers costs. PFMEA sets up procedures to reduce failure risk. This is done by determining the Risk Priority Number (RPN) of different modes of failure. The RPN is makes use of three different criterion, which are the Severity (S) of the failure, its Occurrence (O) and its ease of Detection (D). RPN is the product of these three criteria which are rated on a scale of 1 to 10.

RPN = S*O*D.

The procedure should operate smoothly if the overall RPN is low. Once RPN has been calculated for the entire process, it is simple to concentrate on the regions that need more attention. The PFMEA of a king pin production, i.e. the possible modes of failure during the production of a king pin along the assembly line, their effects and steps taken to prevent their occurrences are shown in the Table 1.

The Figure 2 shows the initial RPN values of the potential failure modes before the preventive steps are taken and the final RPN values after taking action. The values of RPN show a considerable decrease after certain preventive measures, as detailed in the PFMEA chart have been carried out.

Once the PFD and PFMEA have been carried out, the next step is the preparation of the control plan. A control plan is a written document that outlines the steps (such as measurements, inspections, quality checks, or parameter monitoring) needed at each stage of a process to guarantee that the results will meet predefined standards. To put it another way, the Control Plan gives the operator or inspector the knowledge they need to effectively manage the process and create high-quality components or assemblies. It should also specify what has to be done if a non-conformance is found. By defining a standard for quality inspection and process monitoring, the Control Plan helps ensure that quality is maintained in a process even in the event of employee turnover (Table 2).

Table 1. PFMEA of the King Pin production process

Process step/ Variable	Potential Failure Mode	Potential Effect on Customer because of Defect	SEV	Potential cause	OCC	Current Process Control	DET	RPN	Actions Recom-mended	Respons-ibility	Actions Taken	SEV	OCC	DET	Future RPN
Plunge grinding	Corrosion	Life of joint propeller shaft reduced	7	Preservation procedure failure	4	Verifi-cation of inputs	7	196	Operator training on under-standing data	Foremen	Keep the grinding tool clean and lubricative	6	3	5	90
	Burn out diameter	Bearing life reduced and it will face problems in assembly	7	Badly increased speed and depth of grinding	6	Training required by material and corrosive properties	6	252	Operator training on process	Foremen	Proper concen-tration while operation is performing	6	4	4	96
Diameter	Oversize	No assembly	6	Improper mounting, excess run out, improper input stock, material properties	5	By visual inspection and using gauge	8	240	Use of position sensor on HMC, Proper steady setting, use of trained labour	Technician	Mounting of position censor, proper fixture used	6	2	4	48
	Undersize	Loose fitment	4	Loose alignment, power transmission is not usual, damage possibilities	5	Replac-ement of tool, proper lubric-ation or washer is used	7	140	Improper steady, hardened workpiece matrerial	Technician	Optimum input stock set, proper fixture used	3	4	3	36
Surface roughness	Rough surface finish	Pin wear out	7	Tool wear, excess feed rate	5	Tool replac-ement, maintain optimum feed rate	6	210	Tool change after regular interval, process automation	Technician	Proper progra-mming, optimum speed maintained, process automised	7	3	2	42

Table 2. Control plan of King Pin machining processes

Part / Process Number	Process Name / Operation Description	Machine, Device, Jig, Tools for Manufacturing, etc…	CHARACTERISTICS			METHODS						Reaction Plan
			Number	Product	Process	Product / Process Specification / Tolerance	Evaluation / Measurement Technique	SAMPLE SIZE	SAMPLE FREQ.	Control Method		
4	Cutting	Bandsaw Macchine	20	Length		245	Dial Type Height Gauge	10	1	Self Inspection		Reset and Keep in NCP Area
5	Facing	TNMG16	30	Length		245±0.5	Dial Type Height Gauge	10	1	Self Inspection		Reset and Keep in NCP Area
6	Drilling	8mm CHF Tool	40	Chamfer	Set up of RDM machine	Ø 12.0 ±0.25	Vernier	10	1	Self Inspection		Reset and Keep in NCP Area
		8mm CHF Tool	40	Chamfer	Set up of RDM machine	29+2	Vernier	10	1	Self Inspection		Reset and Keep in NCP Area
8	Turning	TNM G16	50	Diameter	Set up of Lathe machine	40 ± 0.05	Micrometer	10	1	Self Inspection		Reset and Keep in NCP Area
9	Turning	TNM G17	60	Chamfer	Set up of Lathe machine	2 ± 0.1	Part to be confirm with QC Inspection	100%	on-going	Visual Inspection		Reset and Keep in NCP Area
10	Slotting	SPM G11	70	Diameter	Set up of Slotting machine	16 ± 0.5	Dial type variable Slot Depth Gauge /Radius gauge/vernier	10	1	Self Inspection		Reset and Keep in NCP Area
11	Counter Drill	11mm CHF Tool	80	Depth	Set up of RDM machine	11 ±0.2	Visually	10	1	Self Inspection		Reset and Keep in NCP Area

