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# Application of Six Sigma to Reduce First Time Yield Loss of Power Contactor

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**Abstract:** ***In Industry, there occurs a considerable amount of rejections of power contactors due to some manufacturing mistakes. This results in production of faulty contactors which are to be remanufactured and which takes a considerable amount of time and labor. In order to avoid this excess labor the First Time Yield (FTY) of the contactor is to be improved. To improve the First Time Yield (FTY) different quality improvement tools of Quality Improvement are deployed. Six Sigma is one of them which seek to improve the quality of the output of a process by identifying and removing the causes of defects and minimizing variability in manufacturing and business processes. This paper discusses the quality and productivity improvement in a manufacturing enterprise. The paper deals with an application of Six Sigma DMAIC(Define–Measure-Analyze-Improve-Control) methodology in an industry which provides a framework to identify, quantify and eliminate sources of variation in an operational process in question, to optimize the operation variables, improve and sustain performance. This paper presents and discusses the improvement in FTY after implementation of the Quality tools.***

**Keywords:** DOE- Design Of Experiments, DPM- Defects Per Million, DMAIC- Define–Measure-Analyze-Improve-Control, FTY- First Time Yield, DUT- Drop Up Time, DOV- Drop Out Voltage, PUV- Pick Up Voltage.

## 1. Introduction

Electrical contactor is basically a switching device capable of making, carrying and breaking currents under normal and overload condition. It provides isolation to downstream equipment in off condition. Basically, it is an on off switching device which is mainly used in control panels. Contactors may be of 3 types: Pneumatic, Hydraulic and Electromagnetic. But most commonly used one is Electromagnet type containing the moving magnet, fixed magnet, Coil, Shading ring, fixed contact and Moving contact. These contactors are manufactured in Electrical and Automation sector of Industry. These are mainly used in motor starters and control panels of various industries. Larsen and Toubro is one of the major manufacturers of Electrical Power Contactors. It has large capacity of manufacturing these contactors on assembly lines. The production rate is quite high and reduction in rejection rate is of primary concern. The yield (output) of the product is measured by its FTY- First Time Yield. FTY is simply the number of good units produced divided by the number of total units going into the process. When contactor is taken for testing on test bench various tests are performed on that contactor like Flashing, Coil Current, Pick Up Voltage, Drop off Time, Drop off Voltage, Humming and HV test. To reduce FTY Loss means maximize the rate of passing of good units.

There are various problems that occur in contactor operation. Many times the contactor gets failed due to some small manufacturing defects like inadequate control voltage due to the low voltage control. Sufficient magnetic force may not produce and hence contactor starts chatter resulting in poor contacts or loose connection in control circuit. These loose contacts cause major voltage drop and hence coil gets low voltage. When long and smaller cross section control cables are used for actuating the contactor, large voltage drop may occur causing chattering of the contactor or even failure to pick up. In this case use of higher size of cable or use a signal relay for the contactor. Major share of failures with contactor are due to burning of coils. If core faces are not closing properly, it leads to sharp rise in magnetizing current which result in burning of coil. Rusting of core faces occur due to humidity as corrosive atmosphere has a profound effect on the performance of contactors. Overheating takes place due to the formation of foreign films at the connection on spring and core faces. Due to inadequate heat ventilation, coil gets heated up and leads to insulation failure. Induced voltage in the coil is proportional to rate of change of current and inductance of the coil. While switching off the contactor the di/dt ratio is very high and induces high voltage this may result burning of coils. By providing suitable resistance in series with the coil discharges the stored energy in the coil when supply cuts keeping di/dt to small. Coil insulation is increased by using varnish. Inter turn short circuit of coil turns due to coil insulation failure. If thermal aging of coil insulation occur then the coil needs a replacement. High control voltages and low frequencies are also causes coil burning.

Humming problem is also there in the magnets. Main reasons for the humming noise are due to minor gap in magnetic faces due to dirt or rust accumulation on magnet faces or due to cracked shaded ring. Sometimes contactor temperature rises abnormally and gives poor performance. This may happen due to improper termination of contactors terminals and loose connection are the main for overheating.

