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Statistical Process Control (SPC) under the Quality Approach of Just In Time (JIT) Manufacturing Philosophie and an Application

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ABSTRACT

Purpose – The objective of this study is to apply Statistical Process Control (SPC) system to the cog wheel production. Continuous quality improvement of manufactured products is a fundamental assumption of Just in Time (JIT) manufacturing. One of the tools to achieve JIT quality through the elimination of variability is Statistical Process Control (SPC). Statistical Process Control is a powerful collection of problem-solving tools in achieving quality about process stability and improving capability through the reduction of variability. Variation can be significantly reduced by the help of statistical process control. This study is aimed at examining the added value of Statistical Process Control (SPC) in terms of quality when applied in production lines.

Design\methodology\approach – The scope of this study is to examine gear wheel production process in the X jeep factory. Before this study was carried out, there was no work on SPC in this factory. First of all the main problem in the gearboxes was understood and the ways for solving the main problem was explained.

Findings – It was found out that SPC is not only a simple control method to determine defective production but also it is a method for blocking defective production.

Discussion – Statistical Process Control (SPC) is the most widely used and effective tool that keeps under control of variability in the process.

1. INTRODUCTION

The subject of JIT means many things to many people. Some business people feel it is an approach; to others it is a methodology; others it is a philosophy, concept or strategy (Pinto et al, 2018). JIT is all these things and more. JIT is a philosophy of manufacturing based on elimination of all waste and continuous improvement of quality to zero defects (Aoki and Mouer, 2015: 2).

The goal in a JIT system is the habitual seeking of zero defects. A JIT operation should make quality a habit and insist all workers do their jobs right the first time. Under the JIT concept called Total Quality Control (TQC) quality is an ongoing and never-ending pursuit of perfection in the product (Masudin and Kamara, 2018:11).

Quality should be checked at each operation rather than wait until a lot has been completed. It is the concept of quality at the source Doing right the first time throughout all areas of the organization is the concept of quality at the source (Psomas and Anthony, 2017: 206). This involves using statistical process control, which focuses on continuous monitoring during the production process itself rather than on post-production inspection of the items produced. TQC concept requires quality control activities of the processes. When defects are found, their causes are immediately determined and corrected (Maskell,1989:34). Delivery of high quality parts and materials is fundamental to successful implementation of Statistical Process Control (SPC).

In statistical process control, simultaneous feedback messages from processes are taken by using processes outputs. By the help of these messages processes are adjusted and so the cost of final control is decreased and it is obstructed for process to produce defective products. For example, in cog wheel shop and at the CNC counter any kind of gear produces. During the operation a malfunction is occurred in the machine because of the dull of cutting implement and defective products are begin to be produced. In classical control these defects

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can be determined at the end of process but in statistical process control because the employee controls the critical measures during the operation with define time intervals, the defective product will be determined simultaneously and| the causes will be searched and corrected so defect-free products will be produced. But SPC should be applied not only in processes but also in procurement. SPC is not a simple control procedure. Its purpose is not only to determine defects but also to block the defective production. The main focus of contemporary quality idea is to obstacle problems before formation instead of reacting to defective products (Farnum, 1993:163).

When the current studies between 2010-2020 about JIT in the national and international literature are examined; Mackelprang and Nair,(2010:283) researched the relationship between JIT manufacturing practices and aggregate performance, Hou et al. (2011:6) talked about the benefits of using JIT in Chinese automotive industry in their studies, Mazanai (2012:5788) investigate the impact of application of Just-In-Time (JIT) inventory management system in the manufacturing sector small and medium enterprise (SMEs) in South Africa, Javadian et al. (2013:8) discusses in depth the implementation of JIT manufacturing. Aradhye and Kallurkar (2014:2234) examined the application of JIT in the service sector. Vandina (2016:403) examined the use of "Just in Time" system in the construction sphere and determined its influence on the level of competitiveness of the construction organization. Zeng et al.(2021:427) in their study examined Just-in-Time (JIT) defect prediction and found out that JIT focuses on program changes rather than whole programs and has been widely adopts and deal with continuous testing. Savcı (2019:291) examined the influence of just-in-time production system on the direct raw material cost by taking a publicly owned tea firm as an example. Şengün (2017:25) examined the scope of the JIT and the short descriptions of basic concepts in the JIT system in his study. Başar (2018:156) compared employees' job satisfaction and task performance levels who work at two different firms that operate according to just in time production and push production systems in his study. Öğünç (2020:1660) examined the effects of the internet of things on the just in time production system.

When the current studies between 2010-2020 about SPC in the national and international literature are examined; Mahesh and Prabhuswamye (2010:194) illustrated the step by step procedure adopted at a soap manufacturing company to improve the quality by reducing process variability using Statistical Process Control in their study, Shamsuzzaman et al.(2021:243)say in their study that the statistical process control (SPC) can be an effective tool for monitoring and controlling carbon emissions from industries, Polit and Chaboyer (2012:82) provided an overview of SPC in their work and used it in a nursing practice improvement in their study, Addeh et al.(2014:1490) investigated the design of an accurate system for the SPC control chart patterns in their study, Madanhirea and Mbohwa (2016:581) in their research focused on studying the statistical process control tool in manufacturing systems with the broad aim of upgrading them to improve on quality and cost effectiveness, Aydın and Kargı (2018:51), aimed to define whether the measurement of front door dynamic closing speed of the automobiles manufactured in an automotive manufacturing plant in Bursa is under statistical control in their study, Akyurt (2020:235) investigated the production lines of an industrial bread manufacturing company's factories with the statistical process control chart in his study. had been understood.

When the national and international literature is examined, it is seen that seperataly there are many studies on both about JIT and statistical process control, but there is no study that approaches the concept of statistical process control from a JIT philosophy point of view. In addition, this thesis, written in 1999, is unique in terms of the time that statistical process control was applied in a factory at the time of writing in national studies.

The objective of study is to apply Statistical Process Control (SPC) system to the cog wheel production, to examine how it creates a change and development in processes deal with the gear wheel production system and. to reveal the importance of SPC, which is one of the components of JIT philosophy,

In this context, in the first part of the study, Just-in-Time System philosophy will be examined, in the secondand third part, Just-In-Time Quality Management, Total Quality Control, Statistical Process Control (SPC) and methods will be explained, and in the forth part, the results of the application of SPC to gear wheel production will be examined.

2. CONCEPTUAL FRAMEWORK

2.1.Just In Time (JIT) Manufacturing Philosophie

Japanese manufacturing management method that is called as Just in Time is developed in 1970s. Taiichi Ohno adopted it at Toyota in order to meet consumer demands (Cheng,and Podolsky,1996:2). Before the introduction of JIT, there were a lot of manufacturing problems for the existing system at that time (Epps , 1995:245). Some of these were, inventory problem, product defects, risen cost, large lot production and delivery delays (Droge and Germain, 1988). For the product defects, manufacturers knew that even one single product defect can destroy the producer's creditability (Phogat and Gupta, 2017:187). They must create a 'defect-free' process (Hirano, 1988:10). JIT is the guiding philosophy that seeks perfection in production (Schonberger, 1987:5). JIT reduces waste by perfecting and simplifying processes (Cheng and Podolsky, 1996:5).JIT is a continuous improvement where non-value-added activities are identified and removed in order to increase quality, performance and innovation and reducing cost. (Wantuck, 1989:185).

JIT is the combination of philosophies and realities that improve the manufacturing process and yields the highest quality production at the lowest possible cost (Keane and King,1989:14). The philosophical, and realistic components of this combination are equally important. JIT philosophies include the goals of zero defects, zero inventory, and zero lead time. These objectives will never be realized without tangible, day-to-day commitment to the practical realities of JIT like employee involvement, statistical process control and inventory reduction. JIT philosophies and realities approach manufacturing in a straightforward manner. They replace non-value adding manufacturing practices with commonsense strategies and techniques that improve the manufacturing process. Quality must be the primary goal of JIT. The best way to maximize profits is to improve quality. Improved quality and reduced costs will increase sales and profit margins, thereby strengthening the organization's competitive position in the market place (Gupta,2012:59)

Although conflicting accounts exist regarding who first developed JIT , most research indicates that early pioneers in the field includes two Americans; Dr. W.E.Deming and Dr. J.M.Juran who developed the concepts of TQC(Total Quality Control) and SPC(Statistical Process Control). Both of these concepts are vital to the implementation of a JIT system (Donchess, 1990:15).

2.2. JIT Quality Management, Total Quality Control (TQC)

There is no single activity in business today that is more important to a company's survival than product quality. Quality control is the function of verifying conformance to product requirements (Oppenheım,1992:162). Under JIT approach product perfection is the goal. Total quality control is an element of JIT that is observed in all production stages from the production process to the delivery of the product (Nugroho et al.,2020:920). Its goal is to eliminate defects in the production process (Schniederjans, 1992:117). Just in Time is one side of the competitive coin. The other side is total quality control. Just in Time exposes the problems and forces to do something about them. Total Quality Control is a tool used to understand and solve those constraints. This is why just in time forces the use of total quality control (Phan et al, 2019:3093).