Table 2 Continued

		11mm CHF Tool	80	Diameter	Set up of RDM machine	6 ±0.2	Visually	10	1	Self Inspection	Reset and Keep in NCP Area
13	Cham-fering	11mm CHF Tool	90	Angle	Set up of Chamfer angle on machine	45 °±0.5°	Visually	10	1	Self Inspection	Reset and Keep in NCP Area
		11mm CHF Tool	90	Dimension	Set up of Chamfer dimension on machine	2 ±0.5	Visually	10	1	Self Inspection	Reset and Keep in NCP Area
13	Drilling	6mm Drill	90	Angle	Set up of RDM machine	45 °±0.5°	Visually	10	1	Self Inspection	Reset and Keep in NCP Area
		6mm Drill	90	Chamfer		2 ±0.5	Visually	10	1	Self Inspection	Reset and Keep in NCP Area
13	Tapping	M10 X 1.25 TAP	100	Tool	Set up of tapping Tool	M10 X 1.25 mm	TPG	10	1	Self Inspection	Reset and Keep in NCP Area
		M10 X 1.25 TAP	100	Threads		29+2	Visually	10	1	Self Inspection	Reset and Keep in NCP Area
15	Grind-ding	Grinding Wheel	120	Diameter		Ø 40-0.025/-0.064	Micrometer	10	1	Self Inspection	Reset and Keep in NCP Area
		Grinding Wheel	120	Perpendi-cularity		0.015	Variable Dial Height gauge	10	1	Self Inspection	Reset and Keep in NCP Area

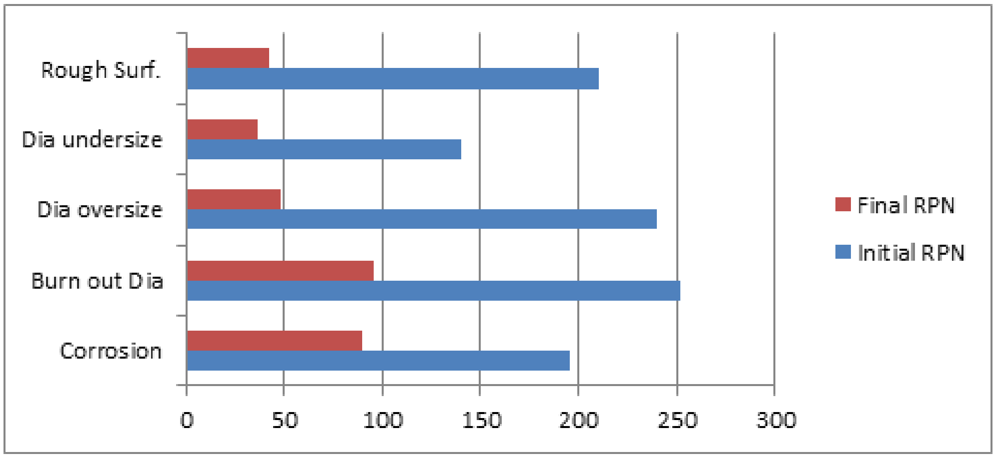

Figure 2. Graph comparing RPN before and after PFMEA.

