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Reduction in the level of noise & enabling smooth running in the diesel engine of tractor by applying Multi-vari analysis & other problem solving techniques

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Abstract- *The present dissertation work was carried out in an XYZ industry in order to reduce the variability in the control rack milling process after the identification of the issue through various trials & techniques. Basically the XYZ industry faces a severe issue with one of its major long standing customers. The issue being a rapid increase in the rejection rate of the 2 types of pumps that the plant manufactures, namely the A08 & 939 types, which are special purpose ones used in the diesel engine of tractors. The rejection rates have been predominantly observed to have followed a trend or a pattern over a period of time. The customer defines the problem as an hunting issue leading to the engine not running smooth. Therefore inorder to figure out where the claimed defect was, trials based upon shainin technique was performed at the vehicle level initially by swapping of pumps and components between good & bad vehicles. From these trials it was revealed that one particular component was being the potential root cause of the issue. Hence inorder to rectify the issue with the component and to find the reason for the defects in them, various problem solving techniques namely multi-vari analysis & Why Why analysis was brought into play. Thereby using these techniques the area of the problem was found & corrective actions in consultation with the industry for reducing the variability in the milling process of the machine were employed with an intent to bring down the defect rate & to put an end to the existing real time customer issue.*

Keywords- *Fuel injection pumps, Control rack, Wire over dimension readings, Rack & Pinion mechanism, Rack milling process, Shainin trials, Multivari data collection, charts & analysis, Why Why analysis.*

I. INTRODUCTION

The XYZ industry pioneered the manufacture of the automotive diesel fuel injection equipment in India. Diesel in-line fuel injection pump was chosen as the subject of the project because of its criticality and since the project being a real time customer issue in this case, it however needed a quick attention. The major purpose of this study is to know the root cause for the noise in the pumps which are supplied by the XYZ industry to one of its customers.

The rejection rate of the Pumps have gradually increased day by day with the problem being stated as a huge rattling noise and vibrations continuing to exist in the vehicle which has brought the issue to be framed as "hunting" in the engine, this hunting case has become a serious problem to the industry and its customer. The Quality department has been striving hard in solving the issue and to understand the region of the problem. With this regard initial shainin trials were performed at the vehicle level and further proceedings were made towards the use of such similar trials to be performed at the pump level and finally furthering down towards running the trial 3 by swapping the components between good & bad pumps. In parallel to this others means of study and analysis were carried out in regard with the fuel injection pump and its components, in the sidelines there were recalibration of the customer returned pumps performed at the calibration bench involving the replacement of different governor covers and monitoring the delivery rate with respect to the control rod position for different discharge levels and other functions of the pump.

On the basis of the facts collected, analysis on the shainin trials were carried out at various levels by means of which the region of the problem was found to be that the control rack engaged in meshing with the pinion of the pump being the potential root cause of the issue. Therefore in order to narrow down the issue and to find the reason behind this root cause, the Ishikawa diagram was put down with an intention to draw out ideas on possible causes leading to the effect of variations in the milling process. After the generation of ideas from the diagram, parameters that could possibly affect the milling process variability were identified. Because of its effectiveness in identifying the sources of variation, a DOE based tool known as the "Multi-vari Analysis" was brought into play in order to serve as a convergent tool for problem solving over Ishikawa.

Before performing the multi vari analysis, prior study was carried out on 2 machines engaged in the production of 3 cylinder control rack from which a plan for the collection of data was generated. Upon finalizing the sequence of activities needed to be performed, an actual complete multi vari data collection and analysis were performed on both the machines. Once data collection and analysis was done, the reason behind the issue was clearly found from the conclusions made through the multi-vari charts that the problem was from Machine 7616. In order to narrow down obtain the area of the problem, a 5XWHY analysis was carried out with the framing of questions and seeking answers to these questions in a step by step procedure which reveals various areas in the machine where problems observed to be persisting. Since the issues from the machine was in regard with the areas such as Fixture, spindle & cutting tool rpm, spindle arbor and depth feed axis, containment actions were brought in and the production from this machine was put to halt. However since reconditioning of the affected areas of the machine became an immediate requirement for restarting the production. All proposed changes to the issues were brought in at the earliest in consultation with the management of the industry. A pilot study based upon multi vari data collection and analysis was carried out and with the help of these data, the multi vari charts were again plotted from which the results were quantified and compared with the earlier charts. The comparison proved to be evident that the target state of the project i.e. the reduction in milling process variability thereby maintaining the wire over dimension values of the control racks on the higher specification side was attained. Therefore in order to validate the changes brought in, the control racks from the reconditioned machine were sent in batches to the customer for the validation process which leads to the result of the pumps passing the tests during the engine testing. Hence forth at this level it is believed that the rejection rate of the pumps are likely to be reduced and a smooth running of the engine with a reduction in the level of hunting noise which is the most important factor to the customer has been achieved.

1.1 Problem identification by shainin trials is explained as under:-

- Trial 1 – At vehicle level
- Trial 2 – At engine level
- Trial 3 - At pump level

1.1.1. Trial 1 :-

The basic reqirements for shainin trials are as under :-

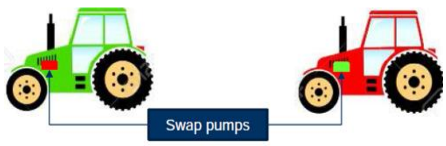
- Good and bad vehicle
- Good and bad engine
- Test bed
- Calibration bench

The initial trial was carried out between the good and bad vehicles. According to this trial each vehicle were to be measured four times in terms of noise, vibrations and RPM level and an inference based upon any contrast visually observed between both the vehicles is to be drawn from them. The result of such is as shown in the figure below.

Factor	GOOD	BAD	Contrast	Inference
Noise	Smooth running with very little variation in Noise level: 83 – 85 dB	High fluctuation of noise level: 80 – 89 dB	YES	Clear case of Hunting (Not combustion induced 'Knocking')
Vibration	No vibrations observed in Gear segment	All three Gear segments vibrating & oscillating together	YES	Suspect → components related to Gear meshing (Elements not suspect since not a combustion noise)
RPM	No variation in RPM observed	No variation in RPM observed	NO	Suspect → Control rod or Gear segment

Figure 1. Observed condition at vehicle level during shainin trials

1.1.2. Trial 2 :-



Result	Inference
Results swap fully (Good → Bad & Bad → Good)	Predominant pump contribution
Partial swap (Only Good → Bad OR Bad → Good)	Interface issue (interaction b/w Vehicle & Pump)

Figure 2. Pump swap between good and bad engines in the calibration bench

In the second trial, two pumps from the good and bad vehicles were taken in the calibration bench and swapped between the engines of both the vehicles, during a full swap of a good pump in a bad engine and a bad pump in a good engine

there was an issue predominantly observed at the pump level and similar interface issue was also observed during a partial swap between the combination of a good pump and a bad engine and vice versa.
Similarly during visual observation it was also seen that all the three Gear segments of the fuel injection pump from the bad vehicle was appearing to be vibrating and oscillating together and on the contrary the pump from the engine of the good vehicle was found with no vibrations observed in the Gear segments. Therefore the Suspect were the components related to meshing and however the elements were not a suspect since it was not a combustion noise.
Eventually when having a comparison between both the vehicles in terms of RPM , it was clear that there seemed to be no variations at this level between both the good and the bad, hence again the suspect was either the control rod or the gear segments or the chances of both the components causing the issue.

1.1.3. Trial 3:-

Identifying parameters in the pump causing the effect

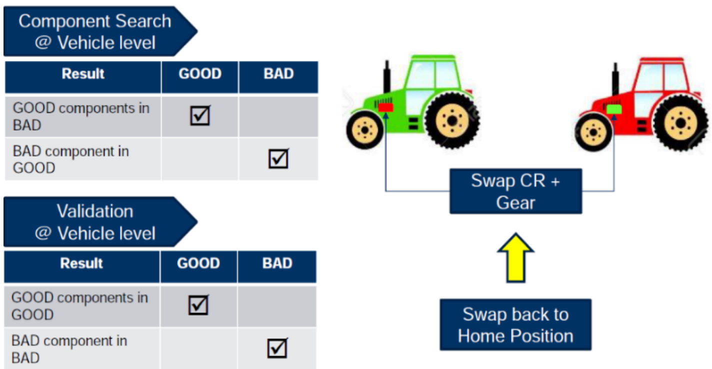


Figure 3. Components or elements swap between good and bad pumps in the calibration bench

After swapping of components or elements between good and bad pumps in the calibration bench, these pumps underwent a series of tests at the vehicle level. During the component search it was observed that when the good components namely the control rack and gear segments were swapped into a bad pump, a good result was obtained and the other end the swapping of bad components into a good pump ended with the result being bad.
Similarly in order to validate this, the components were swapped back to their home position in the pumps and similar tests were carried out at the vehicle level. The result finally turned out that good components in the good pump showed good result whereas bad components in the bad pump ended up with a bad result. Therefore it was evident that the meshing between the elements namely the control rack and the gear segments seemed to be having an issue.