Just in Time and Total Quality Control are synergistic. They are more powerful together than apart. Continuous improvement at every level involving everyone, also known as kaizen, is directed toward satisfying such cross-functional goals as quality, cost, scheduling, manpower development and new product development. Total Quality Control effects and improves all areas of the organization, including customers and suppliers (Hutchins, 1988:108).

Armand V. Feigenbaum, author of the "Total Quality Control", defines it as "an effective system for integrating the quality devolopment, quality maintenance, and quality improvement efforts of the various groups in an organization so as to enable production and service at the most economical levels which allow for full customer satisfaction"(Feigenbaum,1961:93). Total Quality Control (TQC) incorporates a philosophy aimed at continuous process improvements resulting in increased customer satisfaction (Rinne and Mittang,1996:361). The central focus of total quality control is on building quality into the process the process becomes capable of consistently producing defect-free parts and products (Sidiwanto,2018). This result in customer satisfaction. Any defects are unacceptable and every effort must be directed at continuous improvement to achieve zero defects (Deluzio, l993:673).

Continuous quality improvement of manufactured products is a fundamental assumption of JIT manufacturing (Teeravaraprug et al., 2011:101). A JIT manufacturer looks for perfect manufacturing process to reduce variation , because variation requires rework and rework means waste. Quality is a measure of conformance to a standard process. A company that implements the just in time approach should attempt to do perfect processes that every items is produced exactly the same as every other item. To remove variance from the process requires control of process.

2.3. Statistical Process Control (SPC)

As it is stated above process must be controlled. No two things can be all alike and total variation can never be entirely eliminated. But its causes can be identified and controlled and variation can be significantly reduced **(**Keane and King, 1989:10).

To achieve JIT quality through the elimination of piece to piece variability, a company must give its employees a tool that helps them identify and control causes of variation in the process and must change the priority of detecting and sorting defects to preventing the defects from happening in the first place. The tool that must be used to achieve these goals is statistical process control (SPC) (Dobler and Burt, 1990:433).

There are four key points about using statistics to achieve Just in Time quality. These are (AT&T, 1984:121):

-The proper use of SPC can give literal meaning to the term zero defects by using shop floor control and engineering design to prevent defective production,

-SPC implementation should not be limited to use on the shop floor,

-Properly implemented, SPC is a fully realized form of pure employee involvement,

-Improved quality costs significantly less money.

In statistical process control, simultaneous feedback messages from processes are taken by using processes outputs (Botev and Johnson, 2020:103). By the help of these messages, processes are adjusted, the cost of final control is decreased and producing defective products is obstructed. For example, in cog wheel shop and at the CNC counter any kind of gear produces. During the operation a malfunction is occurred in the machine because of the dull of cutting implement and defective products are begin to be produced. In classical control these defects can be determined at the end of process but in statistical process control because the employee controls the critical measures during the operation within define time intervals, the defective product will be determined simultaneously and the causes will be searched and corrected so defect-free products will be produced (Ra´bago-Remy et al., 2014:2169).

So what is process? Process is a place where causes are found. Product is a place where results or outputs are found. So any mistakes in the outputs will be caused by process which includes human, machine, material, method, and environment (Montgomery,1996:108). Process is the series of operations to obtain good quality outputs. It is very important to provide process quality and process quality continuity. So changeability must be taken under control. The meaning of take under control is the ability to hold process variance within the random oscillation by setting aside the causes that creates the problems (Yamak, 1999:344).

Statistical Process Control is the use of statistical methods and techniques in every phase of production in order to provide production of materials in an economical and useful manner (Srikaeo et al., 2005:309). SPC determines the suitability of production to the pre-determined specifications. SPC aims to correlation to the standards and it is a tool used for to minimize the defective production. SPC is not a simple control procedure. Its purpose is not only to determine defects but also to block the defective production. SPC aims to reach defect free production results by using numerical data with the purpose of measuring and controlling qualitative and quantitative properties of supplied materials, methods, processes, machines, and employees. The focus of contemporary quality idea is to obstacle problems before formation instead of reacting to defective products (Akın, 1998:3).

SPC can be branched into six level in practicing quality control (Contello and Charmers, 1992:7):

-The definition of process,

-The determination of characteristics that will be controlled,

-The test of measurement tools,

- The analyze of process,

-The analyze of process performance,

-Process control tables.

The purpose of SPC is to provide an effective tool for operators to monitor quality as the process is going on. SPC provides a technique for production operators to monitoring quality continuously throughout the process. Quality is manufactured into the product, not inspected into it (Montgomery, 2009).

In order for a product to meet customer expectations, it must be produced with a repeatable process. In other words, the product's quality characteristics should show little variation around target values. Statistical Process Control is a problem solving tool that can be applied to any process and used to ensure process stability and reduce variability. (Farnum, 1993:164).

Its seven major tools are: (Cartin, 1993:167) Histogram, Check sheet, Flow chart, pareto chart, Cause and effect diagram, Grouping diagram, Scatter diagram, Control chart. Often referred to as the "magnificent seven", these tools are essential for the continuous improvement of quality. Besides these tools, the support of the management is also important for improving the quality (Halim Lim et al., 2017:176).

3. APPLICATION OF SPC IN X JEEP PLANT AT COG WHEEL PRODUCTION

In this section an example of applying Statistical Process Control (SPC) methods to improve quality and productivity in cog-wheel shop is given. There were no studies about SPC in the factory before making this study. This process was especially characterized by problems in gearbox that contains GT model cog wheels. The problem is the occurrence of unacceptable sounds while shifting gear in GT model jeeps. So there are some problems in cog wheel process. This process area has been chosen for initial implementation of SPC. A process improvement team was formed, consisting of the counter operators, manufacturing engineer responsible for the process , and a quality engineer. All members of the team had been informed about the "magnificent seven". During the first meeting, it was decided to concentrate on the problems of the cog-wheels to improve the process. The team quickly determined (based on the experience of operator) that cog wheels especially improper dimensions of cog wheels may be a major factor for sounds.

The team decided to use a cause and effect analysis to begin to isolate the potential cause of the problems in cog-wheels. Figure 1 shows the cause and effect diagram that was produced during a brainstorming session focused on problems in cog wheels. The team was able to determine 6 major potential cause of problems about cog wheels. These were as follows, machines, materials, methods, measurement, personnel and environment. A brainstorming session ensued to identify the various subcauses in each of these major categories. Then through discussion and the process elimination, the group decided that measurements itself was contained the most likely cause of problems.

But the cause and effect diagram does not include the relative importance of each element. In order to quantify data used check sheet for recording the number of times a given problems occurs. During a one lot GT model cog-wheel production that includes 100 cog wheel the ratio of problems are showed in Table 1 below. As more reliable data concerning the causes of defective cog wheels became available the team was able to analyze it using Pareto analysis in Figure 2 below. Notice that the incorrect dimension is a major cause of problem. Incorrect dimensions can be subclassified into parts as incorrect length, exterior diameter, interior diameter, lurch etc..

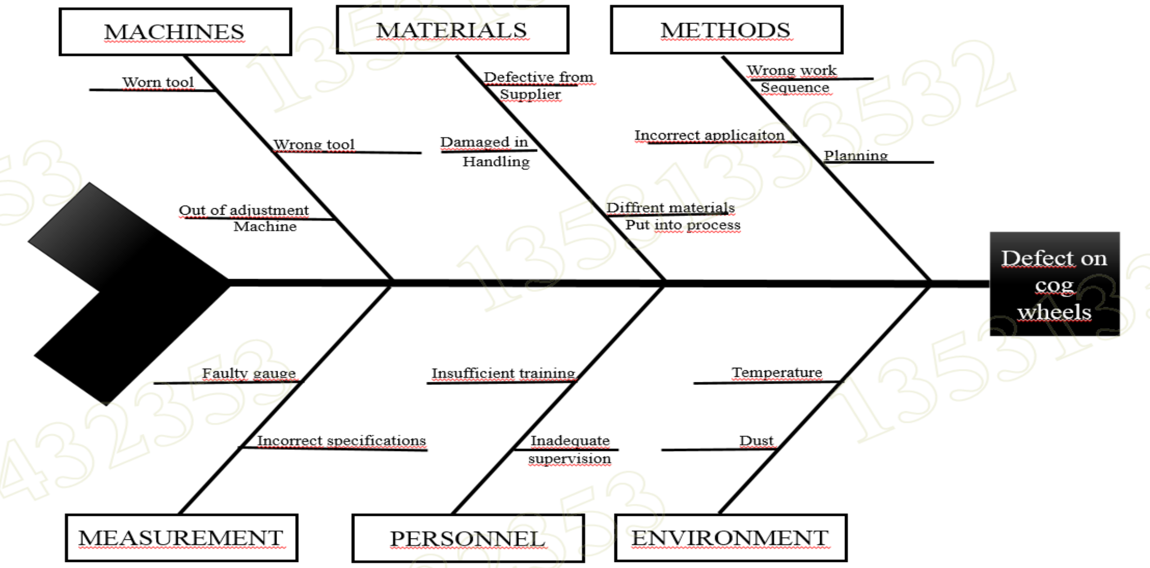

Fig 1. Cause and Effect Diagram for Defective Cog Wheels

Table 1. Defect Check Sheet for Cog Wheels

Machining problems	II	2
Workmanship problems	I	1
Incorrect dimensions	IIII IIII	8
Environmental problems	-	0
Methods	I	1
Materials	IIII	4
Total		16