3.0 Analyzing the Measuring System and Quality

3.1 Measuring System Analysis (MSA)

The process of determining whether a measuring system is capable of exact measurement using statistical methods like a gauge R&R (repeatability and reproducibility) research is known as measurement statistical analysis, or MSA. Furthermore, MSA ascertains the degree of error resulting from the measurement procedure itself. MSA is used to ensure that a chosen measurement system produces accurate, repeatable, and reproducible findings. Every measurement system used in a PPAP is listed in the control plan. For each of these systems, a gauge R&R is conducted to verify accuracy. An MSA chart for the cross pin's length, measured with a dial-style height gauge, is shown below. By establishing trust in data collecting techniques, MSA ensures the accuracy of collected data used in subsequent high-quality studies. Evaluating measuring tools, test processes, and data-collecting strategies are all part of this process. Manufacturers may make well-informed judgments about their products and production methods with the aid of MSA. Measurement system uncertainty is assessed using gauge repeatability and reproducibility (Gauge R&R), which is applied to gauges or instruments that collect variable continuous data. Consider comparing the repeatability and reproducibility levels when understanding the Gauge R&R data. A potential problem with the study's gauge could be indicated if the repeatability value is high compared to the reproducibility value. It could be necessary to replace or recalibrate the gauge. On the other hand, a large reproducibility value relative to the repeatability value would suggest that the variance is operator-related. It's possible that the operator needs more instruction on how to use the gauge correctly, or that utilizing the gauge may need the use of a fixture. The following circumstances qualify a measuring system for the acceptance test:

Condition 1:

- If % GRR < 10, then the results are acceptable.
- If 10 < % GRR < 30, then it is conditionally acceptable if % GRR with respect to Tolerance is less.
- If % GRR > 30, it is not acceptable.

Condition 2:

To guarantee part-to-part variance, the Average chart's number of out-of-control points needs to be greater than 50%.

Condition 3:

The Range chart shouldn't have any out-of-control points.

Condition 4:

More than or equal to 5 distinct data categories (NDC) should exist.

For calculating GRR, the following procedure is followed[4]:

1. A sample of 5 parts is selected for measurement from the lot that represents the specified range of the process variation. 3 appraisers, A, B, C, are assigned are the task of measurement readings without showing them the part numbers.
2. The selected instrument for measurement was calibrated and the least count was noted.
3. Let the appraiser A measure the 5 parts randomly. The readings were noted in the 1st row of appraiser A trial section, as shown below in the data collection chart.
4. Same procedure is followed by the appraisers B and C and their readings are noted in the 1st rows of the respective sections without letting anyone see each other's readings.
5. Repeat the cycle for 2nd and 3rd rows of readings by each appraiser in their respective sections.
6. Calculate the average of all the readings of the 5 parts for each of the 3 trials. The average of each trial is mentioned in the 6th column of each appraiser section.
7. The mean of these averages is the calculated, for each appraiser, that is represented here by Xa, Xb, Xc respectively, and highlighted in the green cell. These are called Appraiser Average.
8. Similarly, the Part Average is also calculated below for all the 5 parts separately. This comprises of the average of all the 5 readings by the 3 appraisers.
9. The Mean Range Ra, Rb, Rc for each appraiser is also calculated by taking the average of the ranges for all the 5 parts for each appraiser.
10. Now the Mean Range of the overall data collection process is calculated. This is represented by
    R D.bar = (Ra+Rb+Rc)/3.
11. The mean of all the Appraiser Averages are also taken. X. D bar = (Xa+Xb+Xc)/3
12. The range of the Appraiser Averages i.e. the difference between the maximum appraiser average and the minimum appraiser average is then calculated. This is represented by
    X Diff = Max (Xa,Xb,Xc) – Min (Xa,Xb,Xc)
13. The upper and lower limits for the range distribution are calculated as shown below:
    UCLr = R D.bar X D_4
    LCLr = R D.bar X D_3
    D_3 and D_4 are constants that are taken from the standard table depending upon the no. of trials[5].
14. Similarly, the upper and lower limits for the mean distribution are calculated as shown below:
    UCLx = {X D.bar + (A_2 * R)}
    LCLx = {X D.bar - (A_2 * R)}
    Again A_2 is a constant taken from the standard table depending upon the sample size[5].