Some of the above mentioned problems are mostly related to the maintenance part of the contactor and can be fixed while performing the maintenance of the contactor. But, there are some manufacturing defects that are responsible for production of faulty contactor at factory level. These defects result in production of faulty contactor that causes the reduction in First Time Yield of a batch of contactors. This reduction in FTY causes a considerable loss of manpower


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and material resources of the organization. The paper presents an application of different tools of Six-Sigma to reduce the FTY loss of power contactors in Larsen & Toubro.

## 2. Methodology

The product quality is basically measured with the help of the sigma index of the product. Sigma (σ) represents variation in the process with respect to mean (average line). Six Sigma is a data-driven approach to process improvement .Objective of this methodology is to achieve zero defects by reducing variation. More the Sigma better is the product quality. The maximum sigma level that a product can ever achieve is Six Sigma. [4] Hence, Six Sigma methodologies are used for the improvement of FTY and quality of Power Contactor. Six Sigma methodologies have proved out to be very useful for all business organizations for achieving high profits by product upgradation and continuous improvement. Six-Sigma uses various tools, techniques and methods such as Project charter, SIPOC, Fishbone Diagram, FMEA. The values of these factors found out first to get the product oriented figures. Then function-improving methods like Decision making matrix, Brain-storming methods, etc. are used to improve the product quality. Six Sigma job plan helps in effective implementation of these methods. Six Sigma uses DMAIC methodology which is mainly classified into five phases which are define phase, measure phase, analyze phase, improve phase and control phase.\

- **Define Phase:** In order to implement Six Sigma methodology it is crucial to define the customer's need, project boundaries and the process to be improved.
- **Measure Phase:** It is essential to measure the performance of Core Business Processes so a plan is to be developed for the collection of data for the process, gather data to identify the defects.
- **Analyze Phase:** The next step in the DMAIC model is to analyze the data and process map to establish causes of defects to improve current performance and goal performance compared to identify gaps.
- **Improve Phase:** Using the data from the implementation of the above phases it is possible to improve the process by designing creative solutions to fix and prevent problems.
- **Control Phase:** To prevent the instinct to return to the old ways of doing things.

All of the above phases use different quality control tools like Pareto Analysis, Fishbone Diagram, Shainin DOE Technique, etc.

- Pareto Analysis is a statistical technique in decision-making used for the selection of a limited number of tasks that produce significant overall effect. It uses the Pareto Principle (also known as the 80/20 rule) the idea that by doing 20% of the work you can generate 80% of the benefit of doing the entire job.
- The Fishbone diagram is an analysis tool that provides a systematic way of looking at effects and the causes that create or contribute to those effects. Because of the function of the Fishbone diagram, it may be referred to as a cause-and-effect diagram.[3]
- The Shainin DOE System is the name given to a problem solving system developed by Dorian Shainin which included several techniques- both known and newly invented – in a coherent step-by-step strategy for process improvement in manufacturing environments. Shainin DOE technique is used to determine whether assembly is creating problem or not and the component search i.e. identifying the component which is contributing to the cause. Shainin Design of Experiments (DOE) offers a powerful and effective experimental design approach for solving the chronic quality problems that plague manufacturers worldwide.

In order to apply the above approaches it is very necessary to have a base data to work on. There are different tests of contactor which are performed on the test bench such as Flashing test i.e. continuity test, Coil Current Test(CC), Pick Up Voltage(PUV), Drop off Time(DOT), Drop off Voltage(DOV), Humming, and High Voltage Test. All of these tests are performed on the test benches available in the manufacturing facility. After these tests contactor is unloaded automatically. Visual indicator for pass and fail contactor- Yellow Indicator for passed contactor and Red Indicator for failed contactor. The data collected after testing is then used to analyze the causes of failure. The failure count is then segregated according to the various approaches of quality control techniques. After carefully studying the data, cause and effect diagram is developed and the possible solutions are found out.