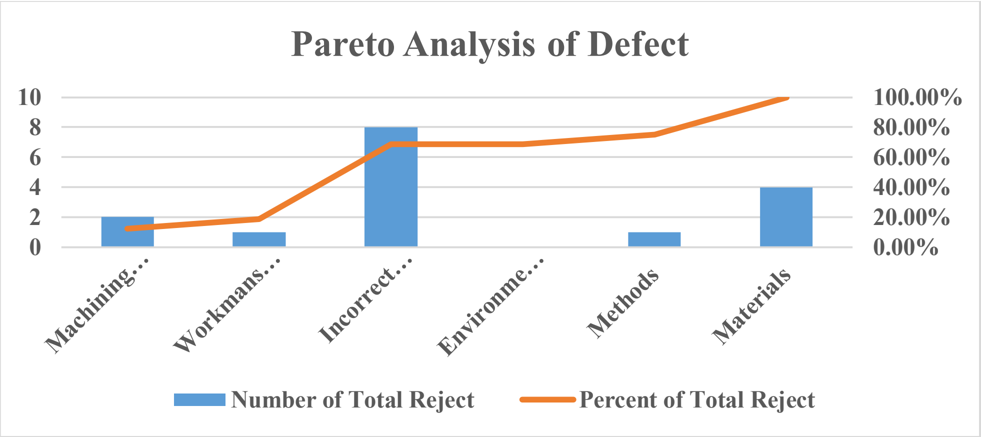

Fig 2. Pareto analysis of defects

After collecting and analyzing these data, it has decided to run statistical control charts on the process. It was wished to establish statistical control of the hole diameter of the GT model cog wheels using $\overline{x}$ and $\hat{R}$ charts. Ten samples, each of size five, were taken with one hour time interval. The data from these samples are shown in Table 2.

Table 2. The Results of Hole Diameter Measurements(mm) on GTCog Wheels

Date; 15-12-….   nominal value: 60.00 mm

Obs.N	time	1	2	3	4	5	$\hat{R}$	x
1.	08.00	60.1	60.2	60.4	60.1	60.1	0.3	60.18
2	09.00	60.1	60.5	60.7	60.3	60.4	0.6	60.40
3	10.00	60.2	60.3	60.3	60.3	60.2	0.1	60.26
4	11.00	59.8	59.9	59.7	59.7	59.5	0.4	59.72
5	12.00	60.4	60.2	59.7	60.9	60.4	1.2	60.32
6	13-15	60.4	60.6	59.7	60.4	60.6	0.3	60.54
7	15.00	60.2	60.5	60.3	60.3	60.7	0.5	60.40
8	16:00	60.6	60.3	60.7	60.7	60.3	0.4	60.52
9	17.00	60	60.5	60.8	61.2	60.4	1.2	60.58
10	18.00	60.1	59.1	58.8	60.7	60.6	1.9	59.86
					Total		6.9	602.78

When setting up $\overline{x}$ and $\hat{R}$ control charts, it is best to begin with the $\hat{R}$ chart. Because the control limits on the x chart depend on the process variability. Using the data in Table 2, the centerline for the $\hat{R}$ chart is computed as follows:

Average Range = $\hat{R}$ = 6.9/10 = 0.69

For samples n=5 its found from Table 3 that D3=0 and D4= 2.115

Table 3. Confidence Factors for the A, D3, D4, d2 Coefficients in the $\overline{x}$ and $\hat{R}$ Process Control Charts

Sample size(n)	A	D3	D4	d2
2	1.88	0	3.265	1.128
3	1.023	0	2.574	1.693
4	0.729	0	2.282	2.059
5	0.577	0	2.115	2,326
6	0.483	0	2.004	2.534
7	0.419	0.076	1.924	2.704
8	0.373	0.136	1.864	2.847
9	0.337	0.184	1.816	2.970
10	0.308	0.223	1.777	3.07
11	0.285	0.256	1.744	3.17
12	0.266	0.283	1.717	3.258

Therefore the control limits for the $\hat{R}$ chart are:

LCL= $\overline{R}$D3 =0.69*0 = 0

UCL = $\overline{R}$D4 = 0.69*2.115=1.459

$\hat{R}$ chart is shown in Figure 3 below.

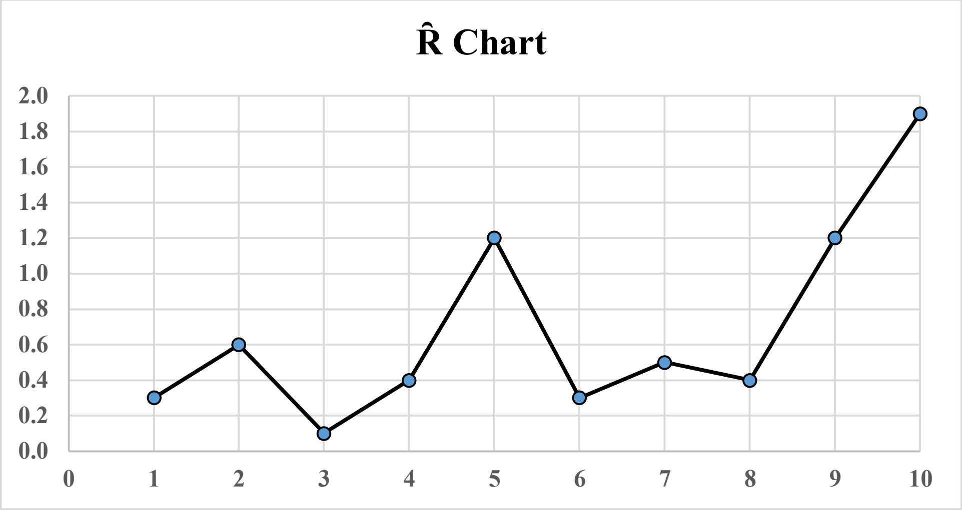

Fig 3. R̂ chart

Figure above illustrates the resulting average range and upper and lower control limits for the subgroup ranges. The R̂ chart is then examined for signs of special variation. One of the points, which is point 10 is out of control limits so there is indication of special sources of variation on the R̂ chart and there is a lack of control. This point should be taken to the control limits by taking precautions. When searched the reasons of point ten, it is found out that the motivation on the work is decreased through the end of working hours. After analyzing the R̂ chart, the x bar chart is constructed. This control chart depicts variations in the averages of the subgroups. The centerline is:

$\overline{X}$ = 602.78/ 10 = 60.278

To find the control limits on the x chart, A =0.577 from Table 3 for samples of size n=5 and control limits are used :

UCL= $\overline{X}$ + $\overline{A}$R

= 60.278+ (0.577)* 0.69 = 60.676

LCL = $\overline{X}$ - $\overline{A}$R

= 60.278-(0.577)* 0.69 = 59.88

The $\overline{x}$ chart is shown in Figure 4 below.

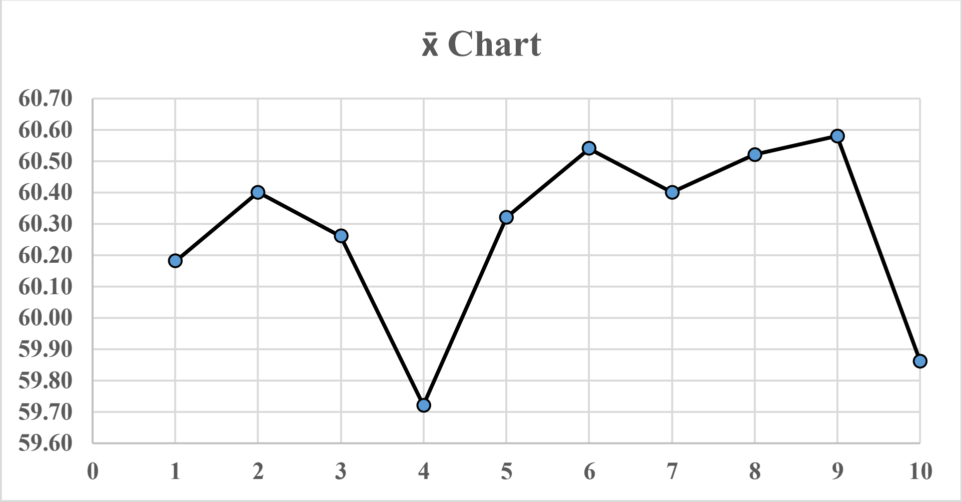

Fig 4. $\overline{x}$ chart

In the x-bar control chart notice that a total of two points are outside of the control limits and therefore indicate a lack of control. So there is a special variation in the process. It is í necessary to take these two outside points into the control limits. When searched the reasons of that situation , it is found out that at 11.00 o'clock, the cutting implement that was dull, has been changed with a new one so the setup of the machine was spoiled or unbalanced. Assuming that the plant adopts JIT quality management principles and that the plant starts solving quality related problems in their operation and a new sample is taken of hole diameters as : 60.20, 60.1, 60.0 , 60.10, and 60.10 mm . And also all observation are made again as shown below Table 4. In a JIT operation the impact of quality improvements should be communicated as soon as possible to reinforce quality as a habit. If the additional sample is added into the computations of the existing UCL and LCL values for both charts, their boundaries will be revised as shown in Figure 5 and 6. below.