1.1.4 Further Investigations after the trials

Table 2. Measurement of bad pump components

Flyweight	Contrast
Bearing Socket Travel	NO
Slider Height Difference	NO
Flyweight Weight variation bet. two	NO

Control Rod	Contrast
Dimension Over Wire	YES
Run Out	NO
Dimension	NO
Parallelism	NO

Sliding sleeve	Contrast
Diameter	NO
Distance	NO
Run out	NO
Parallelism	NO
Thickness	NO
Symmetry	NO

Shackle lever Pin	Contrast
Diameter	NO

Gear Segment	Contrast
Composite Error	NO

Pump housing	Contrast
Pinion Engagement Distance	NO

Table 3. Good and bad pump's control rack wire over dimension readings

All GOOD pumps have control racks having higher values compared to BAD

Component	Control Rod		Part Number :	1 416 026 006							
Measurement Detail											
Sl.No.	Characteristic	Specification	Method of Measurement	55952471	55945381	55947511	55911900	55902975	55908986	55909004	55911908
1	Dimension Over Wire	9.25mm -0.08	Digital Micro Meter 3 250 0 0344	9.273 9.228 9.214	9.230 9.220 9.200	9.250 9.260 9.260	9.122 9.127 9.106	9.189 9.210 9.190	9.212 9.220 9.184	9.186 9.214 9.186	9.173 9.196 9.205

Further investigations on the measured values show a contrast in the control rod's wire over dimension values as indicated in the measurement of pump component's table. Upon measuring and analyzing the wire over dimension values from a batch of good and bad pump control rods, it was observed that all good pump components showed higher values in the specification compared to the bad pump components.

II. PROBLEM STATEMENT

- The diesel system division of the manufacturing plant of the XYZ industry currently faces a serious issue with one of its long standing major customers. The company's quality department has had a huge blow with its supplies being complained of repeated defects and returned back for causing issues in the past for the customer.
- The supplies in this case are the in-line fuel injection pumps and the problem being stated by the customer is that the engine is not running smooth leading to a very huge rattling noise.
- The rate of rejections of these pumps have drastically increased over a period of time. Hence it was very important to find the root cause of the issue immediately and to take corrective actions at the earliest.

III. LITERATURE REVIEW

3.1. Shainin

The Shainin System (SS) is the name given to a problem solving system, with its associated strategies and tools, developed by Dorian Shainin, and widely used and promoted in the manufacturing sector. Dorian Shainin also called this system Statistical Engineering, Reflecting his engineering education and background. The consulting firm, Shainin LLC, offers the system under the trademarked name Red X Strategy. The Shainin method is used to improve product performance, product reliability, and process performance.
The ''Red X'' concept is basically known to be a technical problem solving tool that is most simpler & cost effective compared to other problem solving tools. Dorian demonstrated that the cause can exist as an interaction among various independent variables. The Red X - Swap pairs of parts into faulty & functional equipment in order to discover part that is faulty. Dorian use to claim that the primary defective part would be found within a dozen paired Swaps.

3.2. Multi-vari Analysis

In a multivari investigation, we systematically sample from the process to capture the effect of various time and location based families of variation. Seder (1950a, 1950b, 1990) proposed a multi-vari chart to display such data. A multivari is an excellent tool early in the progressive search for a dominant cause. Figure below shows a multi-vari chart using the diameter of a shaft as the output. The shaft diameters are measured at four locations (left and right sides at different two orientations) for three shafts produced consecutively each hour. In the Figure, we see there is little variation from shaft to shaft within an hour, some variation within shafts, and substantial variation from time-to-time, suggesting that the dominant cause must be an input that varies slowly, i.e. that acts in the time-to-time family. This conclusion may be incorrect if we have not seen most of the full range of diameter variation established in the baseline investigation (i.e. the Green Y distribution). A multi-vari chart provides a visual display of the components of variation associated with each family. However, when there is no obvious dominant family, it is useful to augment the plot with an analysis of variance to numerically estimate the variance components due to each family.

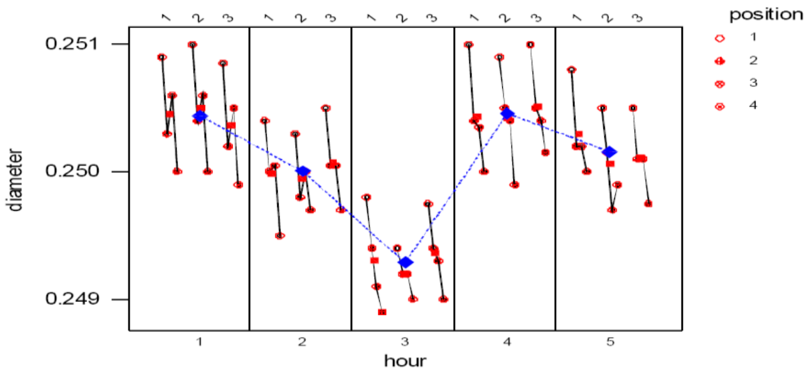


Figure 4. Multi-vari chart example

3.3. (5XWHY?)

It is a method of questioning that leads to the identification of the root cause(s) of a problem.

Purpose

A why-why is conducted to identify solutions to a problem that address its root cause(s). Rather than taking actions that are merely Band-Aids, a why-why helps you identify how to really prevent the issue from happening again.

How to conduct the analysis?

- First start with the problem you'd like to solve. Then ask, "Why is x taking place?" You will end up with a number of answers. Jot these down.
- Repeat the process for each of the answers to the first question.
- Repeat the process for each of the answers to the second 'why' and continue until you've asked why 5 times.
- When you've hit the 5th why, you usually have determined some root causes. Now you can identify specific action plans to address those root causes.

IV. PROJECT PLAN

To carry out the dissertation work in a XYZ industry observation was done in the plant to identify the problem statement. Problem statement was identified as "To reduce the variation in the process of milling thereby maintaining the wire over dimensions of the control racks on the higher specification side". Therefore a literature review was done to solve the current real life problem. Then the milling machines engaged in the production of 3 cylinder control rack and its process flow sequence was studied thoroughly to understand the value added and non-value added activities and to dig deep into the sequence to find out the problem area. Therefore in order to reduce the variations in the milling process of a particular machine, corrective actions were needed to be taken in consultation with the xyz industry. Then data collection based upon multi-vari plan under various settings in the milling process is collected. After the data collection Industrial Engineering concepts such as multi-vari analysis and Why Why analysis were used to solve the problem. After using these concepts results were obtained and problem was solved.

V. PROJECT OBJECTIVES

- To study and analyze each and every part of the engine of a tractor primarily along with its working principle and working mechanisms.
- To understand and make a thorough study on the types of noise related issues to the engine.
- To analyze the parts of the engine that are causing the rattling noise.
- To assess the level of noise and vibrations coming from the engine.
- To carry out a study on different fuel injection pump types.
- To minimize or eliminate the reasons of the issue.
- To reduce the rejection and defect rate.
- To give a best technical problem solution that is cost effective.
- To implement the result in the application.

VI. PROBLEM ANALYSIS AND RESULTS

4.1. Data collection & analysis

4.1.1. Prior Study on the possible parameters causing variations in the process of milling

Table 4. Parameters of variation affecting milling process

FAMILY OF VARIATION		
CONTRAST BETWEEN	HAVING SAME	REMARK
Teeth to Teeth	Segments	
Segment to Segment	Control rod	
Control rod to Control rod	Fixture	
Fixture to Fixture	Setting	1. How many fixture?
		2. Frequency of changing fixture
Position to Position	Fixture	
Setting to Setting	Batch	1. How many settings?
		2. Type change
		3. Cutter tool change
		4. Cutter tool life
		5. Fixture change
		6. Correction
Batch to Batch	Shift	1. How many batch?
		a) supplier wise
		b) cutter tool
Shift to Shift	Machine	

Table above shows the Family of variations which indicates all the parameters that can affect the control rack milling process. These parameters in the table above gives an understanding of the present operations, conditions and other factors associated with the control rack production line. The production line currently operates under two shifts per day basis involving one operator per shift assigned on a single machine. The current production requirement of the control racks per day averages about 1200 quantities that are divided as 600 quantities per shift. After Starting the relation between 4, 8 & 12 teeth of a gear makes a relation segment. If there is any problem in segment the teeth as to be examined to find the solution. The segment to segment relationship creates control rod and then it makes fixture batch, shift and machine. If there is any problem in fixture should check the frequency of fixture change and how many fixtures used which directly or indirectly affect the problems. In the same way if there is a problem in a batch should check the fixture, tool, tool type and frequency of batches. By understanding the relationship in the above table it's very simple to understand the problem area and solution making.

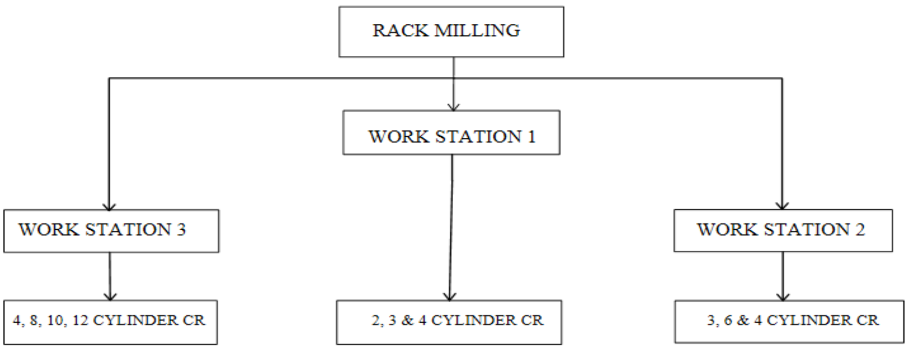


Figure 5. Control rack milling production line

The production of control racks by XYZ Industry on the whole varies from two to twelve cylinder that goes into the fuel injection pump application. Generally there are three machines or workstations engaged in the production of such control racks and these three machines vary with their fixture types and produce parts based upon the type of fixture installed in them. As shown in the figure above the three workstations are basically assigned with the types of control racks which are produced in them from over a long period of time on a regular basis. 2180 HMT machine at the workstation 1 generally produces 4, 8, 10 and 12 cylinder control racks, 7616 HMT machine at workstation 2 produces 3 and 4 cylinder control racks and 6025 kirloskar machine at workstation 3 produces 3, 4 and 6 cylinder control racks. All these control racks are produced on a regular intermittent basis. The type and the quantity of the parts to be produced is based upon the production requirement. And usually as per the schedule 2 control racks are picked and measured after a production of every 20 quantities in regular interval of time. The frequency of the change of fixture in any of stations under this case is very less, generally unless there is a necessity arising for change in cases like damage, wear and tear and so on, the fixture will not be reconditioned or replaced by another. Therefore the frequency of change of fixture in the case of rack milling operation at the production line of the plant is zero. However in this project's case only machine 7616 and 6025 are taken under consideration in order to carry out the study and analysis as the area of concern is only the 3 cylinder control racks.