## 3. Calculations and Result Analysis

A batch of contactors is studied and tested for the faulty and rejected contactors. The study is made on these faulty contactors and various quality improving tools are implemented in order to improve the first time yield of the contactor.

In the Define and Measure Phase collected data of testing from FTY Register is loaded and obtained graph is shown in figure 1. Graph 2.1 showing that DOV and Humming tests contributing the major FTY loss. It is found that contactor fails in these tests due to following reasons:

a) Due to the absence of shading rings on fixed Magnets
b) Presence of burr/dust/external particles from pole faces of both moving and fixed magnets.
c) Loose fitment of rubber pad along with magnet.
d) Loose laminations of magnets.

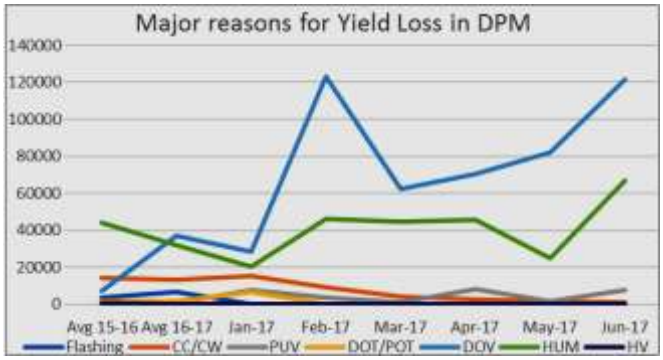


**Figure 1:** Major reasons for yield loss in DPM


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1) Flashing: i. e Continuity Testing – Contactors are tested at 110 % of rated voltage (coil Voltage). Flashing means the two contacts moving and fixed contacts touch to each other. It is checked by giving the supply to contacts and by on and off operation of contactor. There are 50, 35, 20, 10 operations are done on different types of contactor.
2) Coil current (CC): Current measurement at rated voltage.
3) Coil Wattage (CW): Power consumption at rated Voltage.
4) DOT /PUT: Drop off Time & Peak up time.
5) DOV: Drop Off Voltage (Voltage at which contactor switches off after continuous reduction in voltage)
6) PUV: Pick up voltage. (Voltage at which contactor on)
7) Humming: Audible sound /Vibration in contactor on condition
8) HV: High Voltage

Now in order to analyze the percentage contribution of the various reasons for loss in FTY, Pareto analysis in implemented. Pareto Analysis is the statistical technique in decision making. It produces significant overall effect. To use Pareto analysis, identify and list the problems and their causes. Then score each problem and group them by together by their cause.

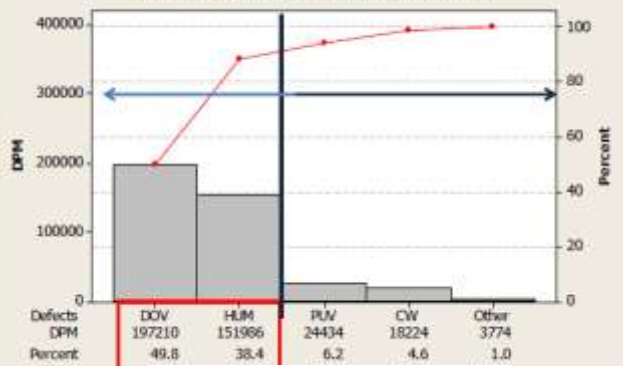


**Figure 2:** Pareto Chart of Defects

From Pareto Analysis, It is clear that DOV contributes 49.8% and Humming contributing 38.4% in FTY Loss. Now the possible causes for increase in DOV and Humming are:

1) Faulty reading shown by test bench
2) Improper maintenance of test bench
3) Wrong Assembly
4) Ignorance towards methods of assembling
5) Assembly of fixed magnet
6) Assembly of contact springs and return springs
7) Air gap of fixed magnet out of specification
8) Roughness and Planarity out of specification
9) Load value of spring out of specification
10) Rubber pads/bush falling out of specification
11) Number of turns of coil out of specification
12) More number of lamination
13) Less or more wire diameter

