A Case Study Approach of Quality Tools in Manufacturing Industry

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Abstract - *In recent years most manufacturing companies have focused on the manufacture of higher value added products with low production costs. Therefore, elimination of waste and improvement in the quality has become an important success criterion for companies to increase the productivity. This study presents the case of a leading industry that manufacture and supply diverse range of robotics and automation products of which an oscillator-a product used in diamond industry, found suffering from high manufacturing defect rates, excess manufacturing and assembly time leading to overall decreased productivity and profit of the company. The study plans to carry out an all-inclusive participatory investigation into option for solving the problem with the help of DMAIC (Define-Measure-Analyze-Improve-Control) methodology of six sigma and its tools along with less expensive ways to mitigate the above noted problems to maximum.*

Key Words: Six sigma, Total quality management (TQM), DMAIC (Define-Measure-Analyze-Improve-Control), Check Sheet, Control Charts, 5 Why root cause analysis, Pareto analysis, Manufacturing.

1. INTRODUCTION

Six sigma method is a project-driven management approach to improve the organization's products, services and processes by continually reducing defects. It is a business strategy that focuses on improving customer requirements understanding, business systems, productivity, and financial performance. It is a company-wide systematic approach to achieve continuous process improvements. Six sigma is not only a technique but also a philosophy, a strategic initiative to boost profitability, increase market share and improve customer satisfaction through statistical tools that can lead to breakthrough quantum gains in quality. The six sigma strategy works well in both multi-billion dollars as well as a small privately held companies. This pilot study was carried out using six sigma methodology and tools to identify and anatomize the causes of the problem, so as to find and implement applicable solutions.

The DMAIC methodology and the steps included in each phase are:

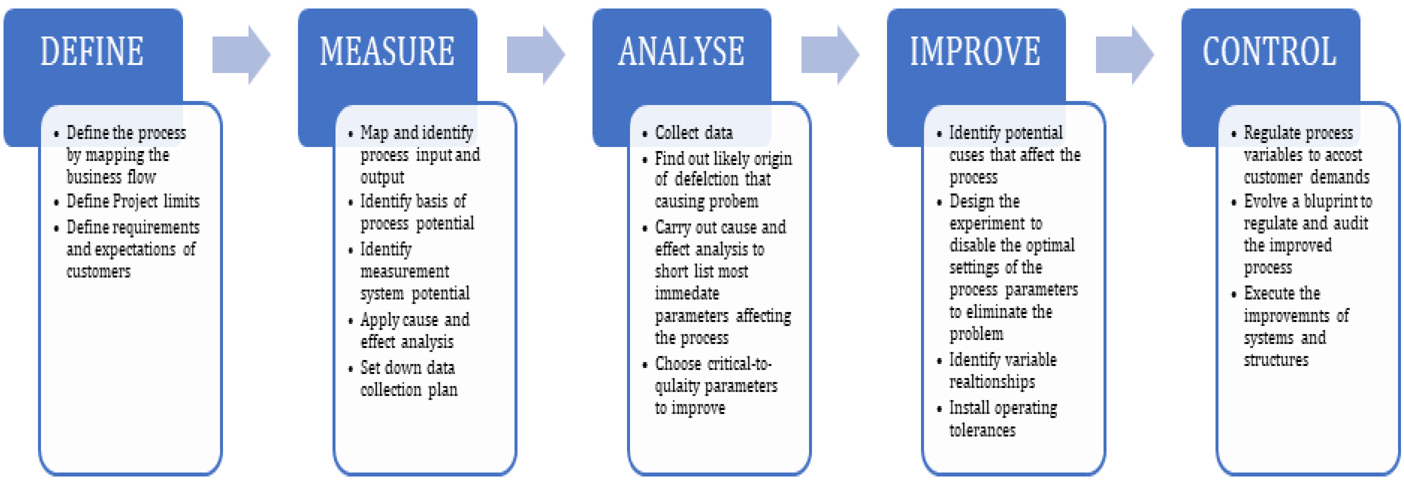


Figure-1: DMAIC methodology and its step

2. METHODOLOGY

2.1 Define

In phase I the observation of current scenario for the product, oscillator was carried out. The complete manufacturing process was observed from raw material to finished product.