4.1.2. Multi vari plan for data collection from machine 1 (7616) and machine 2 (6025)

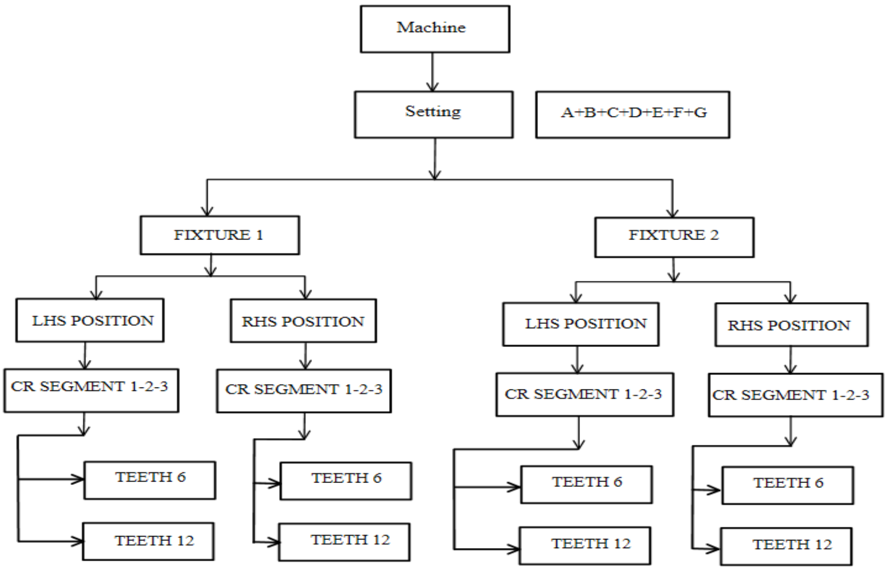


Figure 6. Multi vari data collection plan for control rack

Figure above displays the multi vari plan for data collection and analysis from machine 7616 and 6025. The data to be collected as per the multi vari plan depends mainly on the type of settings involved. The types of settings contributing to the variations in the control rack are listed down as under.

A. Mid process
B. Before part type change
C. After part type change
D. Before resharpening of cutting tool
E. After resharpening of cutting tool
F. After blackening of control rack
G. After bend removal of control rack

As for the Mid process it indicates the collection of the required quantities from their respective machines as and when the milling operation is underway. Coming to the Change in part types i.e Before the part type change involves the collection of a certain quantity of 3 cylinder racks right before they are replaced by another cylinder type. Similarly as for the After part type change, it indicates the collection of a certain quantiy of 3 cylinder racks right after a batch of control racks of different cylinder engaged in the milling process getting replaced by the 3 cylinder control rack batch. And as for the before and after resharpening of the cutting tool engaged in the milling process, involves collection of a batch of quantities in somewhere at a stage where the cutting tool approaches the end of tool life and similarly a batch of quanties right after a new or a resharpened tool is employed. The same procedure repeats for After Blackening and After Bend Removal of the quantities as well.

There are over all 19 teeths in each set of segments of the control rack for the three cylinder control rod application of an A type pump, out of which the measurement of each control rack is carried out from the sample pieces collected after the production of these quantities & the particular operations, a random of 25 control racks are being picked from each setting namely After which each control racks from thier respective settings are measured for teaths 6 & 12 from each segment using the WOD measuring gauge by means of a digital micrometer.

4.1.3. Data collection based upon the multi vari plan

NOTE: - All the values are in mm & the specification limit for control rack is of range (9.17 - 9.25)

Table 5a. Midprocess - (m/c 1)

SLNO	M/C 1 (BEFORE CHANGE OF PART TYPE)									
	LHS POSITION					RHS POSITION				
	SEGMENT	1	2	3	AVERAGE	SEGMENT	1	2	3	AVERAGE
	COMPONENT NO	6	6	6		COMPONENT NO	6	6	6	
1	1	9.15	9.17	9.18	9.17	51	9.2	9.19	9.18	9.19
2	3	9.16	9.17	9.19	9.17	54	9.2	9.19	9.18	9.19
3	5	9.17	9.17	9.15	9.16	55	9.17	9.19	9.17	9.18
4	7	9.19	9.17	9.15	9.17	57	9.17	9.19	9.17	9.18
5	9	9.16	9.17	9.15	9.16	60	9.18	9.19	9.18	9.18
6	12	9.15	9.17	9.15	9.16	61	9.18	9.2	9.18	9.19
7	13	9.2	9.19	9.17	9.19	63	9.21	9.17	9.14	9.17
8	15	9.14	9.18	9.16	9.16	65	9.15	9.17	9.15	9.16
9	17	9.15	9.17	9.16	9.16	67	9.14	9.15	9.12	9.14
10	19	9.17	9.2	9.22	9.20	69	9.15	9.15	9.12	9.14
11	21	9.15	9.15	9.16	9.15	71	9.17	9.15	9.12	9.15
12	23	9.16	9.15	9.19	9.17	73	9.17	9.15	9.12	9.15
13	25	9.2	9.17	9.16	9.18	75	9.14	9.15	9.15	9.15
14	27	9.21	9.2	9.19	9.20	77	9.14	9.15	9.14	9.14
15	29	9.19	9.19	9.18	9.19	79	9.16	9.17	9.15	9.16
16	31	9.19	9.15	9.12	9.15	81	9.17	9.14	9.14	9.15
17	33	9.19	9.18	9.18	9.18	83	9.18	9.18	9.19	9.18
18	35	9.19	9.11	9.15	9.15	85	9.18	9.16	9.14	9.16
19	37	9.17	9.12	9.16	9.15	87	9.18	9.15	9.14	9.16
20	39	9.12	9.13	9.14	9.13	89	9.16	9.17	9.15	9.16
21	41	9.15	9.16	9.16	9.16	92	9.17	9.17	9.16	9.17
22	43	9.12	9.16	9.21	9.16	93	9.13	9.18	9.16	9.16
23	45	9.18	9.2	9.17	9.18	95	9.16	9.18	9.16	9.17
24	47	9.17	9.19	9.2	9.19	97	9.12	9.17	9.17	9.15
25	49	9.16	9.19	9.21	9.19	100	9.16	9.14	9.18	9.16

Table 5b. Midprocess - (m/c 2)

M/C 1 (MIDPROCESS)																		
	LHS POSITION									RHS POSITION								
SEGMENT	1		AVG	2		AVG	3		AVERAGE	1		AVG	2		AVG	3		AVERAGE
COMPONENT	6	12		6	12		6	12		6	12		6	12		6	12	
1	9.18	9.18	9.18	9.18	9.18	9.18	9.2	9.18	9.19	9.19	9.19	9.19	9.19	9.19	9.19	9.18	9.19	9.19
2	9.18	9.18	9.18	9.18	9.15	9.17	9.18	9.18	9.18	9.19	9.19	9.19	9.19	9.14	9.17	9.19	9.19	9.19
3	9.15	9.15	9.15	9.18	9.14	9.16	9.18	9.14	9.16	9.19	9.14	9.17	9.19	9.13	9.16	9.19	9.13	9.16
4	9.14	9.2	9.17	9.2	9.2	9.20	9.2	9.2	9.20	9.13	9.18	9.16	9.18	9.18	9.18	9.18	9.18	9.18
5	9.18	9.18	9.18	9.2	9.18	9.19	9.18	9.15	9.17	9.19	9.19	9.19	9.18	9.19	9.19	9.19	9.14	9.17
6	9.18	9.18	9.18	9.18	9.18	9.18	9.2	9.18	9.19	9.19	9.19	9.19	9.19	9.19	9.19	9.18	9.19	9.19
7	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.13	9.16	9.19	9.19	9.19	9.19	9.19	9.19	9.19	9.12	9.16
8	9.2	9.18	9.19	9.2	9.2	9.20	9.2	9.18	9.19	9.18	9.19	9.19	9.18	9.18	9.18	9.18	9.19	9.19
9	9.2	9.2	9.20	9.18	9.18	9.18	9.2	9.18	9.19	9.18	9.18	9.18	9.19	9.19	9.19	9.18	9.19	9.19
10	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.15	9.17	9.19	9.19	9.19	9.19	9.19	9.19	9.19	9.14	9.17
11	9.18	9.18	9.18	9.15	9.2	9.18	9.2	9.18	9.19	9.17	9.17	9.17	9.14	9.18	9.16	9.18	9.17	9.18
12	9.14	9.2	9.17	9.2	9.2	9.20	9.14	9.2	9.17	9.13	9.18	9.16	9.18	9.18	9.18	9.13	9.18	9.16
13	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
14	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.15	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.14	9.16
15	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.15	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.14	9.16
16	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
17	9.2	9.2	9.20	9.14	9.2	9.17	9.14	9.14	9.14	9.18	9.18	9.18	9.13	9.18	9.16	9.13	9.13	9.13
18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17	9.17
19	9.18	9.18	9.18	9.18	9.15	9.17	9.14	9.13	9.14	9.17	9.17	9.17	9.17	9.14	9.16	9.13	9.12	9.13
20	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.15	9.17	9.2	9.2	9.20	9.2	9.2	9.20	9.2	9.14	9.17
21	9.2	9.18	9.19	9.2	9.2	9.20	9.18	9.18	9.18	9.18	9.2	9.19	9.18	9.18	9.18	9.2	9.2	9.20
22	9.15	9.14	9.15	9.2	9.18	9.19	9.18	9.15	9.17	9.14	9.13	9.14	9.18	9.2	9.19	9.2	9.14	9.17
23	9.2	9.2	9.20	9.18	9.18	9.18	9.2	9.18	9.19	9.18	9.18	9.18	9.2	9.2	9.20	9.18	9.2	9.19
24	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.15	9.17	9.2	9.2	9.20	9.2	9.2	9.20	9.2	9.14	9.17
25	9.18	9.18	9.18	9.2	9.18	9.19	9.18	9.15	9.17	9.17	9.17	9.17	9.18	9.17	9.18	9.17	9.14	9.16