As the above are the possible causes, so in order to move from Possible Causes to Probable Causes Fishbone Diagram is used which is shown in Fig. 3

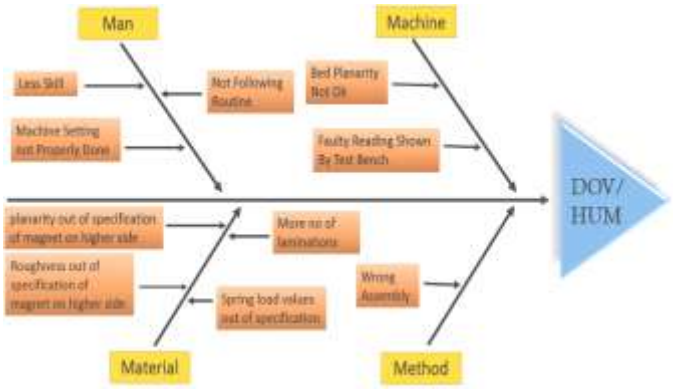


**Figure 3:** Fishbone Diagram introducing probable causes

Fishbone diagram does not give the exact causes hence we take the prioritization matrix in which we gives the priority to the possible causes and that priority can be given by some senior engineers.

**Table 1:** Priority index for causes of failure

| | DOV | HUM | PUV | CC/ CW | TOTAL |
|---|---|---|---|---|---|
| Weightage | 8 | 10 | 3 | 1 | - |
| Ra(Roughness) value of magnet | 6 | 5 | 1 | 1 | 103 |
| Planarity of Magnet | 7 | 8 | 1 | 2 | 140 |
| Load Value of Springs | 8 | 5 | 1 | 1 | 118 |
| Assembly Problem | 1 | 1 | 2 | 1 | 25 |
| Bed Planarity | 1 | 1 | 1 | 1 | 22 |
| More no. of laminations | 0 | 1 | 0 | 0 | 10 |

From above table we conclude that Planarity of magnets, Roughness value of magnet and load values of spring can cause a problem. But From Brain Storming, Fishbone Diagram and Prioritization matrix we did not get the exact i.e. the major cause of failure hence by applying the Shainin DOE technique the major cause is found out. In order to apply the Shanin DOE method take Good Contactors and Bad Contactors then swap each component simultaneously. This technique is used to find the cause in a short time.
Steps to find the cause by Shainin DOE technique are as below:

**Step 1**: Identification of whether assembly or the component is the problem or not.

**Table 2:** Readings of Good and Bad Contactor

| Defect / Specification | DOV GOOD ( 108V – 156V) | DOV BAD (>156V) |
|---|---|---|
| Initial Value | 128 | 179 |
| 1st Disassembly & Re-Assembly of Contactor | 132 | 168 |
| 2nd Disassembly & Re-Assembly of Contactor | 129 | 170 |
| Median (Middle Value) | 129 | 170 |
| Range (Highest – Lowest) | 4 | 11 |
| D (Difference between the medians) | 41 | |
| D (Average of the ranges) | 7.5 | |


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If D/d >= 1.25 then assembly is not creating the problem.
Here D/d is 5.46 which is greater than 1.25 hence here assembly is not creating the problems.

**Step 2**: Identifying which component is the problem (Initial Swapping)

Two contactors are taken and swapping of each component of it is done such as return spring, contact spring, coil assembly, fixed magnet assembly, moving magnet assembly, moving magnet bush and moving magnet. Instantly the component causing failure of test is found out.