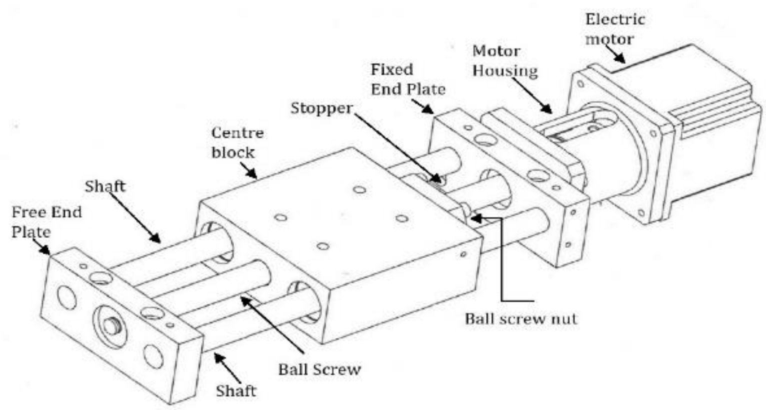


Figure-2: Schematic diagram of oscillator

The oscillator is a mechanical product assembled from number of other singular components, some of which are manufactured in the company while other are imported readymade. The manufacturing process generally included processes such as cutting, milling, operations on (Ace Micromatic Group) AMS CNC (drilling, boring, reaming, slitting), chamfering, tapping, slotting, buffing respectively. These operations were carried out on seven different workstations. Finally, the manufactured singular components were forwarded to assembly section where with other readymade components (electric motor, bearings) assembly of oscillator was carried out manually.

On mapping the process flow following observations were made:

- Firstly, the operations at some workstations were taking longer machining time than required due to which next operation in production line delayed further consuming more time.
- Secondly, time taken by assembly was distinctively more.
- Thirdly, two personnel's were carrying out assembly when it can be done single handed.
- Fourth most, rework on faulty work pieces consumed manufacturing time in line of production and rejected finished products further added to losses.

Hence, the problem was defined and the ultimate aim of the study oriented to increase the yield of the oscillator by solving its manufacturing-assembly time and issue of defect rate by overall process improvement.

2.2 Measure

The oscillator manufacturing and assembly time of each component was carried out by data collection in process sheets. Individual Process sheets were made for every element of the oscillator. The time study was carried out by stopwatch. Dimensions of the elements were measured using Vernier caliper in sampling sheets. In order to make study time more reliable and dependable, cycle time and takt time was taken five times for each component and an average was calculated along with dimensions and number of defects.

Table-1: Observed cycle time and takt time

Sr. no	Elements / Operations	Centre Block	Fixed End Plate	Free End Plate	Shaft	Ball Screw	Motor Housing	Ball Screw Nut	Stopper	Takt time in minutes / Cycle time in minutes	Number of Workers
1	Cutting	0.5 / 2.05	0.5 / 2.62	0.5 / 2.62							1
2	Milling	1 / 18.84	1.5 / 44.6	1.6 / 44.6			0.5 / 1.62	0.5 / 2.2			1
3	AMS (CNC)	2.4 / 21.13	2.5 / 8.37	2.5 / 7.41							1
4	Chamfer	- / 1.32	- / 1.32	- / 1.32				- / 0.128			1
5	Tapping	0.5 / 1.36	0.5 / 0.78	0.5 / 0.78			0.5 / 0.68	0.5 / 0.4			1
6	Facing				0.5 / 1						1
7	Flat milling				0.5 / 0.72						1
8	Turning					1 / 1.73	1 / 1.162				1
9	Grooving				- / 0.04						1
10	Grinding				- / 0.14						1
11	Drilling						0.5 / 0.52	0.5 / 0.36			1
12	Slotting						- / 0.5				1
13	Cutting II				0.5 / 0.11				0.5 / 0.023		1
14	Assembly	- / 22.5									2
	Total	21.5 / 192.953									15