Table 6a. Before change of part type - (M/C 1) (i.e. before 4 cylinder control rod replacing 3)

M/C 2 (BEFORE CHANGE OF PART TYPE)																		
	LHS POSITION									RHS POSITION								
SEGMENT	1		AVG	2		AVG	3		AVERAGE	1		AVG	2		AVG	3		AVERAGE
COMPONENT	6	12		6	12		6	12		6	12		6	12		6	12	
1	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.2	9.22	9.24	9.24	9.24	9.25	9.21	9.23	9.2	9.2	9.20
2	9.23	9.23	9.23	9.23	9.23	9.23	9.18	9.2	9.19	9.24	9.2	9.22	9.21	9.24	9.23	9.25	9.2	9.23
3	9.25	9.23	9.24	9.23	9.23	9.23	9.2	9.19	9.20	9.19	9.24	9.22	9.25	9.25	9.25	9.25	9.25	9.25
4	9.18	9.2	9.19	9.23	9.2	9.22	9.2	9.2	9.20	9.24	9.21	9.23	9.25	9.24	9.25	9.25	9.25	9.25
5	9.18	9.18	9.18	9.2	9.2	9.20	9.2	9.23	9.22	9.24	9.24	9.24	9.2	9.2	9.20	9.25	9.2	9.23
6	9.19	9.18	9.19	9.23	9.23	9.23	9.2	9.23	9.22	9.2	9.24	9.22	9.25	9.22	9.24	9.19	9.25	9.22
7	9.18	9.21	9.20	9.23	9.23	9.23	9.23	9.23	9.23	9.24	9.24	9.24	9.25	9.19	9.22	9.2	9.2	9.20
8	9.2	9.18	9.19	9.23	9.2	9.22	9.23	9.22	9.23	9.24	9.24	9.24	9.25	9.25	9.25	9.25	9.22	9.24
9	9.23	9.2	9.22	9.2	9.2	9.20	9.19	9.2	9.20	9.23	9.24	9.24	9.24	9.2	9.22	9.25	9.2	9.23
10	9.23	9.23	9.23	9.23	9.23	9.23	9.19	9.19	9.19	9.2	9.25	9.23	9.19	9.25	9.22	9.2	9.25	9.23
11	9.23	9.23	9.23	9.23	9.23	9.23	9.17	9.19	9.18	9.24	9.24	9.24	9.25	9.25	9.25	9.2	9.25	9.23
12	9.23	9.23	9.23	9.23	9.2	9.22	9.19	9.19	9.19	9.21	9.21	9.21	9.25	9.2	9.23	9.25	9.2	9.23
13	9.23	9.22	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.21	9.21	9.21	9.18	9.25	9.22	9.21	9.2	9.21
14	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.17	9.20	9.25	9.2	9.23	9.2	9.2	9.20
15	9.23	9.25	9.24	9.25	9.2	9.23	9.25	9.23	9.24	9.21	9.21	9.21	9.2	9.2	9.20	9.2	9.2	9.20
16	9.23	9.25	9.24	9.25	9.23	9.24	9.2	9.2	9.20	9.21	9.21	9.21	9.21	9.25	9.23	9.22	9.25	9.24
17	9.23	9.25	9.24	9.25	9.25	9.25	9.2	9.23	9.22	9.19	9.2	9.20	9.25	9.2	9.23	9.24	9.2	9.22
18	9.2	9.2	9.20	9.2	9.25	9.23	9.25	9.19	9.22	9.24	9.24	9.24	9.2	9.2	9.20	9.2	9.2	9.20
19	9.2	9.19	9.20	9.2	9.25	9.23	9.2	9.23	9.22	9.2	9.2	9.20	9.2	9.22	9.21	9.24	9.21	9.23
20	9.23	9.25	9.24	9.25	9.2	9.23	9.25	9.23	9.24	9.24	9.24	9.24	9.2	9.2	9.20	9.2	9.21	9.21
21	9.23	9.23	9.23	9.23	9.23	9.23	9.25	9.23	9.24	9.24	9.24	9.24	9.2	9.2	9.20	9.19	9.2	9.20
22	9.23	9.23	9.23	9.2	9.23	9.22	9.23	9.23	9.23	9.2	9.2	9.20	9.2	9.22	9.21	9.2	9.2	9.20
23	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.24	9.24	9.24	9.2	9.2	9.20	9.2	9.2	9.20
24	9.23	9.2	9.22	9.2	9.2	9.20	9.2	9.2	9.20	9.2	9.2	9.20	9.2	9.2	9.20	9.24	9.24	9.24
25	9.21	9.2	9.21	9.2	9.23	9.22	9.23	9.2	9.22	9.24	9.24	9.24	9.24	9.24	9.24	9.19	9.24	9.22

Table 6b. Before change of part type - (M/C 2) (i.e. before 4 cylinder control rod replacing 3)

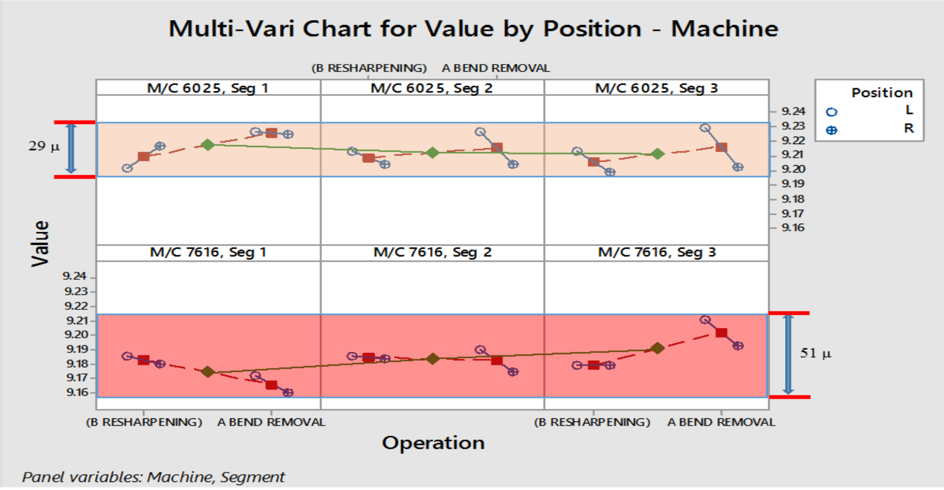
M/C 2 (MIDPROCESS)																		
	LHS POSITION									RHS POSITION								
SEGMENT	1		AVG	2		AVG	3		AVERAGE	1		AVG	2		AVG	3		AVERAGE
COMPONENT	6	12		6	12		6	12		6	12		6	12		6	12	
1	9.23	9.23	9.23	9.24	9.23	9.24	9.21	9.18	9.20	9.21	9.22	9.22	9.22	9.21	9.22	9.2	9.2	9.20
2	9.21	9.22	9.22	9.24	9.23	9.24	9.23	9.2	9.22	9.21	9.2	9.21	9.19	9.19	9.19	9.19	9.18	9.19
3	9.25	9.23	9.24	9.24	9.22	9.23	9.2	9.2	9.20	9.23	9.22	9.23	9.21	9.22	9.22	9.19	9.19	9.19
4	9.21	9.21	9.21	9.21	9.2	9.21	9.18	9.18	9.18	9.21	9.21	9.21	9.22	9.22	9.22	9.24	9.24	9.24
5	9.19	9.19	9.19	9.2	9.2	9.20	9.2	9.21	9.21	9.23	9.22	9.23	9.2	9.2	9.20	9.21	9.2	9.21
6	9.22	9.23	9.23	9.23	9.23	9.23	9.25	9.24	9.25	9.25	9.24	9.25	9.24	9.23	9.24	9.23	9.24	9.24
7	9.22	9.22	9.22	9.23	9.22	9.23	9.21	9.21	9.21	9.24	9.23	9.24	9.21	9.21	9.21	9.2	9.2	9.20
8	9.2	9.21	9.21	9.21	9.21	9.21	9.21	9.22	9.22	9.24	9.23	9.24	9.22	9.23	9.23	9.22	9.23	9.23
9	9.21	9.2	9.21	9.2	9.19	9.20	9.21	9.2	9.21	9.22	9.22	9.22	9.19	9.17	9.18	9.19	9.18	9.19
10	9.21	9.21	9.21	9.23	9.22	9.23	9.23	9.23	9.23	9.25	9.25	9.25	9.24	9.24	9.24	9.21	9.21	9.21
11	9.23	9.23	9.23	9.24	9.24	9.24	9.24	9.23	9.24	9.23	9.24	9.24	9.24	9.22	9.23	9.22	9.23	9.23
12	9.22	9.23	9.23	9.24	9.23	9.24	9.24	9.22	9.23	9.24	9.23	9.24	9.19	9.18	9.19	9.24	9.14	9.19
13	9.23	9.23	9.23	9.24	9.23	9.24	9.24	9.22	9.23	9.23	9.22	9.23	9.25	9.22	9.24	9.21	9.2	9.21
14	9.21	9.22	9.22	9.23	9.22	9.23	9.22	9.21	9.22	9.23	9.22	9.23	9.22	9.2	9.21	9.18	9.17	9.18
15	9.23	9.23	9.23	9.24	9.24	9.24	9.23	9.23	9.23	9.22	9.21	9.22	9.18	9.16	9.17	9.13	9.12	9.13
16	9.21	9.22	9.22	9.22	9.21	9.22	9.2	9.2	9.20	9.24	9.24	9.24	9.23	9.24	9.24	9.22	9.22	9.22
17	9.21	9.22	9.22	9.22	9.22	9.22	9.22	9.21	9.22	9.22	9.22	9.22	9.21	9.2	9.21	9.19	9.2	9.20
18	9.2	9.2	9.20	9.22	9.21	9.22	9.21	9.22	9.22	9.23	9.23	9.23	9.2	9.18	9.19	9.17	9.17	9.17
19	9.17	9.17	9.17	9.18	9.19	9.19	9.2	9.19	9.20	9.2	9.2	9.20	9.2	9.2	9.20	9.24	9.23	9.24
20	9.22	9.22	9.22	9.23	9.23	9.23	9.21	9.19	9.20	9.22	9.23	9.23	9.23	9.23	9.23	9.23	9.23	9.23
21	9.21	9.22	9.22	9.23	9.22	9.23	9.25	9.23	9.24	9.23	9.23	9.23	9.23	9.23	9.23	9.22	9.21	9.22
22	9.22	9.22	9.22	9.23	9.22	9.23	9.22	9.21	9.22	9.2	9.2	9.20	9.21	9.2	9.21	9.14	9.14	9.14
23	9.19	9.19	9.19	9.21	9.21	9.21	9.21	9.22	9.22	9.23	9.22	9.23	9.2	9.2	9.20	9.2	9.2	9.20
24	9.19	9.18	9.19	9.17	9.17	9.17	9.18	9.18	9.18	9.2	9.2	9.20	9.18	9.17	9.18	9.24	9.24	9.24
25	9.18	9.18	9.18	9.2	9.19	9.20	9.19	9.2	9.20	9.19	9.19	9.19	9.19	9.19	9.19	9.19	9.19	9.19