Table 4. New Results

Obs.	time	1	2	3	4	5	R̂	x
1	08.00	60.1	60.2	60.4	*60.1*	60.1	0.3	60.18
2	09.00	60.1	60.5	60.7	60.3	60.4	0.6	60.40
3	10.00	60.2	60.3	60.3	60.3	60.2	0.1	60.26
4	11.00	60.40	60.2	60.3	60.20	60.3	0.2	60:28
5	12.00	60.1	60.2	60.4	60.1	60.1	0.3	60.18
6	13.00	60.5	60.3	60.7	60.7	60.3	0.4	60.5
7	15.00	60.2	60.5	60.3	60.3	60.7	0.5	60.40
8	16.00	*60.5*	60.3	60.7	60.7	60.3	0.4	60.5
9	17.00	60.1	60.5	60.7	60.3	60.4	*0.6*	60.40
10	IS. 00	60.2	60.5	60.3	60.3	60.7	0.5	60.40
11	19.00	60.2	60.1	60.0	60.1	60.10	0.2	60.1
			New total				4.1	663.60

Average Range =R̄ = 4.1 / 11 = 0.372

For samples n=5 founded from Table 3 that D3=0 and D4= 2.115

Therefore the control limits for the R̂ chart are:

LCL = R̄D3 - 0.472*0 = 0

UCL= R̄D4 = 0.372*2.115 =0.79

The new R chart is shown in Figure 5 below.

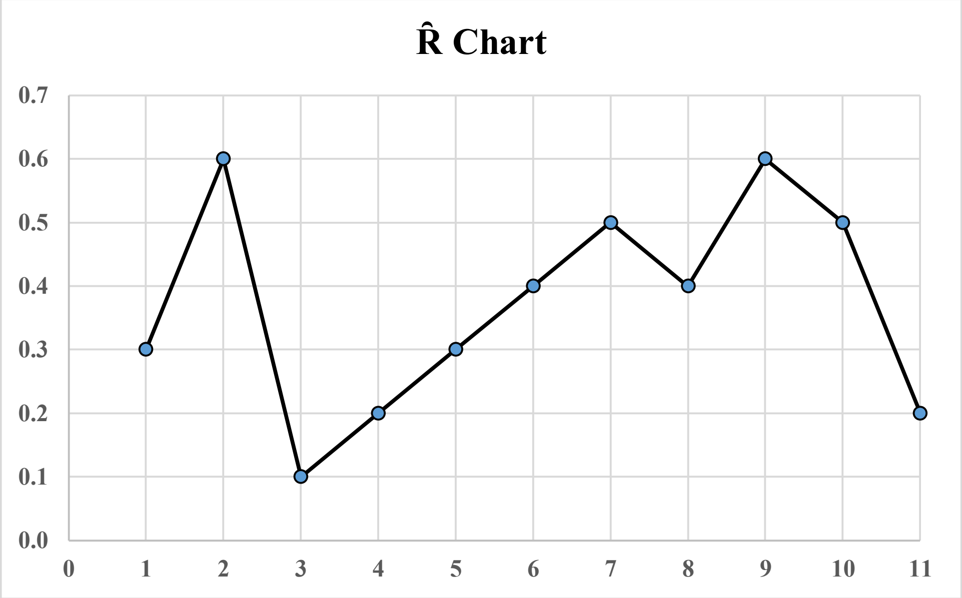

Fig 5. R̂ chart

So as shown in Figure there is no indication of an out of control condition. After analyzing the R chart, it is constructed the new x bar chart. This control chart depicts variations in the averages of the subgroups. The centerline is:

$\overline{x}$ = 663.60/ 11 =60.32

To find the control limits on the $\overline{x}$ chart, A= 0.577 from Table 3 for sample size of n=5 and control limits are used:

UCL= $\overline{X} + \overline{A}R$

= 60.32+ (0.577)* 0.372 = 60.53

LCL = $\overline{X} - \overline{A}R$

= 60.32 - (0.577)* 0.372 = 60.10

The new $\overline{x}$ chart is shown in Figure 6 below.

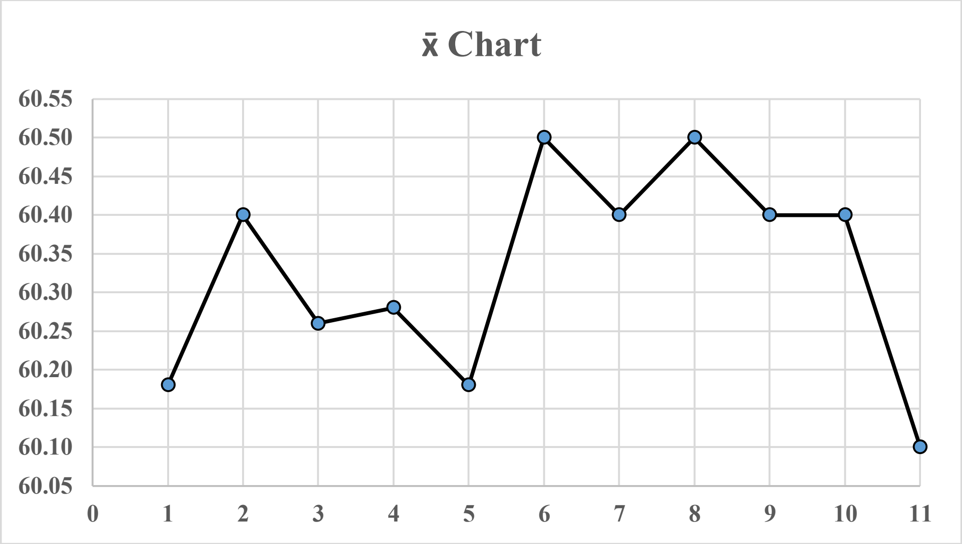

Fig 6. $\overline{x}$ chart

So as shown in Figure, there is no indication of an out of control condition. Therefore, since both the $\overline{x}$ and R charts exhibit control, it can be concluded as the process is in control. As it is seen, the UCL and LCL have been narrowed, reflecting an improvement in quality by a reduction in process variation. Workers at work centers can easily see and understand that the narrowing of boundaries is a direct reflection of their efforts to improve quality, that their efforts are making a difference, and that there is still more variation needing reduction. After analyzing hole diameters of GT model cog wheels , there is a need to establish charts for quality characteristics of cog wheels that can not be measured. So p-chart and c-chart are used for attribute quality characteristics of cog wheels. At control point 4, it is searched for surface split control of the cog wheels. The sample size was 50. And searched this attribute through 15 days. This test would be evaluated on a two outcome basis of surface of cog wheels being either defective or not defective (crack or not). The collected data are shown in Table 5 below.

Table 5. p Chart Data

Sample number	number of defective cog wheel	sample fraction
1	12	0.24
2	15	0.30
3	8	0.16
4	10	0.20
5	4	0.08
6	7	0.14
7	12	0.24
8	9	0.18
9	13	0.26
10	10	0.20
11	5	0.10
12	6	0.12
13	14	0.28
14	12	0.24
15	22	0.44
	159	0.212

$\overline{p} = 159 / (15)*(50) = 0.212$ = mean fraction defective

Using $\overline{p}$ as an estimate of the true process fraction non-conforming, it is calculated the upper and lower control limits as:

$$UCLp = 0.212 + 3\sqrt{\frac{0.212*0.788}{50}}$$

$$= 0.385$$

$$LCLp = 0.212 - 3\sqrt{\frac{0.212*0.788}{50}}$$

$$= 0.038$$

The control chart with centerline at $\overline{p} = 0.212$ and the upper and lower control limits is shown in Figure 7 below.