Formulae Used For Calculations

1. Repeatability: This denotes the Equipment Variation and is represented by EV.
   EV = R. D bar * K_1
   K_1 = 5.15/d_2, the value of d_2 is taken from the constant table[6] depending upon number of trials (n) and subgroup size (k) i.e., no. of parts times the no. of appraisers. Here n = 3 and k = 5 * 3 = 15, therefore d_2 = 1.7 and K_1 = 3.
2. Reproducibility: This is the Appraiser Variation and is denoted by AV.
   AV = SQRT {(X Diff * K_2)^2 – (EV^2 /mr)}
   m is the no. of parts and r is the no. of trials. K_2 = 5.15/d_2, the value of d_2 depends upon no. of appraisers (n) and the subgroup size k = 1 as the calculation is only for one range.
   Here, n = 3, therefore d_2 = 1.91 and K_2 = 5.15/1.91 = 2.69.
3. Gauge Repeatability and Reproducibility (GRR): This denotes the total variation in the process, produced by the equipment and the Appraiser.
   GRR = SQRT (EV^2 + AV^2)
4. Part Variation PV = Rp * K_3, where K_3 = 5.15/d_2, where the value of d_2 depends on the no. of parts (n) and the subgroup size (k). For this thesis, n = 5 and k = 1 as the calculation is only for one range. Therefore, d_2 = 2.48 and K_3 =2.07.
5. Total Variation TV = SQRT (GRR^2 + PV^2)
6. Percentage of Equipment Variation, % EV = (EV/TV) *100

Table 3. Data collection sheet for MSA

DATA COLLECTION								
No of Trials / Parts		**1**	**2**	**3**	**4**	**5**	**Average**	
1	**1**	245.1	244.95	245	244.95	245.05	**245.01**	
	2	245.15	245	244.95	244.95	244.95	**245**	
	3	245.05	245.05	245.05	245	245.05	**245.04**	
	Avg. Xa						**245.0167**	
	Range Ra	0.1	0.1	0.1	0.05	0.1	0.09	
No of Trials / Parts		1	**2**	**3**	**4**	**5**		
2	**1**	245.05	245.05	245	245	244.95	**245.01**	
	2	245.05	244.95	245	245	245	**245**	
	3	245	245.05	244.95	244.95	245.05	**245**	
	Avg Xb						**245.0033**	
	Range Rb	0.05	0.1	0.05	0.05	0.1	**0.07**	
No of Trials / Parts		1	2	3	4	**5**		
3	**1**	244.95	244.95	245.05	245.05	244.95	**244.99**	
	2	244.95	245	245	244.95	245	244.98	
	3	245.05	244.95	245	245.05	245	**245.01**	
	Avg Xc						**244.9933**	
	Range Rc	0.1	0.05	0.05	0.1	0.05	**0.07**	
Part Average		245.04	244.99	245	244.995	245	**X D.Bar=**	245.0044
							Rp =	0.3833
R D.bar= {(Ra+Rb+Rc)} /3	0.0767		**UCLr = R D.bar X D4**			0.1978	**UCLx = {X D.bar + (A2 * R)}**	245.083
X Diff ={ Max X - Min X }	0.0233		**LCLr = R D.bar X D3**			0	**LCLx = {X D.bar - (A2 * R)}**	244.926
Trials / Appraisers	A2	D3	D4	K1	K2	K3	5	3
3 Trials 3 Appraisers	1.02	0	2.58	3	2.69	2.07	**Number of Parts (n)**	**Number of Trials r**

7. Percentage of Appraiser Variation, % AV = (AV/TV) *100
8. Percentage of GRR, % GRR = (GRR/TV) *100
9. Percentage of Part Variation, % PV = (PV/TV) *100
10. Number of Distinct Data Category, ndc = 1.41 (PV/GRR)
11. Repeatability and Reproducibility with respect to total tolerance = (GRR/Total Tolerance) *100

The chart for measuring the GRR of the Cross-pin measuring system is shown in Table 3.