Table-2: Observed dimensions of elements entering the operation

Elements	Centre block						Fixed End Plate/ Free End Plate						
Operation / Sample	Milling (90x90x35)			AMS (CNC) (85x85x32)			Milling (90x16x14)			AMS (CNC) (85x14x36)			Dimensions in mm
	L	B	H	L	B	H	L	B	H	L	B	H	
1	90	92	35	85	85	32	90	17	40	85	14	36.2	
2	90	90.5	35	85.2	85.2	32.5	90	17	40	85	14	36.2	
3	90	91	35	85	85	32	90	16	40	85.5	14.5	36	
4	90	92	35	85.5	86	32	90	17	40	85	14.3	36	
5	90	92	35	85	86	32.2	90	16.5	40	85.1	14	36	
Average	90	91.5	35	85.14	85.44	32.14	90	16.17	40	85.12	14.16	36.08	
Dimensional tolerances	+1 -1			+0.02 -0.02			+1 -1			+0.02 -0.02			

*L-length, B-breadth, H-height

Table-3: Observed defect rate

Sr no	Source of defect	Number of defected elements
1	Milling	3
2	AMS (CNC)	2
3	Assembly	2
4	Customer	1

2.3 Data analysis

In this phase III, the data and the root causes of failure in product manufacturing and assembly process are analyzed. Takt time had been calculated for manufacturing of oscillator components to determine how often a line should process one part, based on rate of sale, for fulfilling the customer requirement. Thus, the takt time is used as a guideline in the production line balancing to re-design the future process. If the cycle time of a work operation is higher than calculated takt time, that particular work operation is the bottleneck. This may be causing overproduction waste or work in process (WIP) in some areas that required extra processing time, such as overtime, to meet demand.

$$\text{Takt time} = \frac{\text{availabe work time per shift}}{\text{customer demand rate per shift}}$$

Table-4: Calculation of takt time

Shift length (A)	9 hours = 9x60 = 540 minutes
Breaks (B)	(1 small tea break x 10 mins) + (60 mins lunch break) + (10 mins material handling time) + (5 mins maintenance time) + (5 mins clean up time) = 90 minutes
Planned Production (C)	(A-B) = 540-90=450 minutes
Customer Demand (D)	25 oscillators having 8 individual component Thus, 25 x 8 = 200 pieces in 6 days That is 200÷6 = 33.33 pieces per day
Takt time	450÷33.33 = 13.50 minutes/piece

The observed takt time is different than calculated takt time. From table-1, it can be observed that some work process are taking longer than required time and their takt time is more, causing long waiting time for part arrival and longer time to complete the assigned process. Assembly time is more and defect rate is unacceptable. From table-2, it is seen that elements entering Milling operation widely varies in dimensions, although after milling for desired dimensions some of the elements entering next process station- AMS (CNC) operations shows unacceptable tolerances, which is the leading cause for further dimensional error of the operations and rejection and rework of the element.

Within acceptable tolerances the element remained un-rejected though it increases assembly time so as to make adjustments according to acquired tolerances of the elements due to pressure of timely delivery and prevention of losses. Thus the dimensional accuracy should be maintained at Milling and at AMS (CNC) operations to avoid bottleneck, rework, rejection, high machining time and decrease assembly time and man labor. Pareto analysis is based on the 80/20 principle that is 80% of problems can be solved by solving 20% of key problems.