Sample fraction nonconforming

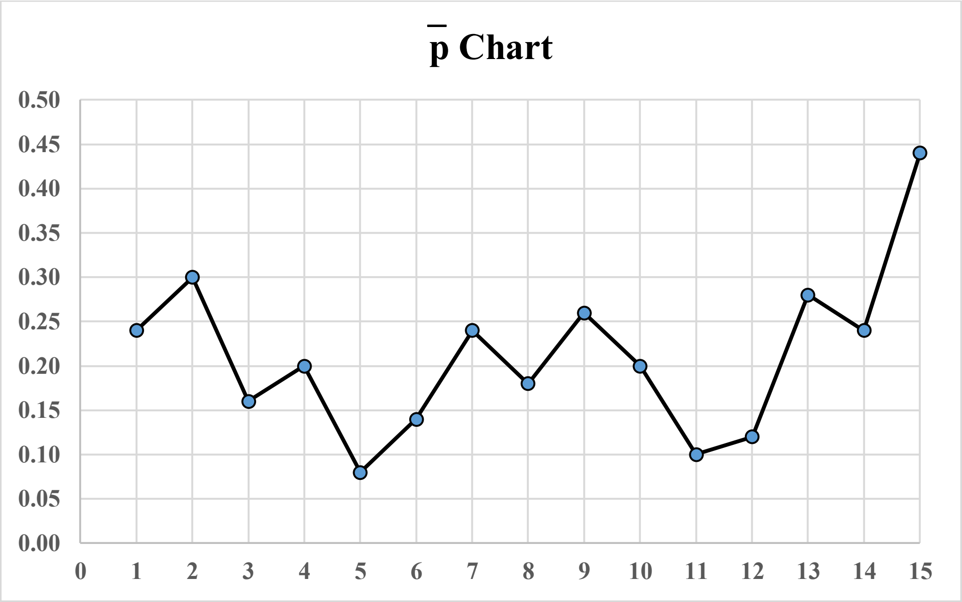

Fig 7. $\overline{p}$-chart

Analyses of the chart indicates that point 15 is above the upper control limit, so the process is not in control. This point must be investigated to determine assignable causes. When the reason of point 15 is searched, it is found that a new raw material was put into production during that time and it was not suitable to the standards. It means that there are very little problems with the raw material and also it can be understood from pareto chart above. In pareto chart it is said that there are problems about the raw materials but these problems are little or smaller than incorrect dimension problems. After that, it is wanted to inspect the occurrence of nonconformities on cog wheels components as a whole (dull or bright, helix and profile control etc.) and set up a c-control chart to monitor the quality of cog wheels. The control chart is to be set up to monitor the observed number of flaws in the parts of cog wheels. Obviously $\bar{x}$. and R chart can not be used because we are not measuring flaws, only counting them. Likewise, it can not be used p chart because there is no way to know how many possible flaws can exist on a component, so a fraction defective can not be determined. So c-chart can be used because flaws are countable. Table 6 below presents the number of nonconformities observed in 5 samples of 50 cog wheels.

Table 6. Data of nonconformities

Data on the number of nonconformities in samples of 50 cog wheels

Sample number	number of nonconformities
1	1
2	2
3	4
4	5
5	6
	+
	18

Since the 5 samples contain 18 total nonconformities c can be calculated as:

$\bar{c} = 18/5 = 3.6$

$UCLc = 3.6+3* \sqrt{3.6} = 9.29$

$LCLc = 3.6-3* \sqrt{3.6} = 0$

The control chart is shown in Figure 8 below.

number of nonconformities

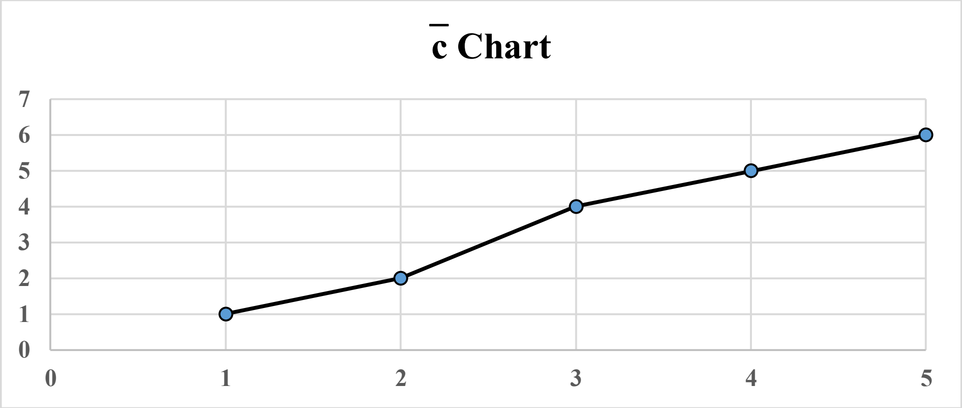

Fig 8. c- chart

In Figure 8 above it appears that although all points are between the control limits , the number of flaws is increasing steadily over time so there is need to take some corrective actions to improve the process. When the reasons are searched, it is found that the machine to polish the cog wheels is broken down and not to stop the production(while repairing the machine) the process had been continued so a work sequence error during the production of that cog wheels are occurred. After determining some mistakes in the process, it is wanted to provide information about the performance or capability of the process about hole diameter. From the $\bar{x}$ chart in Figure 4, it can be estimated the mean hole diameter of the GT model cog wheel as $\bar{x}$ = 6,278 mm. The process standard deviation can be estimated as:

б = $\bar{R}$/ d2 - 0.69/ 2.326 = 0.296

$\bar{R}$= average range

б = estimated process standard deviation

Where d2 is a constant and value of d2 for samples of size five is found in Table 3. The specification limits on this cog wheel are 60 +- 0.8 mm. The control chart data can be used to describe the capability of the process to produce GT model cog wheels relative to these specifications. Defining that cog wheels hole diameter is a normally distributed random variable with mean 60.278 and standard deviation 0.296, it can be estimated the process capability as:

Cp = Engineering tolerance/ Process variation

= (upper specification limit- lower specification limit) / 6 б

= USL-LSL / 6 б

= 60.800- 59.200/ 6*0.296

= 1.6/ 1.74

= 0.90

Cp < 1, 0.9<1

Notice that the 6 б spread of the process is the baste definition of the process capability. Since б is usually unknown , it can be replaced with an estimate (б). The Cp result implies that the natural tolerance limits in the process (3 б above and below the mean) are not inside the lower and upper specification limits. That is, the process uses up more than 100 % of the tolerance band. In this case, the process is very yield sensitive and a large number of nonconforming units will be produced. Shortly process is not sufficient or process con not make production within determined specifications. It can be showed in Figure 9 below.

LNTL: lower natural tolerance limit

LSL : lower specification limit

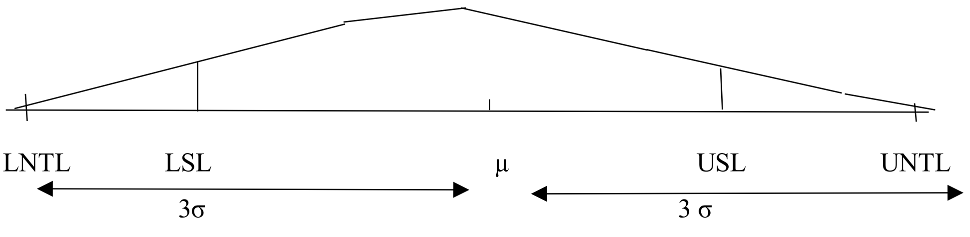

Figure 9. Process Capability Ratio

But this is not adequate to say process is sufficient or not. Also it must be searches for process capability index(Cpk). The process capability is calculated assuming the process is centered between the upper and lower tolerance limits. It measures the potential capability. Another ratio, called the capability index takes into account the lack of centering of the process. Cp index controls the spread of process. Cpk index controls not only the spread of the process, but also controls variance of the process mean from target. But in order to achieve that objective Cpk index should be formed two sided.

Cpk index**.** A measure of both process dispersion and its centering about the average.

Cpk,Cp < 1.00 Process is not capable.

1.00 <= Cpk,Cp < 1.33 Process is marginal. Process should be under control.

Cpk, Cp >= 1.33 Process is capable.

The capability index

- considers only the spread of the characteristic in relation to specification limits
- assumes two-sided specification limits

The product can be bad if the mean is not set appropriately. The process performance index takes account of the mean ($\bar{x}$) and is defined as:

C_{pk} - min[(USL - $\bar{x}$) / 3 б, ($\bar{x}$ - LSL) / 3 б]

The process performance index can also accommodate one sided specification limits

for upper specification limit Cpk = (USL - $\bar{x}$)/3 б

for lower specification limit: C_{P}k = ($\bar{x}$ - LSL)/3 б

After giving this information, Cpk index for Figure 4 is found as :

C_{P}k low = 60.278 - 59.2/ 3*0.296

= 1.21

Cpkup = 60.800-60.278/3*0.296

= 0.587 < 1

Cp has been calculated as = 0.9 and smaller than 1.

It will be taken minimum value of Cpk, so Cpk upper value are taken and it is 0.587 and smaller than 1. Finally it can be said that process is not sufficient and precautions should be taken to correct the process. In Figure 5 and in Figure 6, the mistakes were found and precautions are taken and a new result is found. According to new result, the new Cp and Cpk indexes are found as,

б new= $\bar{R}$new/ d2

= 0.372/2.326 = 0.16

Cp_{new}= 1.6/6*0.16 = 1.66>1

Cpk new up= 60.800- 60.32/3*0.16= 1

Cpk new low= 60.32- 59.2/ 3*0.16 = 2.33

As a result of these information, it can be said that process is capable but still it should be under control.

After seeing that process is under control, it is desired to be seen in histogram according to data in Table 4. The histogram about the GT model cog wheels hole diameter is drawn below in Figure 10.