Similar other data in tables under different settings as indicated in the multi vari plan for machine 1 (7616) & 2 (6025) were collected & their respective graphs were plotted which is shown below.

The graphs below show the comparisons of machine 7616 and machine 6025 for the various sequence of operations involved in the control rack production. These multi vari charts are plotted from the table values which were obtained by means of measuring the control rack's wire over dimensions. The charts generally compare variations between segments, positions, machines and the type of settings engaged in the sequence of operations involved in the process. Therefore the charts will serve as a basis in finding the cause for the source of variations in the process. The circles from the graphs indicate LHS and RHS positions of the milling fixture from which the control racks are removed and measured after undergoing milling operation. The first half of the graph indicate the samples from machine 6025 and the second half indicate the samples from machine 7616 with their respective segments.

NOTE :-

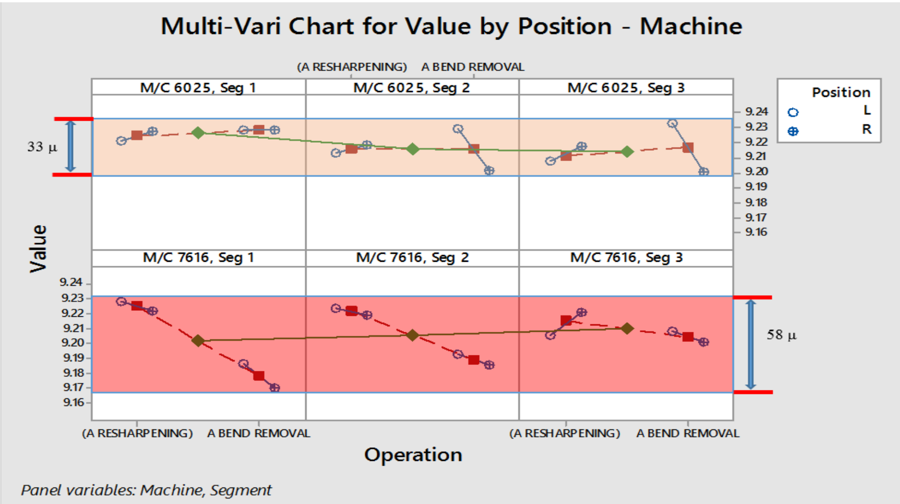
- In this case A stands for "After" and B stands for "Before".
- All values in the graph are in mm.



Graph 1. Before resharpening of cutting tool Vs after bend removal of control rack

The variation between the overall minimum to maximum value in machine 6025 and 7616 from all segments under various settings is as under:-

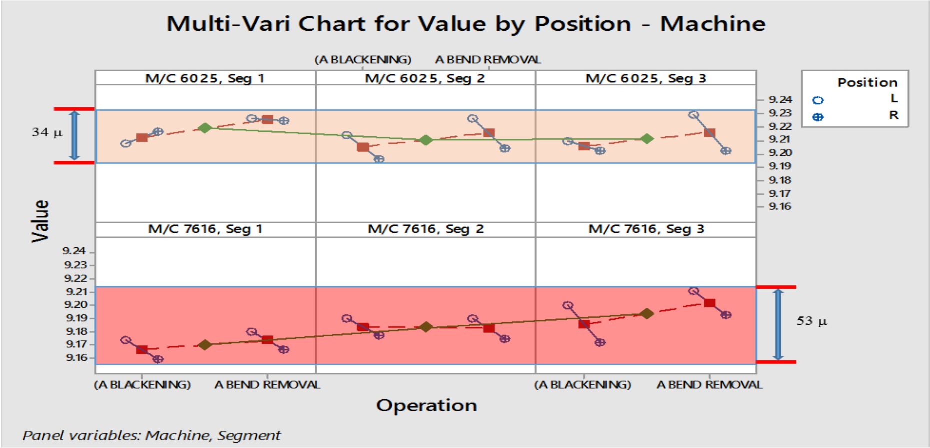
Machine 6025:- Minimum to Maximum overall value = (9.201 mm - 9.23 mm), Variation level = 0.029 mm
Machine 7616:- Minimum to Maximum overall value = (9.160 mm – 9.211 mm), Variation level = 0.051 mm



Graph 2. After resharpeneing of cutting tool Vs after bend removal of control rack

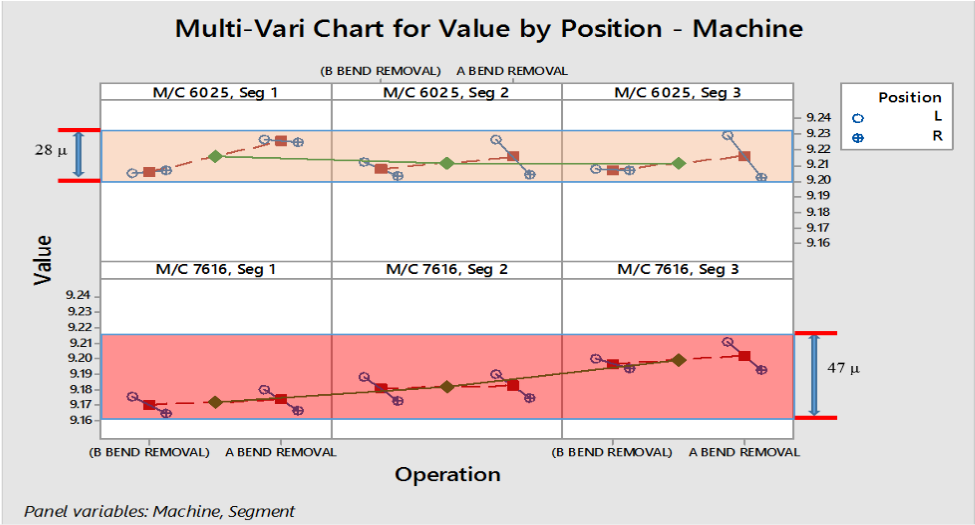
The variation between the overall minimum to maximum value in machine 6025 and 7616 from all segments for a graph of before resharpening of cutting tool Vs after bend removal of control rack is as under:-

Machine 6025:- Minimum to Maximum overall value = (9.20 mm - 9.233 mm), Variation level = 0.033 mm
Machine 7616:- Minimum to Maximum overall value = (9.170 mm – 9.228 mm), Variation level = 0.058 mm