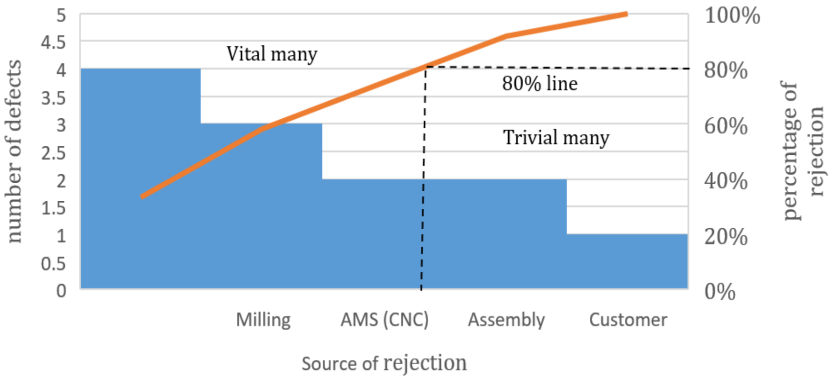


Chart-1: Pareto Analysis of rejection Rate

The 80% line drawn on chart helps to establish the "Vital few" sources of problems that needs to be addressed at forefront from "Trivial many". Usually solving vital problems subsidizes the trivial issues.

From chart-1, the Milling and AMS (CNC) operations fall under vital few percentage. Thus focusing on these 20 % vital sources will help solve 80% of problems. Thus the main focus of this study remains to improve manufacturing process at these two work stations but removing bottleneck, high operation time and variation in dimensions. After pinpointing sources of problems through Pareto analysis, brainstorming and discussions were carried out to find out basis of cause of failures. Thus, the 5 why analysis was carried out to establish the root causes of failure in oscillator.

The root causes are based on by repeatedly asking the question "Why" (thumb rule-five times), which peels away the layers of symptoms which can lead to the root cause of the problem.

Table-5: Five why root cause analysis

Sr no	Issues	Bottleneck at Milling operation of center block and Free/Fixed end plate	High operation time at AMS (CNC) operation of Centre block and Free/Fixed end plate	High rate of rejection from customer and assembly line	High assembly time	Increased man labor	Variation in dimensions
1	Why	Increased takt time and operation time and rework	Increased takt time Improper tooling	Failure in design element Improper alignment of machined elements	Increased efforts to assemble elements in place	Rework on element	Lack of inspection at work station after operation
2	Why	Variance in operation tools arrangement	Variance in operation tools arrangement Lack of tooling knowledge	Error in tolerance of dimensions	Improper alignment of machined elements	Rejection from assembly line, AMS (CNC) workstation	
3	Why	Dimensional variability of elements arriving at milling work station	Dimensional variability of elements arriving at AMS (CNC) work station	Lack of inspection of elements dimensions leaving work station	Error in tolerances of dimensions	Variance in dimension of elements	
4	Why	Lack of dimensional tolerance of elements arriving at milling station	Lack of dimensional tolerance of elements arriving at AMS (CNC) work station		Lack of inspection of elements dimensions leaving work station	Lack of inspection of elements dimensions leaving work station	
5	Why	Lack of inspection of elements dimensional inspection	Lack of inspection of elements dimensional inspection				

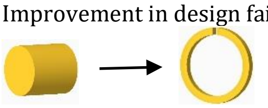
It can concluded that main causes for bottleneck, high operation time, dimensional error and excessive manpower are improper tooling, unnecessary process handling, inconsistent work operation sequence, unbalanced workstation, defective items and lack of inspection. This in turn causing high assembly time, rejection and rework.

2.4 Improve

This phase IV is to ameliorate the manufacturing process with effective solutions after analysing the current situation. The considerations that would be taken into account towards the solutions proposed included budget, feasibility and the expected outcome of each station.

The improvement listed are mutually exclusive to each other but are proposed in relation to the manufacturing process as whole, it might affect certain workstations as well as other improvements.