Minimum value : 60.0 Maximum value : 60.7

Class interval size : 0.2

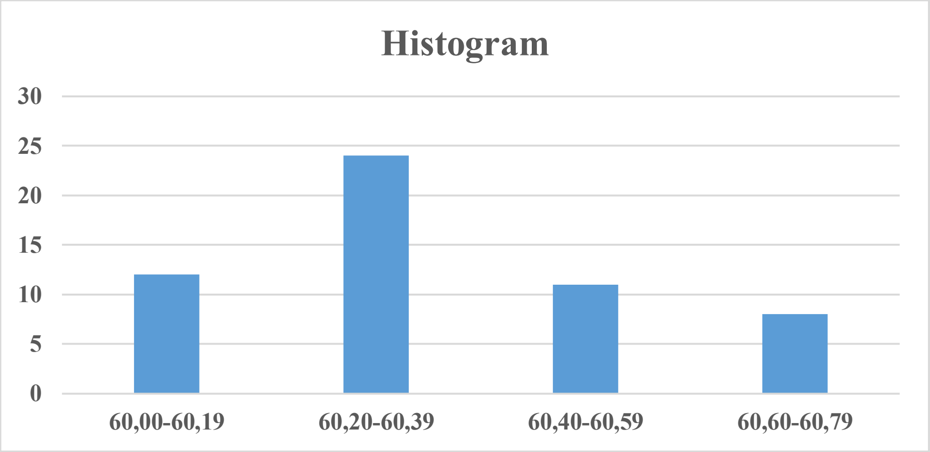

Fig 10. Histogram

As shown in Figure 10 above, all columns of the histogram are placed within the upper and lower specification limits. So it can be said that process is stable and capable of meeting specifications. GT model cog wheels consist of another properties that should be analyzed. Some of these are: length of cog wheel, exterior diameter of the cog wheel, W4 size , rolling control etc.. First of all, the length of cog wheel is searched. The same procedure was followed as made in examining hole diameter of the cog wheel. The observation data was collected with the same sample size (Ten samples, each of size five) and same time interval. (Table 7) These raw data will not be presented here but only the $\overline{x}$ and R values will be given.

Length of cog wheel nominal value: 35.43 +- 0.04 cm

Table 7. Sample

	$\overline{X}$	R
	35.422	0.02
	35.43	0.02
	35.42	0.02
	35.428	0.02
	35.43	0.02
	35.42	0.02
	35.416	0.01
	35.402	0.01
	35.408	0.02
	35.414	001
Total	354.19	0.17

$\overline{\overline{X}}$ = 35.419 $\overline{R}$= 0.017

For R chart;

UCL= D4*$\overline{R}$ = 2.115*0.017= 0.036

LCL = D3*$\overline{R}$ = 0*0.017 = 0

For x chart;

UCL= $\overline{x}$ + A*R

UCL = 35.419 +0.577*0.017 = 35.43

LCL = 35.419 - 0.577* 0.017 = 35.40

After calculation , the $\overline{x}$ and R charts are drawn in Figure 11 and 12 below.

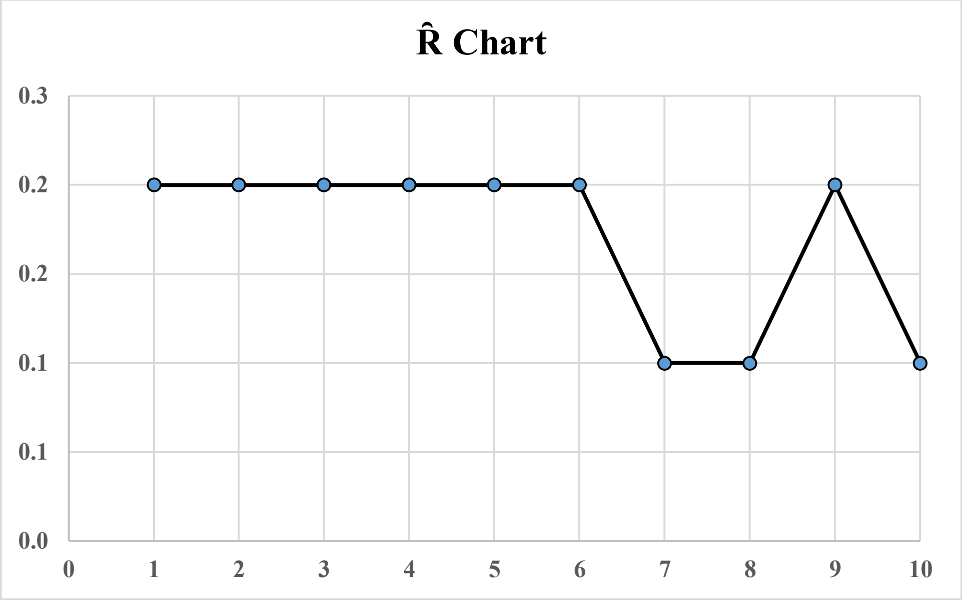

Fig 11. R chart

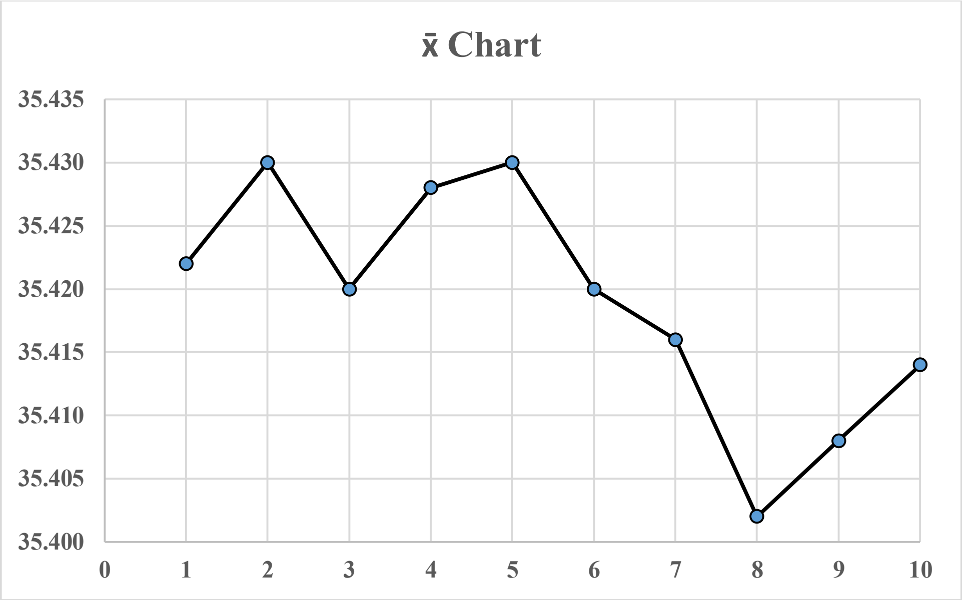

Fig 12. $\overline{x}$ chart

As a result of these Figures it can be said that the process about the length of cog wheel is under control. There are not any points that out of control limits so special variation is not determined in the process. After that, process capability analyzes is made to control the convenience of process to the specification limits and indexes are calculated as shown in below.

LSL = 35.39

б = $\overline{R}$/d2 = 0.017/2.326 = 0.0073

Cp = 35.47-35.39/6*0.0073

= 1.82

Because 1 82>1 so process is capable.

Cpkup = 35.47 - 35.419/3*0.0073

= 1.872

Cpk low = 35.419- 35.39 / 3*0.073

= 1.32

= 1.87>1

=1.32>1

So process is under control and process can go on to the production about the length of cog wheel. After analyzing the length of cog wheel, the exterior diameter is searched with the same procedure. The raw data is presented below (Table 8):

Exterior diameter nominal value: 100 +- 0.03 mm

Table 8. Raw Data

$\bar{x}$	R
99.97	0.03
99.98	0.03
99.97	0.05
99.99	0.01
100.0	0.02
99.98	0.03
99.97	0.03
100.03	0.06
100.01	0.05
99.99	0.03
999.89	0.34

$\bar{x}$ = 999.89/ 10 = 99.989

$\bar{R}$= 0.34/ 10 = 0.034

For R chart;

UCL=D4*$\bar{R}$ = 2.115*0.034= 0.07

LCL = D3*$\bar{R}$= 0*0.034 = 0

For $\bar{x}$ chart;

UCL= $\bar{x}$ + A*$\bar{R}$

UCL = 99.989 +0.577*0.034 = 100.0

LCL = 99.989 - 0.577* 0.034 = 99.969

After calculation, the $\bar{x}$ and $\bar{R}$ charts are drawn in Figure 13 and 14 below.

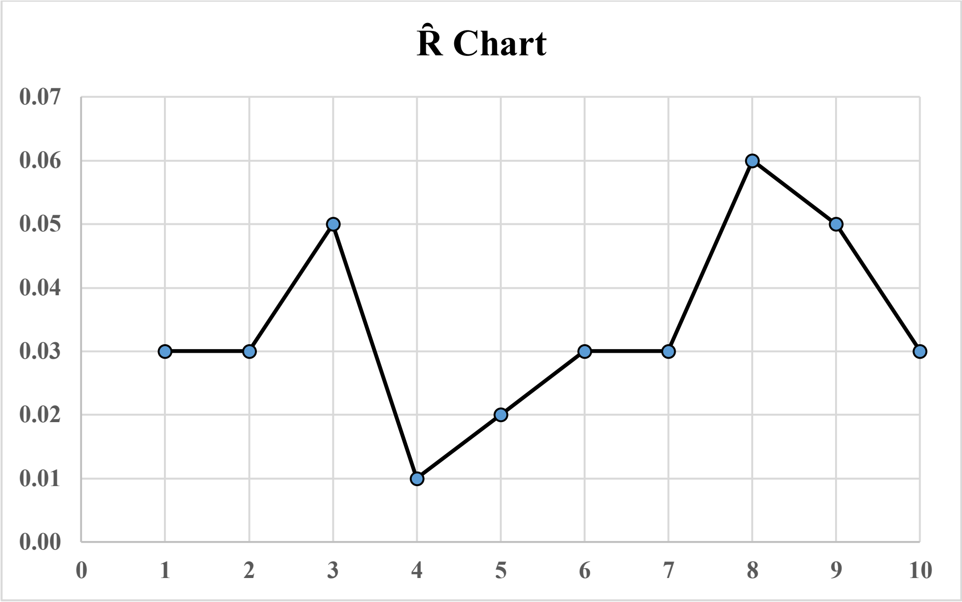

Fig 13. R chart

All points are within the control limits. There is not any indication of out of control condition. So the $\overline{x}$ chart can be drawn now.