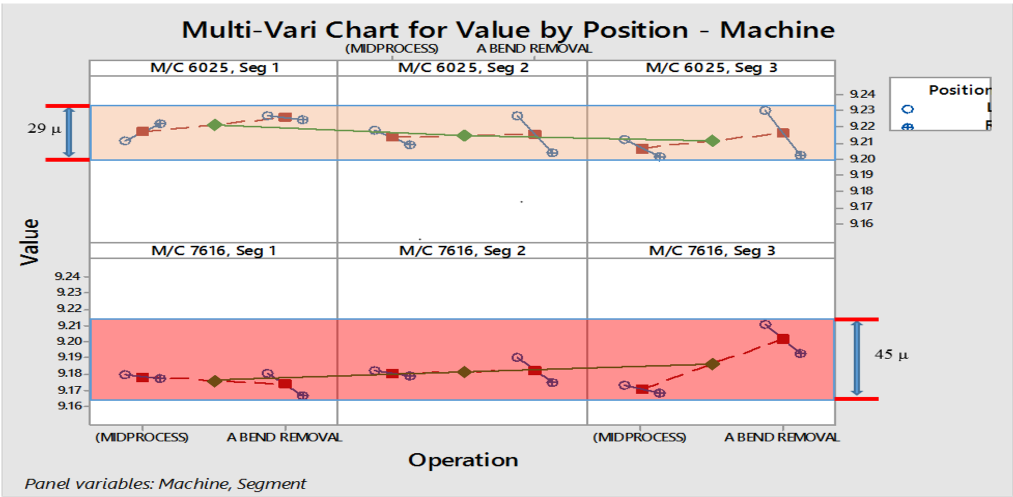
Graph 3. After blackening Vs after bend removal of control rack

Machine 6025:- Minimum to Maximum overall value = (9.196 mm - 9.230 mm), Variation level = 0.034 mm
Machine 7616:- Minimum to Maximum overall value = (9.158 mm - 9.211 mm), Variation level = 0.053 mm



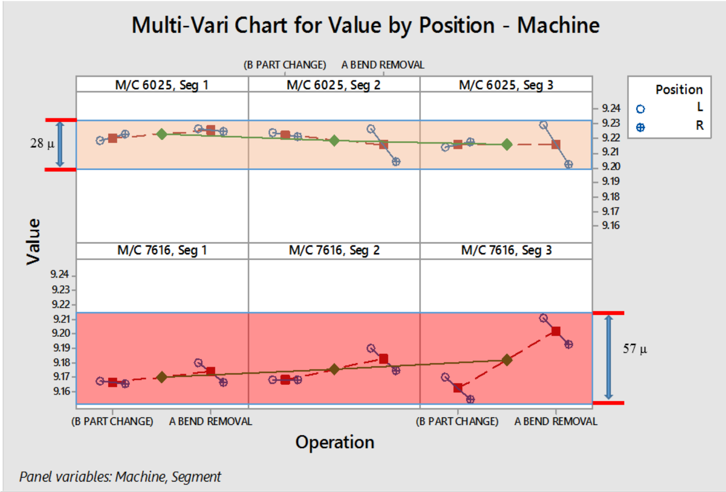
Graph 4. Before bend removal Vs after bend removal of control rack

Machine 6025:- Minimum to Maximum overall value = (9.202 mm - 9.23 mm), Variation level = 0.028 mm
Machine 7616:- Minimum to Maximum overall value = (9.164 mm - 9.211 mm), Variation level = 0.047 mm



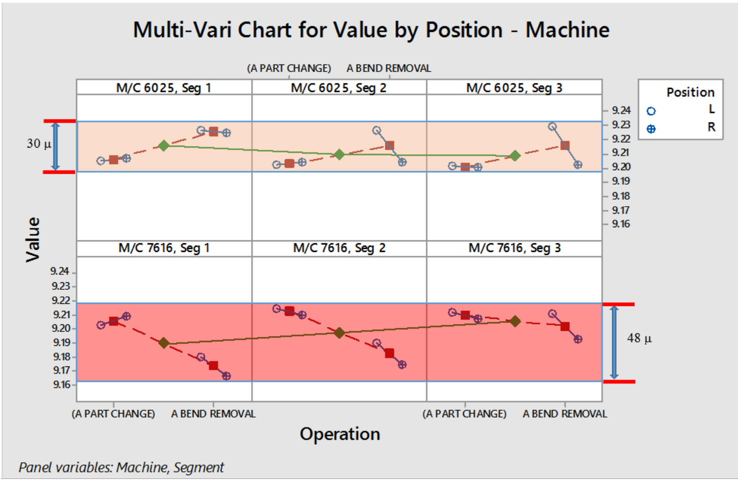
Graph 5. Midprocess Vs after bend removal of control rack

Machine 6025:- Minimum to Maximum overall value = (9.201 mm - 9.23 mm), Variation level = 0.029 mm
Machine 7616:- Minimum to Maximum overall value = (9.166 mm – 9.211mm), Variation level = 0.045 mm



Graph 6. Before change of part type Vs after bend removal of control rack

Machine 6025:- Minimum to Maximum overall value = (9.202 mm - 9.23 mm), Variation level = 0.028 mm
Machine 7616:- Minimum to Maximum overall value = (9.154 mm - 9.211 mm), Variation level = 0.057 mm



Graph 7. After change of part type Vs after bend removal of control rack

Machine 6025:- Minimum to Maximum overall value = (9.20 mm - 9.23 mm), Variation level = 0.03 mm
Machine 7616:- Minimum to Maximum overall value = (9.166 mm - 9.214 mm), Variation level = 0.048 mm

On carrying out a deep comparison between machine 7616 and 6025 with respect to each setting & by quantifying from the graphs, it was evident enough that the machine 6025 on an average taken from all the settings from the sequence, seemed to have a lesser variation in the process of milling with its wire over dimension values falling on the higher side of the specification, of range (9.2 – 9.23) & on the contrary machine 7616 proved to have a high process variation with its wire over dimension values falling on the lower side of specification, of range (9.166 – 9.214).
Generally in order to achieve a good process capability, the allowable variation in the milling process is not to exceed 40 microns. Therefore while referring to the values from the tables, it was also noticeable that more number of parts from machine 7616 under various settings were falling out the tolerance limit. The the highest variation from the graphs was registered to be around 60 microns from the machine 7616. By taking an average on the variation level from different settings for machine 7616, a value of 51 microns was registered.
Hence as per the study, in order to achieve the desired target state of the project, it is very important to produce parts with reduced variations in the process of milling, with its wire over dimension values to be maintained on the higher specification side i.e. of range (9.20mm - 9.25mm).

4.1.4. Reasons for the variations - (Multi-vari analysis conclusion)

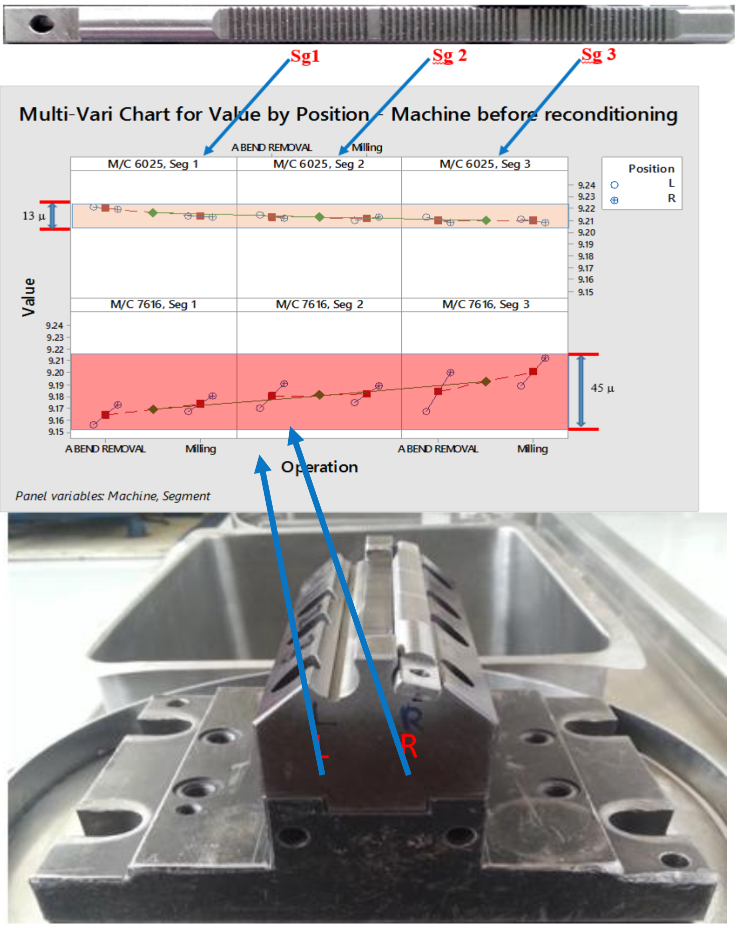


Figure 7. Dismantled fixture of defective machine (7616) – front profile view

Report of the fixture measurement from CMM

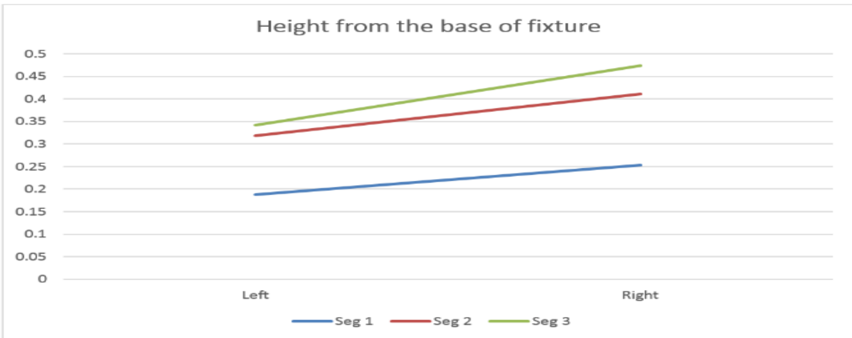


Figure 8. Fixture measuement report from cmm for lhs & rhs positions between segments

Table 7. Fixture readings from cmm

	Seg 1	Seg 2	Seg 3
Left	0.1871	0.1312	0.0239
Right	0.2525	0.1584	0.0626

Parallelism, perpendicularity and height from the base at 3 fixed point at positions where the segments lie during milling operation for postions, LHS and RHS were measured in the CMM. The report it can be concluded as under:-

- Machine 1 (7616) is having more variation than machine 2 (6025).
- Within Component, there is taper with respect to Segment 1, 2 and 3.
- Within Fixture position, there is taper with respect to Right side position to Left side position.
- This has shown a clear correlation with Fixture Parallelism measurement done in CMM.