3.2 Statistical Process Control (SPC)

SPC is a method that utilizes statistical and numerical techniques for controlling the quality of a product in manufacturing industries. Using a statistical method design, an SPC chart is utilised in the process selection to ascertain the quality attributes, records, and management control. Instead of controlling the number of defects, variable control charts are designed to regulate process or product parameters that are measured on a continuous measurement scale, such as pounds, inches, millimetres, etc. The most often used control charts in manufacturing are mean and variance, which need to be closely watched in tandem to ensure high-quality yield. For almost 50 years, the process mean and variance have been managed by joint Shewhart the and R (or S) control charts[7]. Similar X and R bar charts have been used in this paper for quality control. Given below is the SPC chart showing the sample analysis of Cross pin Diameter; Control charts are employed in process stability checks. under this sense, if the quality characteristic's probability distribution remains consistent throughout time, a process is considered to be "in statistical control." The process is said to be "out of control" if there is a gradual change in this distribution. An out of control condition, on the other hand, indicates that there is an assignable or particular cause fluctuation in the distribution. To get the process back to a statistically controlled state, this kind of variance needs to be identified and removed[7].

Based on the time sequence of the extracted sample points plus sequence point, there are three different boundaries: the Centre line (CL), the control limit (UCL), and the control limit (LCL). It is simple to have state two errors while using the control chart analysis technique. Relaxing the control limit can lower the likelihood of misjudgment (a), but P will increase. Similarly, reducing the compression control limit can lower the probability of p, but a and increases. Class, one involves misjudgment, and the probability was recorded on the questionnaire. Consequently, the minimal total losses for the concept should result in two errors in the control chart's appropriate assessment of the control limit. Based on empirical evidence, it is more suitable to use the control limit range for 3σ. Consequently, in the control chart where CL is u and UCL is u + 3σ, LCL is u-3σ[8]. If there are only common reasons and no unique causes have been found, the data points on the control chart should lie between the control boundaries. While exceptional causes are typically outliers or fall outside of the control boundaries, common causes will fall within the control limits. A process must not have any special causes in any of the charts to be considered to be in statistical control. When a process is in control, its data should fall between the control limits and no unique causes will be found in it.

The whole exercise of preparing and evaluating the Control charts is carried out to analyze the Process capability and stability of the king pin manufacturing. Over the past 20 years, process capacity analysis has emerged as a crucial and well-defined tool in SPC applications for ongoing quality and productivity improvement. After that, the process's suitability for meeting requirements is evaluated by computing one or more capability indices. The percentage of things produced by the process that meet specifications is the easiest to understand among these[7]. Process capability is a measurement of the process's capability to operate in the presence of noise and process inputs that may affect the process and cause its output to deviate from the target and not fall within the target line.

The indexes that are used to measure Process Capability are:

1. **Process Capability Ratio (Cp)** - It indicates whether this process is capable of producing product to specifications. The capability index is calculated using specifications limits and the standard deviations only.
2. **Process Capability Index (Cpk)** - This indicates whether the procedure can produce within requirements and also shows how well the procedure can follow the desired specification[7].

The values of Process Capability Ratio and Process Capability Index[7] indicate the performance of the process.

The process performs better the closer the values of Cp and Cpk are to one another. Both Cp and Cpk provide process capability; however, Cp discusses data dispersion and range breadth, Cpk focuses on data points that are close to the mean. Cpk provides a more accurate process capability even if both have the same capability. Unlike Cp, which offers the data points between the USL and LSL, it sees the data point with mean. Data points can be distant from the aim but within the specification limitations. Therefore, if there is less distance between the points and the target—as shown by the Cpk value—the process will be more capable.

Simply expressed, a stable process is one in which all known reasons of variation are addressed, the process is then guided by common causes of variation, and the process's outcome is reasonably foreseeable. It is necessary for management decisions to enhance the process's capabilities even more. Process stability is the process's consistency with regard to significant process attributes, such as the variance in a key dimension or its average value. We refer to a process as stable or under control if its behavior remains constant across time.