Table-6: Enlistment of improvements or solutions

Sr no	Issues/Problems	Solutions
1	Bottleneck at milling operation	Inspection sheet for components leaving cutting operation and milling operation Use of improved face mill tool with increase feed rate from 0.002 to 0.005 per tooth is used to reduce machining time
2	High operation time at AMS (CNC)	Use of U-drill in center block instead of twisted drill bit to reduce operation time Use of Centre-finder of every component before AMS (CNC) operation Inspection sheet for components leaving AMS (CNC) operation
3	High rate of rejection from customer	Improvement in design failure of the component "Stopper". 
4	High rate of rejection from assembly line	Selective inspection of components before entering assembly line
5	High assembly time	Use of inspection sheet and selective inspection as mentioned above
6	Increased man labor	Application of above solutions will reduce rework, rejection thus consequently reduces man labor
7	Variation in dimensions	Proper tooling, operation and inspection as mentioned above subsequently reduces dimensional variability

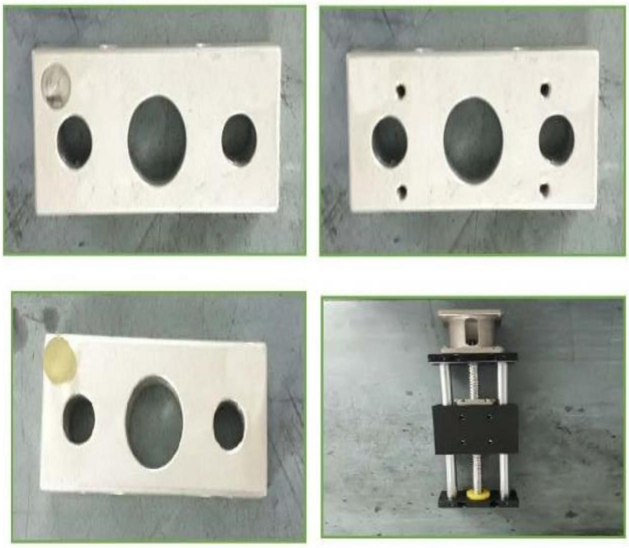
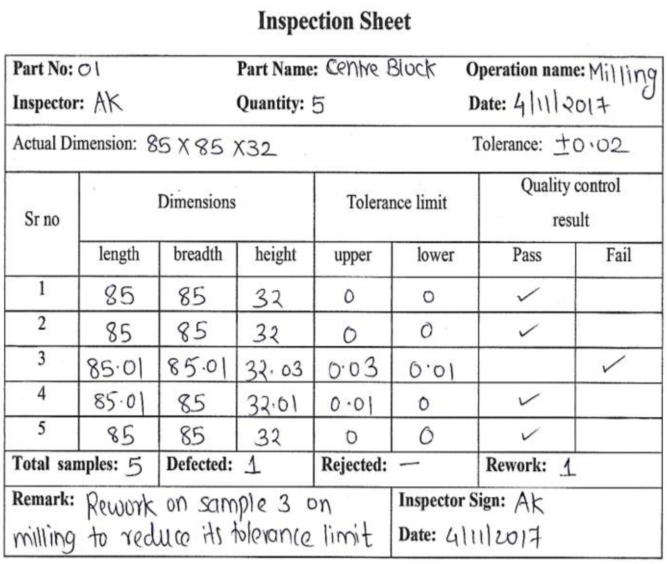


Figure-3: Changes in design of stopper



Inspection Sheet

Part No: 01 | Part Name: Centre Block | Operation name: Milling
Inspector: AK | Quantity: 5 | Date: 4/11/2017
Actual Dimension: 85 X 85 X32 | Tolerance: ±0.02

Sr no	Dimensions			Tolerance limit		Quality control result	
	length	breadth	height	upper	lower	Pass	Fail
1	85	85	32	0	0	✓	
2	85	85	32	0	0	✓	
3	85·01	85·01	32·03	0·03	0·01		✓
4	85·01	85	32·01	0·01	0	✓	
5	85	85	32	0	0	✓	

Total samples: 5 | Defected: 1 | Rejected: — | Rework: 1

Remark: Rework on sample 3 on milling to reduce its tolerance limit | Inspector Sign: AK | Date: 4/11/2017

Figure-4: Sample inspection sheet used in improvement phase

Although the sample inspection sheet in figure-4, was used for time being, it is subjected to changes as the improvement process further enhances. For this project, the inspection sheet was used at two different workstations- milling and AMS (CNC) machine and at assembly for three vital components of the product- center block, fixed and free end plate. Vernier caliper was used as a measuring device for carrying out inspection.