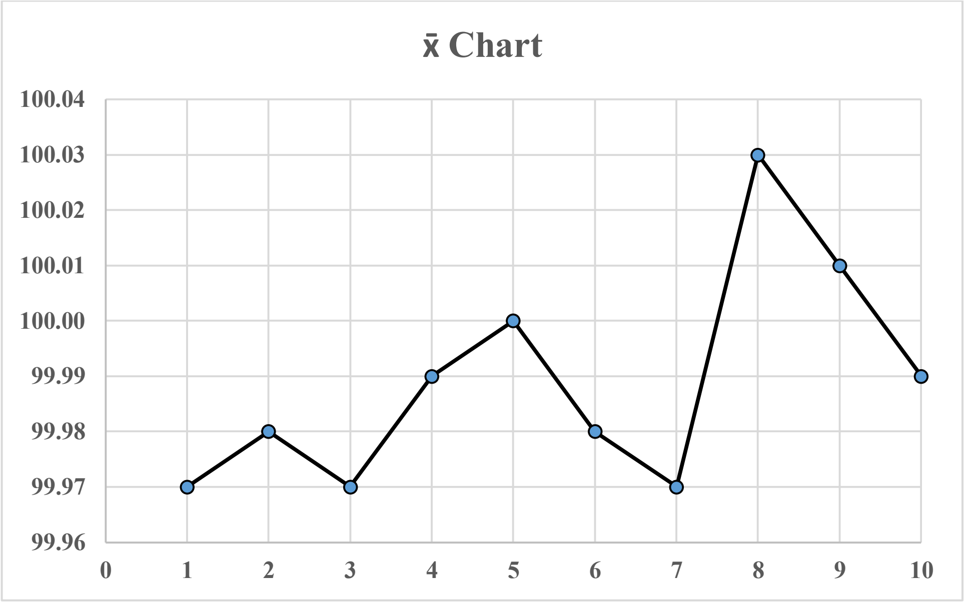

Fig 14. $\overline{x}$ chart

After analyzing the $\overline{x}$-bar chart, it can be said that there are two points outside the control limits, indicating that assignable causes are present in the process and process is out of statistical control. The reasons should be searched and corrected to eliminate special causes. When the causes of problem is searched, it is found that inexperienced worker made incorrect gauge at sample 8 and 9. When these gauges are corrected, it is found that these points are within specification limits. The new and corrected values of sample 8 and 9 are:

$\overline{X}$	$\overline{R}$
100.0	0.03
99.99	0.02

the new total : 999.84 and for R : 0.28

X= 99.984 $\overline{R}$= 0.028

For R chart;

UCL= D4*R = 2.115*0.028= 0.06

LCL = D3*R = 0*0.028 = 0

For x chart;

UCL = x + A*R

UCL = 99.984 +0.577*0.028 = 100.0

LCL = 99.984 - 0.577* 0.028 = 99.967

After that, process capability analyzes is made to control the convenience of process to the specification limits and indexes are calculated as shown in below.

USL= 100.03 LSL = 99.97

б = $\overline{R}$/ d2 = 0.028 / 2.326 = 0.012

Cp= 100.03-99.970/6*0.012 = 0.83

Because 0.83<1 so process is not capable.

Cpk low = 99.984-99.97/3*0.012

= 0.38

= 0.38<1

So process is not capable and sufficient. The process is under control but it does not mean it is capable. So in order to increase Cp and CPK values, process should be developed and specification values, limits should be revised. After analyzing the exterior diameter of cog wheel, the W4 size is searched with the procedure. The raw data is presented below (Table 9):

W4 size nominal value: 33.92 + 0.02 mm

Table 9. Raw Data

$\overline{X}$	R
33.94	0.04
33.92	0.02
33.90	0.03
33.91	0.02
33.90	0.02
33.89	0.03
33.91	0.02
33.92	0.04
33.88	0.02
33.90	0.03
Total 339.07	0.27

x = 339.07/ 10 = 33.907

R= 0.27/ 10 = 0.027

For R chart;

UCL= D4*R= 2.115*0.027= 0.0571

LCL = D3*R = 0*0.034 = 0

For $\overline{x}$ chart;

UCL= $\overline{x}$+ A*R

UCL = 33.907 +0.577*0.027 = 33.92

LCL = 33.907 - 0.577* 0.027 = 33.89

After calculation, the $\overline{x}$ and R charts are drawn in Figure 15 and 16 below.

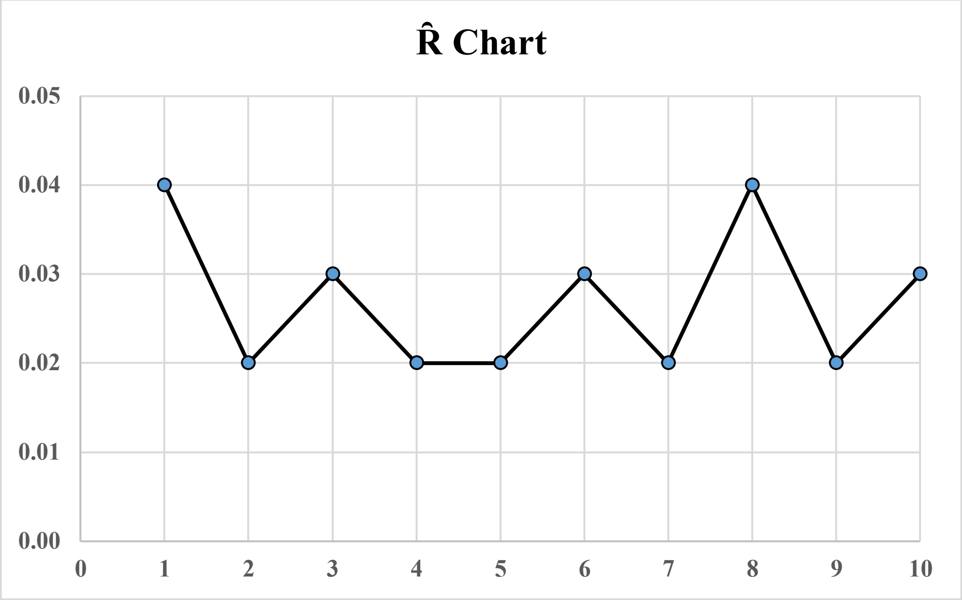

Fig 15 R chart

All points are within the control limits. There is not any indication of out of control condition. So the x chart can be drawn now.

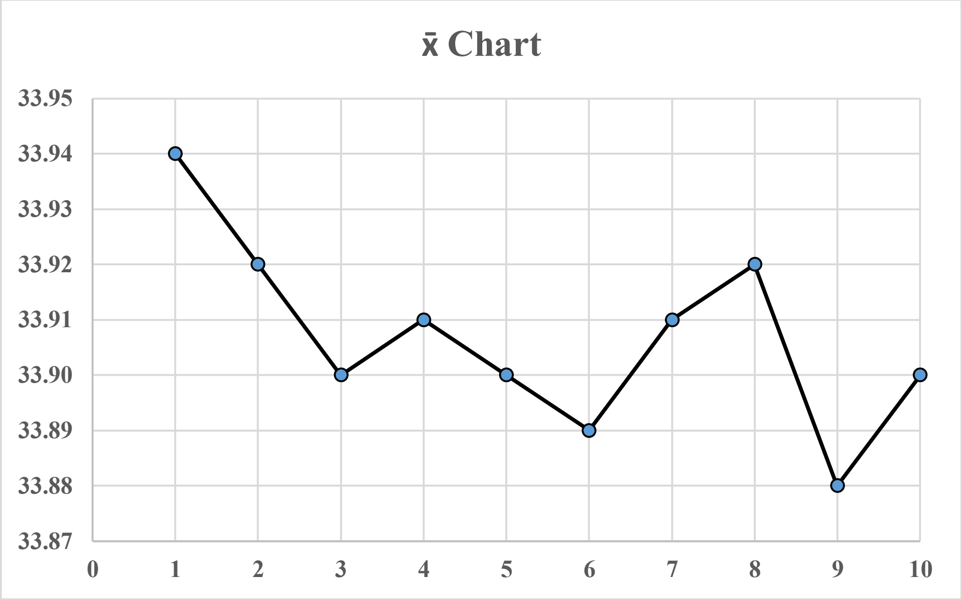

Fig 16. $\overline{x}$ *chart*

After analyzing the x-bar chart, it can be said that there are two points outside the control limits, indicating that assignable causes are present in the process and process is out of statistical control. The reasons should be searched and corrected to eliminate special causes. When the causes of problem is searched, it is found that a new raw material was put into production during production process and it was not suitable to the standards. After that, process capability analyzes is made to control the convenience of process to the specification limits and indexes are calculated as shown in below.