SPC charts[8] are maintained for the quality control of the product that is to be delivered to the customer after the production. The procedure followed for the data collection of SPC[4] is as followed:

1. A sample of 10 parts was selected from the given lot representing the specified range of the process variation.
2. The instrument used for the measurement was calibrated and the least was noted.
3. For each part, 5 measurements were taken and the reading was noted in the column below it.
4. Similar to the GRR data sheet, calculate the values of mean of each part, overall process means, range for each part reading, the mean range of the process, upper control limit, lower control limit of the process etc. The procedure and formulae for calculation are mentioned below.

Formulae Used For Calculation

1. Range of measurement sample for each part.
   Range = X_{LARGE} - X_{SMALL}
   Where X_{LARGE} = Maximum measurement in the sample
   X_{SMALL} = Minimum measurement in the sample
2. Mean/Average of each samples of each part
   AVG = (X1+X2+X3+X4+X5)/n
   Where n = sample size, here 5
3. Range of all the means (AVG) of each part
   R_{MEAN} = X_{MAX} - X_{MIN}
   Where X_{MAX} = Maximum value of AVG among the 10 parts
   X_{MIN} = Minimum value of AVG among the 10 parts
4. Mean of all the averages of part samples (Mean of AVGs)
   X_{MEAN} = (X1+X2+X3+X4+X5+X6+X7+X8+X9+X10)/k
   Where k = no. of parts, here 10
5. Upper and Lower Control limits of the sample i.e., UCL and LCL for X chart
   UCL = X_{MEAN} + A_2 X_{RANGE}
   LCL = X_{MEAN} - A_2 X_{RANGE}
   Where A_2 = constant taken from the standard table depending upon the sample size.
6. Upper and Lower Control limits of the sample i.e., UCL and LCL for R chart
   UCL = D_4 X_{RANGE}
   LCL = D_3 X_{RANGE}
   Where D_3, D_4 = constants taken from the standard table depending upon the sample size.
7. Specifications for the X bar graphs
   - Process Width (P) = R_{MEAN}
   - Design Centre (D) = (USL-LSL)/2, where
     USL = Upper Specified/Tolerance limit of the part
     LSL = Lower Specified/Tolerance limit of the part
   - Starting Point = Least reading from among all the samples
   - Specification Width (S) = USL – LSL
   - No. of Readings i.e. 50 in this case
   - No. of Classes = No. of Readings/ 10
   - Interval = P/No. of classes
   - Shift of X_{MEAN} from the design center 'D' = X_{MEAN} - D
   - Index = 2* (Shift of Xmean)/S
8. Frequency
   FREQ. = 1/(Interval (Time))
9. Cumulative frequency

Table 4. Data collection sheet for SPC

DATA COLLECTION: -												
SNO.	1	2	3	4	5	6	7	8	9	10		
1	39.99	40.01	40.02	39.99	40	39.98	39.97	39.98	39.99	40.01	**U.S.L.**	**40.05**
2	40.01	40.02	40.01	40.02	39.99	40.01	40.01	40.01	40.01	40.03		
3	39.98	39.99	39.99	40.01	39.97	40.02	39.98	39.99	40.02	39.99		
4	40.02	39.98	40.01	39.98	39.98	40.01	40.01	40.02	39.98	40.04	**L.S.L**	**39.95**
5	40.01	40.01	40.02	40.01	40.01	39.99	39.97	39.98	40.01	40.01		
FOR HISTOGRAM												
XLARGE	40.02	40.02	40.02	40.02	40.01	40.02	40.01	40.02	40.02	40.04	Xmax.=	40.04
XSMALL	39.98	39.98	39.99	39.98	39.97	39.98	39.97	39.98	39.98	39.99	Xmin.=	39.97
RANGE	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.05	**Rmean**	**0.04**
AVG.	40.002	40.002	40.01	40.002	39.99	40.002	39.988	39.996	40.002	40.016	**Xmean**	**40.001**

CU. FREQ. = Previous FREQ. + Current FREQ.