4.1.5. Hypothesis – Why Why Analysis

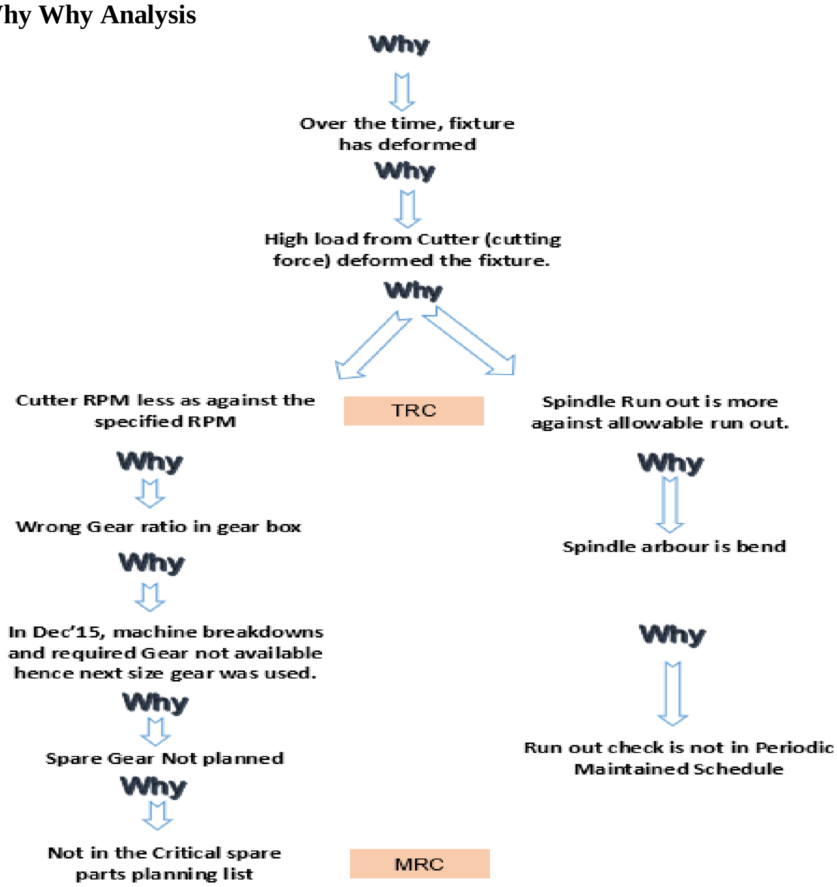


Figure 9. Why Why analysis

Table 8. Current condition of machine 1 (7616) and machine 2 (6025)

Description	Ideal Condition	Machine 1	Machine 2	Inference
Spindle Run Out	<0.03 mm	0.3mm	0.025 mm	Runout of mc is Not Ok
Spindle RPM	300	196	298	RPM is low in mc 1
Table movement	Smooth	Jerky motion	Smooth	Jerky movement not ok

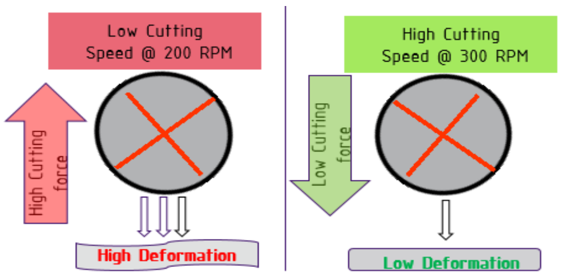


Figure 10. Relationship between cutting force & cutting speed

The power to perform machining can be computed from :-
Fc = Pc / v
Where Pc = Cutting power
Fc = Cutting force
v = Cutting speed

Since cutting speed is proportional to cutting force, low cutting speed of the cutting tool can exert more cutting force on the workpiece enabling a high deformation rate compared to the higher speeds. From the why why analysis study on the control rack process capability it is suspected that though machine 6025 was engaged in production, there were still rejections starting to be noticed, meantime machine 7616 breaks down with the requirement of an appropriate gear to be replaced in the gear box. Since the required size of gear was not available the next size gear was used which made the machine 7616 more worst resulting with a large drop in the cutting speed rpm of the spindle, due to this low cutting speed of the spindle, more force has been exerted by the cutting tool on the work piece and this in turn has caused a taper in the fixture & this taper in the fixture of machine 7616 has ultimately led to variations in the milling process with other following issues including spindle run out i.e. a bend in the arbor/shaft along with a jerky movement in the machine bed which was left unnoticed during operations. Hence it can be concluded that all these issues from the machine 7616 has been the root cause and major contributors to the problem that has been persisting from the past in the production line.

4.1.6. Result and Discussion – (Implementation of corrective actions)

Table 9. Corrective actions implemented

Problem	Corrective action	Result	Status
Spindle Runout More (0.3mm)	Spindle arbor assembly replaced	Runout reduced to 0.03mm	Completed
Taper in Fixture (0.06mm)	Fixture wear Part changed.	Taper reduced to <0.01mm	Completed
Backlash in depth feed axis (0.4mm)	Feed Screw rod adjusted and refitted.	Backlash reduced to <0.02mm	Completed
Spindle RPM less as against Specified RPM	Required diameter Gear ordered	To increased Cutter RPM	completed

Spindle arbor/shaft: - There parameter spindle speed has an effect on the control rack's WOD value. Its effect has an impact on the control rack with its uneven removal in the process of milling from segment to segment. The bend in the spindle arbor was more than 300 microns earlier and after replacing the spindle arbor assembly the run out has been reduced to 30 microns.

Taper in the fixture: - The effect of the taper in fixture of machine 7616 has had its impact on the variability in the milling process values. Its effect on the control racks have caused a lot of issues in the pumps. The taper in the fixture was around 60 microns that has been drastically reduced by 50 microns after the reconditioning stage.

Backlash in the depth feed axis: - The effect of the backlash on the feed axis has its impact on the process of milling. After the reconditioning of machine 7616 by making adjustments and refitting the feed screw rod the backlash in the depth feed axis has been reduced by 380 microns. **E**

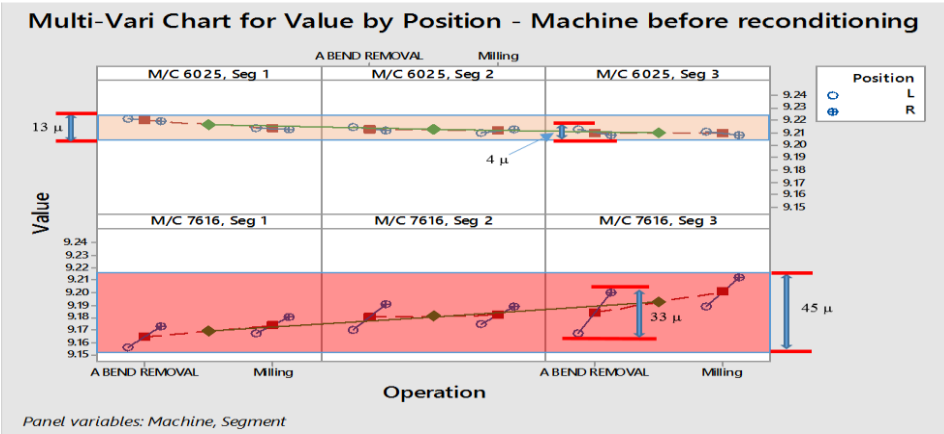
Spindle RPM: - Since cutting force is proportional to cutting speed the impact of the lower speeds of the spindle causes more deformation in the control rack milling process leading to an unevenness in the removal rate on the surface of the work piece by the cutting tool. Hence required diameter gear was ordered and replaced with the consent of the management which increases the cutting speed rpm by 100.
Using these factor levels, a pilot study was carried on the reconditioned machine and the results were compared.