Use of inspection for in detailed operations will further improve the process productivity and will help to reduce defect rates, also use of intrinsic measuring instruments such as micrometer can be used for increased accuracy.

By implementing improvements into manufacturing process, the operators are more utilized with less rework due to reduced defect rate, the productivity of the process is increased, and the process shows no bottleneck since all the cycle time is under takt time, making the process smoothed influencing cost savings.

Table-7: Improved overall process time for each workstation

Sr. no	Operations \ Elements	Centre Block	Fixed End Plate	Free End Plate	Shaft	Ball Screw	Motor Housing	Ball Screw Nut	Stopper	Takt time in minutes / Cycle time in minutes	Number of Workers
1	Cutting	0.5 / 2.05	0.5 / 2.62	0.5 / 2.62						Takt time in minutes / Cycle time in minutes	1
2	Milling	0.5 / 18.84	0.5 / 22.61	1.5 / 22.61			0.5 / 1.62	0.5 / 2.2			1
3	AMS (CNC)	1.5 / 14.46	1.5 / 6.89	2.5 / 5.73							1
4	Chamfer	- / 1.32	- / 1.32	- / 1.32				- / 0.128			1
5	Tapping	0.5 / 1.36	0.5 / 0.78	0.5 / 0.78			0.5 / 0.68	0.5 / 0.4			1
6	Facing				0.5 / 1						1
7	Flat milling				0.5 / 0.72						1
8	Turning					1 / 1.73	1 / 1.162				1
9	Grooving				- / 0.04						1
10	Grinding				- / 0.14						1
11	Drilling						0.5 / 0.52	0.5 / 0.36			1
12	Slotting						- / 0.5				1
13	Cutting II				0.5 / 0.11				0.5 / 0.006		1
14	Assembly	- / 10									1
	Total	14 / 126.626									14

Table-8: Improved dimensions of elements entering the operation

Elements	Centre block						Fixed End Plate/ Free End Plate						
Operation / Sample	Milling (90x90x35)			AMS (CNC) (85x85x32)			Milling (90x16x14)			AMS (CNC) (85x14x36)			Dimensions in mm
	L	B	H	L	B	H	L	B	H	L	B	H	
1	90	90	35	85	85	32	90	16	40	85	14	36.02	
2	90	90.5	35	85	85	32	90	16.2	40	85	14	36.02	
3	90	90.5	35	85.02	85.02	32.03	90	16	40	85	14	36	
4	90	90.2	35	85.02	85	32.02	90	16	40	85.02	14	36	
5	90	90	35	85	85	32	90	16.1	40	85.02	14	36.02	
Average	90	90.2	35	85	85	32	90	16.06	40	85	14	36	
Dimensional tolerances	+1 -1			+0.02 -0.02			+1 -1			+0.02 -0.02			

*L-length, B-breadth, H-height

Table-9: Reduced defect rate

Sr no	Source of defect	Number of defected elements
1	Milling	0
2	AMS (CNC)	1
3	Assembly	1
4	Customer	0

2.5 Control

The aim of the control phase is to sustain gains from processes which had improved by institutionalizing process or product improvements and controlling operations. This project being a pilot study and due to time limits, the improvements were applied for singular batch of five of oscillator manufacturing process. However, the two batches of oscillator under consideration for study had shown tremendous improvement in manufacturing process with simple application of six sigma and its quality tools. For future benefits at large levels, the improvements carried out in this study at small scale needed to be implemented, sustained, monitored and controlled further in future as mentioned below:

- Inspection sheets

Making a habit of compulsion to cutting, milling and AMS (CNC) operator to fill out inspection sheets on average of five count in the batch of twenty-five oscillators. The inspection can be carried out initially on alternate component basis till the operator gets his hands on with the process and also it will ensure consistency of quality from previous and later work station operations. However after satisfactory results, the inspection can be average to five percent inspection of the batch size, as the manufacturing process is smoothed out.