10. Standard Deviation

$$\sigma^2 = \frac{\sum(X - AVG)^2}{k}$$

11. Process Capability Ratio
    $C_p = (USL\text{-}LSL)/6\sigma$
12. Process Capability Index
    $C_{pk} = \min [(Xmean\text{-}LSL)/3\sigma, (USL\text{-}Xmean)/3\sigma]$

4.0 Results and Observations

Using the data sheet for MSA, the values for different parameters have been calculated which are shown in the Table 5.

As can be seen in the results, the % GRR of the measuring system is 28.08%, which between 10 and 30. Also the value of ndc is less than 5 and % GRR with respect to tolerance is high too. This hints that the measuring system is not acceptable for carrying out the

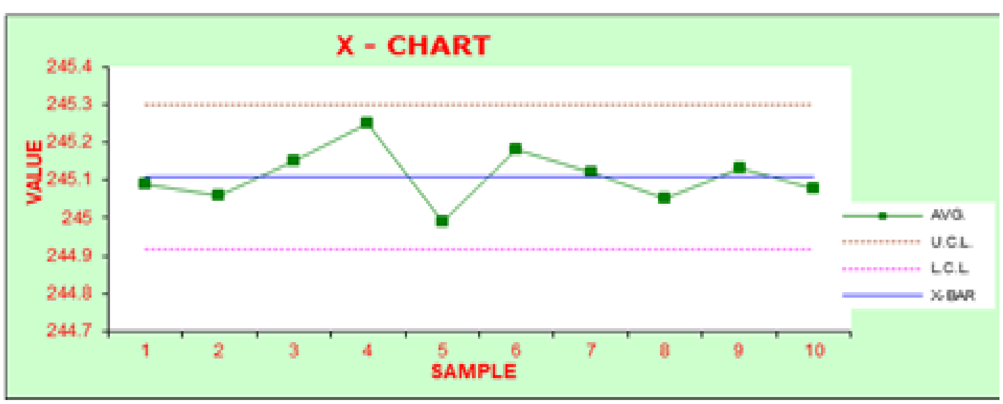

Figure 3. X bar chart for the SPC of King Pin.

Table 5. Result evaluation for the MSA of King Pin

RESULTS / EVALUATION	
Repeatability (Equipment Variation) EV= R double bar* K1	0.26000
Re-producability (Appraiser Variation) AV= O{(X diff* K2)^2-(EV/nr)}	0.1.61
Repeatability & Re-producability (R&R) R & R = O(EV^2+AV^2)	0.2808
Part Variation (PV) PV=Rp X K3	0.79350
Total Variation (TV) TV= O(R&R^2+PV^2)	0.8417
% Equipment Variation (EV) %EV=(EV/TV) *100	30.89
% Appraiser Variation (AV) % AV=(AV/TV) *100	12.60
% Repeatability & Reproducability (R&R) % R&R = (R&R/ TV) *100	33.36
% Part Variation (PV) %PV=(PV/TV) *100	94.27
No. of Distinct Data Categories ndc = 1.41 (PV/ GRR)	3.98
Repeatability & Reproducability (R&R) w.r.t Total Tolerance	28.08

Table 6. Defining parameters of the process

Process Width (P) = 0.5501	Specification Width (S) = 1.000	Index (K) = 0.2201
Design Centre (D) = 245.0000	Interval = 0.110100	Selecting no. of classes = 5
Starting Point = 244.8400	No. of readings = 50.0000	Shift Of 'Xmean' from 'D' = 0.110000