VII. CONCLUSION

The important conclusions drawn from the present work are summarized as follows:

7.1. Comparison of M/C 7616 before & after reconditioning

Figure 11. Milling machine 7616 during the time of reconditioning



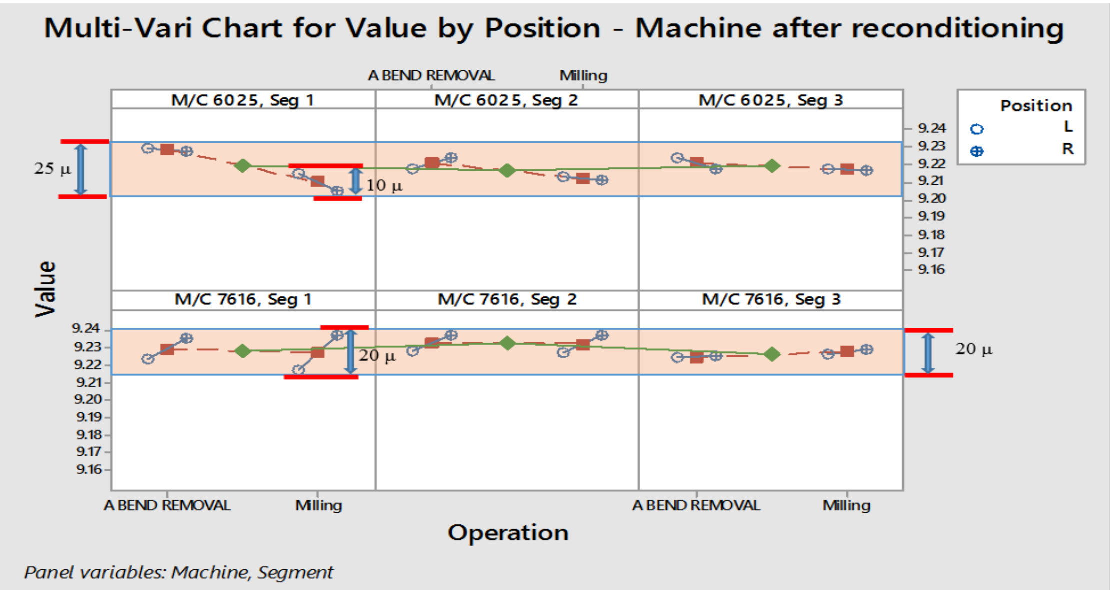
Graph 8. Milling Vs after bend removal (before reconditioning)

Table 10. Values collected from machine 7616 – (After Milling)

M/C 1 (MILLING)																			
	LHS POSITION									RHS POSITION									
SLNO	SEGMENT 1		AVG	SEGMENT 2		AVG	SEGMENT 3		AVERAGE	SEGMENT 1		AVG	SEGMENT 2		AVG	SEGMENT 3		AVERAGE
	6	12		6	12		6	12		6	12		6	12		6	12	
1	9.26	9.28	9.27	9.28	9.27	9.28	9.27	9.26	9.27	9.22	9.23	9.23	9.25	9.24	9.25	9.25	9.21	9.23
2	9.21	9.22	9.22	9.23	9.23	9.23	9.25	9.24	9.25	9.21	9.24	9.23	9.25	9.24	9.25	9.24	9.22	9.23
3	9.26	9.26	9.26	9.25	9.24	9.25	9.25	9.25	9.25	9.23	9.24	9.24	9.23	9.22	9.23	9.24	9.22	9.23
4	9.16	9.19	9.18	9.22	9.22	9.22	9.22	9.21	9.22	9.25	9.26	9.26	9.26	9.24	9.25	9.24	9.23	9.24
5	9.24	9.24	9.24	9.22	9.21	9.22	9.22	9.22	9.22	9.23	9.22	9.23	9.24	9.23	9.24	9.22	9.21	9.22
6	9.12	9.16	9.14	9.21	9.21	9.21	9.24	9.22	9.23	9.21	9.23	9.22	9.25	9.24	9.25	9.26	9.23	9.25
7	9.21	9.23	9.22	9.24	9.23	9.24	9.24	9.21	9.23	9.26	9.27	9.27	9.26	9.25	9.26	9.25	9.23	9.24
8	9.19	9.18	9.19	9.19	9.19	9.19	9.21	9.2	9.21	9.24	9.24	9.24	9.24	9.22	9.23	9.23	9.22	9.23
9	9.24	9.23	9.24	9.23	9.23	9.23	9.2	9.18	9.19	9.26	9.26	9.26	9.23	9.22	9.23	9.23	9.23	9.23
10	9.23	9.23	9.23	9.23	9.21	9.22	9.22	9.21	9.22	9.22	9.22	9.22	9.22	9.21	9.22	9.21	9.21	9.21

Table 11. Values collected from machine 7616 – (After bend removal)

M/C 1 (AFTER BEND REMOVAL)																		
	LHS POSITION									RHS POSITION								
SLNO	SEGMENT 1		AVG	SEGMENT 2		AVG	SEGMENT 3		AVERAGE	SEGMENT 1		AVG	SEGMENT 2		AVG	SEGMENT 3		AVERAGE
	6	12		6	12		6	12		6	12		6	12		6	12	
1	9.26	9.28	9.27	9.27	9.27	9.27	9.25	9.26	9.26	9.22	9.22	9.22	9.23	9.24	9.24	9.25	9.2	9.23
2	9.2	9.22	9.21	9.23	9.23	9.23	9.25	9.24	9.25	9.21	9.24	9.23	9.25	9.24	9.25	9.24	9.22	9.23
3	9.26	9.25	9.26	9.25	9.23	9.24	9.25	9.24	9.25	9.23	9.24	9.24	9.23	9.22	9.23	9.24	9.2	9.22
4	9.2	9.19	9.20	9.22	9.22	9.22	9.22	9.21	9.22	9.25	9.26	9.26	9.26	9.24	9.25	9.24	9.23	9.24
5	9.24	9.24	9.24	9.22	9.21	9.22	9.2	9.22	9.21	9.23	9.22	9.23	9.24	9.22	9.23	9.21	9.21	9.21
6	9.18	9.21	9.20	9.22	9.23	9.23	9.24	9.22	9.23	9.21	9.21	9.21	9.25	9.24	9.25	9.26	9.23	9.25
7	9.21	9.23	9.22	9.24	9.23	9.24	9.24	9.21	9.23	9.27	9.27	9.27	9.26	9.25	9.26	9.25	9.22	9.24
8	9.19	9.18	9.19	9.19	9.2	9.20	9.21	9.2	9.21	9.24	9.24	9.24	9.24	9.23	9.24	9.23	9.22	9.23
9	9.22	9.23	9.23	9.23	9.23	9.23	9.2	9.19	9.20	9.25	9.26	9.26	9.23	9.22	9.23	9.22	9.23	9.23
10	9.24	9.23	9.24	9.23	9.21	9.22	9.22	9.21	9.22	9.22	9.22	9.22	9.22	9.23	9.23	9.21	9.2	9.21



Graph 9. Milling Vs after bend removal (after reconditioning)

7.2. Quantifying & concluding the difference in the process variation in machine 7616 (Before and after reconditioning)

The allowable variation in wire over dimension value is less than or equal to 40 microns. However machine 7616 in terms of process variation shows a drastic difference of around 30 microns as compared to before reconditioning. The values predominantly appear to be maintained on the higher side of the specification as desired & other comparisons are shown in detail as under.

<u>MACHINE 7616</u>

Before reconditioning
Minimum to Maximum overall value = (9.155 mm - 9.200 mm), Variation level = **0.045 mm**

After reconditioning
Minimum to Maximum overall value = (9.217 mm - 9.237 mm), Variation level = **0.02 mm**

Therefore the variation level in the wire over dimension values after reconditioning have reduced by **0.025 mm or 25 microns and a shift of the values to the higher specification side is also observed**.

Highest variation between positions in the Machine 7616:-

Before reconditioning – LHS to RHS = (9.167 mm - 9.200 mm), Variation level in the LHS to RHS value = **0.033 mm**
After reconditioning – LHS to RHS = (9.217 mm - 9.237 mm), Variation level in the LHS to RHS value = **0.02 mm**

Therefore the variation level in the wire over dimension values between positions LHS & RHS after reconditioning have reduced by **0.013 mm or 13 microns and a shift of the values to the higher specification side is also observed**.

Position to position variation between milling and after bend removal in segments of machine:-

SEGMENT 1

Machine before reconditioning
(LHS to LHS) = 0.011 mm = **11 microns**
(RHS to RHS) = 0.008 mm = **8 microns**

Machine after reconditioning
(LHS to LHS) = 0.006 mm = **6 microns**
(RHS to RHS) = 0.002 mm = **2 microns**

Therefore from comparing the process values of the before and after reconditioning of machine from position to position between the setting (milling & after bend removal) it can observed that the control rack's wire over dimensions have reduced by **0.005 mm or 5 microns for positions (LHS to LHS) and 0.006 mm or 6 microns for positions (RHS to RHS) and a shift of the values to the higher specification side is also observed**.

SEGMENT 2

Machine before reconditioning
(LHS to LHS) = 0.005 mm = **5 microns**
(RHS to RHS) = 0.002 mm = **2 microns**

Machine after reconditioning
(LHS to LHS) = 0.001 mm = **1 micron**
(RHS to RHS) = **0**

Therefore from comparing the process values of the before and after reconditioning of machine from position to position between the setting (milling & after bend removal) it can observed that the control rack wire over dimensions have reduced by **0.004 mm or 4 microns for positions (LHS to LHS) and 0.002 mm or 2 microns for positions (RHS to RHS) and a shift of the values to the higher specification side is also observed**.

SEGMENT 3

Machine before reconditioning
(LHS to LHS) = 0.021 mm = **21 microns**
(RHS to RHS) = 0.012 mm = **12 microns**

Machine after reconditioning
(LHS to LHS) = 0.002 mm = **2 microns**
(RHS to RHS) = 0.004 mm = **4 microns**

Therefore from comparing the process values of machine 7616 before and after reconditioning from position to position between the setting (milling & after bend removal), it can observed that the control rack wire over dimensions have reduced by **0.019 mm or 19 microns for positions (LHS to LHS) and 0.008 mm or 8 microns for positions (RHS to RHS) and a shift of the values to the higher specification side is also observed**.

Multi-vari analysis helps in increasing quality by reducing process variability and aligning customer's expectations, providing financial returns to the management by avoiding the defect and rejection rates. The application of shainin trials have also been effective in finding out the project area at the initial level. These techniques used by shainin are increasing to be widely used as a method for problem solving by the quality department of various manufacturing firms worldwide. In this context, this project has been carried out for finding the root cause. The actual parameters were identified and the improvements in the required area was proposed and made.

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