- Knowledge of proper tooling

As it was observed that use of proper tooling can affect cycle time of an operation tremendously. Thus, getting equipped with modernized tools and their also training operators regarding the same can save man labour, time and finance of the company. Operators with knowledge on tooling can further adds to improvement in process of manufacturing of other products also.

- Process map

The process map of the new process that was created during improve phase should be reviewed and updated as necessary to reflect any modifications that may have occurred during roll out. It will be used for training and reference so that the new process will be clear. In case of multiple individual involvement in the process, a deployment flowchart should also be developed to clarify roles and task.

- Process monitoring plan

The most critical aspect of control is establishing a plan to monitor the new process and act when results are not up to spec, so that the project gains will be maintained. The monitoring plan clarifies how the process performance will be continuously monitored, who will be notified if there is a problem and how that will happen and what response is required. The first part of the monitoring plan specifies the metrics that will be tracked to summarize process performance, as well as specifying how and how often they will be tracked. The monitoring plan also indicates what constitutes satisfactory performance and what should be considered red flag indicating possible problems.

- Control charts

A control chart should be continuously updated so that the manufacturing head can watch for process shifts or other signs that there may be a problem with process performance.

- Brainstorming

Even after successful implementation of six sigma and its quality tools for process improvement, to maintain that gain continuous brainstorming between operators, engineers and managers is required. The brainstorming can be done during training lectures, in meets on regular basis. This helps to share knowledge and further improves company productivity as every element of company is thriving towards betterment. A small improvement in any ongoing process improvement can further enhance potential of company output and make it stand competitive market with quality assurance.

3. RESULT

The results after implementation had been compared, analyzed and gathered. From the implementation results, the project goal was contentedly achieved with the performance in terms of reduction of total cycle time, takt time, defect rate, manpower and dimensional tolerance. The achievement is not only to prove the robustness of the process improvement methodology but also to weigh up the acceptability ad practicality of the developed methodology for industrial application.

Table-10: Comparison before and after

<table>
<tr><th></th><th>Total cycle time (minutes)</th><th>Takt time (minutes)</th><th>Defect Rate (Percentage)</th><th>Manpower</th><th colspan="2">Dimensional tolerances</th></tr>
<tr><td>Before improvement process (x)</td><td>192.953</td><td>21.5</td><td>40</td><td>15</td><td>+0.835</td><td>+0.18</td></tr>
<tr><td>After improvement process (y)</td><td>126.626</td><td>14</td><td>10</td><td>14</td><td>+0.42</td><td>+0.00</td></tr>
<tr><td rowspan="2">Percentage in reduction</td><td rowspan="2">34.37</td><td rowspan="2">34.88</td><td rowspan="2">75</td><td rowspan="2">6.66</td><td>49.70</td><td>100</td></tr>
<tr><td colspan="2">74.85%</td></tr>
</table>

Formula used in calculating percentage is, Reduction in percentage = (x-y) ÷x *100

4. CONCLUSION

The process improvements methodology that has been developed based on six sigma concept had improved the flow of completing the project by separating the task into phases. This model is leading the project to better utilization of resources, decreases the unnecessary wastes and maintains consistent quality of the process output via systematic and well-organized phases. The six sigma improvement methodology, viz. DMAIC project shows that the performance of the company is increased to a better level as regards to: enhancement in customer satisfaction, adherence of delivery schedules, and development of specific methods to redesign and recognize a process with a view to reduce or eliminate errors, defects; development of more efficient, capable, reliable and consistent manufacturing process and more better overall process performance, creation of continuous improvement and “do it right, the first time” mind-set.

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