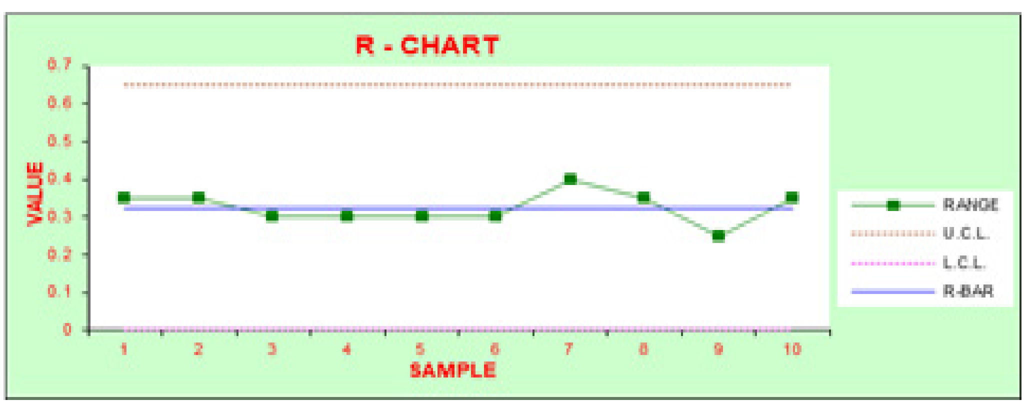

Figure 4. R bar chart for the SPC of King Pin.

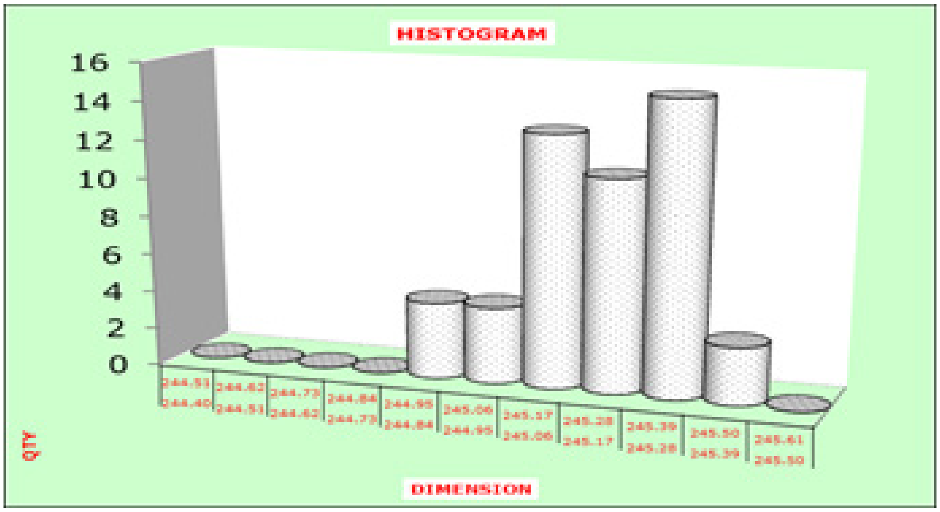

Figure 5. Histogram of the Range Distribution

Table 7. Performance indexes for the process

U.C.L. X-chart	245.30175
L.C.L. X-chart	244.91825
U.C.L. R-chart	0.6513
L.C.L. R-chart	0
Std.Dev."σ"=	**0.14639**
Cp=(S/6σ)=	**1.13860**
Cpk={1-K}xCp)=	**0.88800**

manufacturing of the new proposed design of the King pin.

The control graphs for the statistical process control of the process have been traced below along with other defining parameters of the process. The graphs show the normal distribution of the mean (X bar graph) and the range (R bar graph) of the process.

The X Bar and the R Bar graphs illustrate the mean and the range of the new proposed manufacturing process lies within the acceptable limits of the normal distribution the process and there are no out of control points in the process which is a good sign.

The Figure 5 shows that the distribution of the part tolerance within different range limits. In the given histogram, maximum number of the parts lies within the tolerance limit of 245.28 and 245.39.

The process's capacity to produce a product that meets standards is indicated by the process capability ratio, or Cp. The process's capacity to produce within specifications and its ability to follow the goal specification are both indicated by the process capability index, or Cpk. The values of Cp and Cpk, as shown in the Table 7, are more than 1, indicating that the process is centred, capable of delivering high-quality results with minimal defects, and that the tolerance spread is within the bounds of the normal distribution.

5.0 Conclusion

The existing measuring system shows quite a poor acceptability for the proposed design of the king pin. As such, there may be need for purchasing new more sophisticated and precise measuring equipment's. While, the process capability indexes of the system are within the acceptable limits and the process is capable of manufacturing parts within the specified tolerance limits with very few defects. This means that the control process for the proposed design of the King Pin is capable of producing accurate and precise results and maintain the whole system within the required designed specifications.

6.0 References

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