USL= 33.94

LSL= 33.90

б = R/ d2 = 0.027/ 2.326 = 0.0116

$Cp = 33.94-33.90/6*0.0116$

$= 0.574$

Because $0.574<1$ so process is not capable.

$CpkuP= 33.94 - 33.907/3*0.0116$ $\quad$ $CPk\ low = 33.907- 33.90 / 3*0.073$

$= 0.94 \quad = 0.2$

$= 0.94<1=0.2<1$

So process is not capable and sufficient. The process is not under control and it is not capable. So in order to increase Cp and Cpk values, process should be developed and specification values, limits should be revised.

4. APPLICATION RESULTS

After the problem is determined in GT model gearboxes that contain GT model cog wheels, the possible causes are searched . Under the control of management leadership, process is defined, a quality team is formed and informed about the seven tools. The characteristics that will be controlled is determined and the calibration of the measurement tools is made and tested. By the help of brainstorming session , possible six causes of problem is determined, cause and effect diagram is formed. In order to quantify data, the check sheet and pareto chart is used. Finally, control charts are drawn and process capability and performance analysis is made and interpreted.

Firstly, the hole diameter of the cog wheel is searched. After the raw data is collected, by the help of R and x bar chart it is seen that there is a sign of special causes in the process. The causes of variation is searched and corrected .After , a new data is collected and it is seen that there is no indication of an "out of control" condition. Therefore, since both the $\overline{x}$ and R charts exhibit control, it can be concluded as the process is in control. As it is seen, the UCL and LCL have been narrowed, reflecting an improvement in quality by a reduction in process variation. After analyzing hole diameters of GT model cog wheels , charts for quality characteristics of cog wheels that can not be measured is formed. So p-chart and c-chart for attribute quality characteristics of cog wheels is used. After analyzing these charts, possible causes of variation for attribute quality characteristics are found.

After constructing control charts, process capability and performance analysis are made and interpreted for both new and old values. After seeing that process is under control, it is desired to be seen in histogram and histogram is formed about hole diameter of the cog wheel and it can be said that process is stable and capable of meeting specifications. GT model cog wheels consist of another properties(parts) that should be analyzed. Some of these are: length of cog wheel, exterior diameter of the cog wheel, W4 size. First of all, the length of cog wheel is searched. The same procedure was followed as made in examining hole diameter of the cog wheel. The control charts($\overline{x}$ and R) is formed and interpreted. After that, process capability analyzes is made to control the convenience of process to the specification limits. Finally it is said that process is under control and process can go on to the production about the length of cog wheel. After analyzing the length of cog wheel, the exterior diameter is searched with the same procedure. The control charts(x and R) is formed and interpreted. After that , process capability analyzes is made to control the convenience of process to the specification limits. Finally it is said that process is not capable and sufficient. The process is under control but it does not mean it is capable. So in order to increase Cp and Cpk values, process should be developed and specification values, limits should be revised. After analyzing the exterior diameter of cog wheel, the W4 size is searched with the. same procedure. The control charts ($\overline{x}$ and R) is formed and interpreted. After that , process capability analyzes is made to control the convenience of process to the specification limits. Finally it is said that process is not capable and sufficient. The process is not under control and it is not capable. So in order to increase Cp and Cpk values, process should be developed and specification values, limits should be revised.

At the end of quality control, a control report form is prepared that summarizes the results in Table 10. below. This report is prepared by using old values. At the end of each correction, the report should be reorganized by using new values.

Table 10. Control Report Form

<table>
<tr><td colspan="7">The classification of positions with respect to process capability and performance</td></tr>
<tr><td>Control charts</td><td>Process capability</td><td>Process performance</td><td>Recommended recaution</td><td colspan="3">process</td></tr>
<tr><td>Within control limits</td><td>Good Cp ≥1.00</td><td>good Cpk ≥1.00</td><td>go on process</td><td colspan="3">A</td></tr>
<tr><td>Out of control Limits</td><td>Good Cp ≥1.00</td><td>bad Cpk < 1.00</td><td>Process should be under control</td><td colspan="3">B</td></tr>
<tr><td></td><td>Bad Cp < 1.00</td><td>bad Cpk < 1.00</td><td>Insufficient process</td><td colspan="3">C</td></tr>
<tr><td colspan="2">MODEL NAME OF THE COG WHEEl</td><td colspan="5">GT MODEL COG WHELL</td></tr>
<tr><td>part number</td><td>part name</td><td>control chart position</td><td>Specification limits</td><td>Cp</td><td>Cpk</td><td>process</td></tr>
<tr><td>1</td><td>Hole diameter</td><td>sign of special</td><td>60 – 0.8 mm</td><td>0.9</td><td>0.587</td><td>C</td></tr>
<tr><td>2</td><td>Length</td><td>no sign of special variation</td><td>35.43 – 0.04 mm</td><td>1.82</td><td>1.32</td><td>A</td></tr>
<tr><td>3</td><td>Exterior diameter</td><td>sign of special</td><td>100 – 0.03 mm</td><td>0.68</td><td>0.43</td><td>C</td></tr>
<tr><td>4</td><td>W4 size</td><td>sign of special</td><td>33.92 – 0.02 mm</td><td>0.574</td><td>0.2</td><td>C</td></tr>
<tr><td colspan="2">Prepared by</td><td>Date</td><td colspan="4">Seal</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="7">Explanations</td></tr>
</table>

This report is prepared by using the old raw data.

5. CONCLUSION AND DISCUSSION

There are three major elements of JIT that must be present in order to succeed. These three elements are: Total employee involvement, Inventory reduction and The use of statistical tools to improve quality. In this study, one of these elements, SPC concept ,is discussed in detail.

Quality is a concept that can be found and demanded in our daily life from health to production. A quality product or service must conform to specification and a quality product or service must meet or exceed customer requirements and expectations..

Continuous quality improvement of manufactured products is a fundamental assumption of JIT manufacturing. A JIT manufacturer looks for perfect manufacturing process to reduce variation, because variation requires rework and rework means waste. A company that implements the just in time approach should attempt to do perfect processes that every items is produced exactly the same as every other item. To remove variance from the process requires control of process. But making process statistically in control is not the end. When the statistical control is achieved, further studies can initiated in order to increase the quality and economic side of production.

The tool that should be used to achieve these goals is Statistical Process Control (SPC). As it is stated above process must be controlled. No two things can be all alike and total variation can never be entirely eliminated. But its causes can be identified and controlled and variation can be significantly reduced by the help of statistical process control.

In application, the methods of controlling process (by applying SPC) is explained. The necessity of using statistical methods in plant that make production for a long time, although the process is out of control, is shown and by the help of applying SPC ,the improvements in the process is obtained and the ratio of defective production is decreased.

In order to improve and stabilize process, it should be well defined and documented. This can be accomplished mainly through the use of seven tools that is used in the study. A stable process is a process that exhibits only common variation.

There are many organizations that are not aware of widely applicable perspective of statistical thought. They think of statistics as a costly and difficult method to implement. But in contrast proper use of statistics can cause gaining profits to the organizations. They do not know the advantages of statistics and these advantages are explained and applied in study. Before this study, there was problem in the gear boxes, this has not been investigated and the defective production had continued. In the study, the necessity of applying process control methods are explained and necessity of taking corrective action is shown and as a result effective improvements are obtained. Application procedure is explained.

The main problem in the gearboxes is understood and the ways for solving the main problem is explained and it is found out that SPC is not only a simple control method to determine defective production but also it is a method for blocking defective production. In this study, instead of reacting to the defective products, the blocking problems before occurring is emphasized. Statistical process control should involve all aspects of production effort, from product conception through work in process to the delivery of the product. . Its goal is to eliminate defects in the production process. SPC is not a one- time program to be applied when the business is in trouble and later abandoned. Quality improvement must become part of the culture of the organization. To apply SPC in cog wheel shop is not sufficient. It should also be applied in the other shops of factory. Factory should be thought as a whole system and in order to control the processes of system, all parts should adopt and use SPC concept to improve quality as a whole. Especially in procurement phase of raw material should be under control because quality begins at source. Quality is the responsibility of every person not only of quality division so quality circles should be formed in the factory. The machines that is using in the production of cog wheels should be modernized and spare parts of machines (cutting implement etc.) should be ready whenever required. Preventive maintenance should be adopted and multi-skill workers should be trained. And quality should be the responsibility of every person in the factory. Standardization should be provided in every phase of production that is related with cog wheels from procurement of raw materials to the delivery of cog wheels and also in the plant. As a final word, Statistical Process Control (SPC) is the most widely used and effective tool that keeps under control of variability in the process.

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