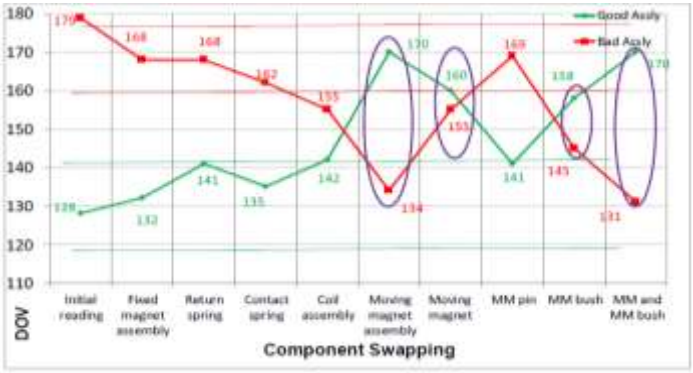


**Figure 4:** Component Swapping Results

At the time of swapping of components, moving magnet and moving magnet bush are swapped. Good contactor becomes Bad Contactor and bad becomes good i.e. moving magnet and moving magnet bush is contributing to the major failure.
It indicates that bush is getting collapsed inside after inserting into the magnet and causing interference with magnet pin. To check which dimension of component is contributing failure "Paired Comparison" is done.
Steps for paired comparison are given below:

1) Eight good contactors and eight bad contactors are taken which have DOV problem.
2) Rubber bush is removed from all the 16 contactors.
3) Listed product parameters which can explain the difference in good and bad parts which are as under-
   For Rubber Bush,
   - 8.9 +0.1/-0.2 Dimension
   - Concentricity 0.05
   - Inner Diameter 7+/-0.2
   - Length 21mm

   For Moving Magnet Side Plate,
   - Hole Dimension 9+/-0.05
4) All the good and bad parts for the parameters above are identified and written whether the part belongs to GOOD or BAD.

The number of time the good and bad remarks occuring are counted as shown in table Table 3(a) and 3(b) and then the summary of counts is presented in Table 4.

**Table 3(a) and (b)** Count of Various parameters

| Concentriity | GOOD/ BAD | Length | GOOD/ BAD | Inner Dia. | GOOD/ BAD |
|---|---|---|---|---|---|
| 0.19 | BAD | 21.2 | BAD | 6.85 | BAD |
| 0.19 | BAD | 21.1 | BAD | 6.91 | GOOD |
| 0.18 | BAD | 21.05 | BAD | 6.95 | BAD |
| 0.15 | BAD | 21.05 | GOOD | 6.95 | GOOD |
| 0.15 | BAD | 21.05 | GOOD | 6.98 | BAD |
| 0.14 | BAD | 21.04 | GOOD | 6.99 | BAD |
| 0.14 | BAD | 21.04 | GOOD | 7 | GOOD |
| 0.12 | BAD | 21.04 | BAD | 7 | GOOD |
| 0.05 | GOOD | 21.03 | BAD | 7.01 | BAD |
| 0.05 | GOOD | 21.01 | BAD | 7.01 | BAD |
| 0.04 | GOOD | 21.01 | GOOD | 7.01 | GOOD |
| 0.03 | GOOD | 20.85 | GOOD | 7.05 | GOOD |
| 0.02 | GOOD | 20.85 | GOOD | 7.05 | GOOD |
| 0.02 | GOOD | 20.85 | GOOD | 7.05 | BAD |
| 0.02 | GOOD | 20.80 | BAD | 7.1 | BAD |
| 0.02 | GOOD | 20.78 | BAD | 7.15 | GOOD |

| Outer Dia. | GOOD/BAD | Hole Dimension | GOOD/BAD |
|---|---|---|---|
| 9.18 | BAD | 8.86 | GOOD |
| 9.17 | BAD | 8.86 | GOOD |
| 9.16 | BAD | 8.86 | GOOD |
| 9.16 | BAD | 8.85 | GOOD |
| 9.15 | BAD | 8.85 | GOOD |
| 9.15 | BAD | 8.85 | GOOD |
| 9.15 | BAD | 8.83 | GOOD |
| 9.14 | BAD | 8.81 | BAD |
| 9.02 | GOOD | 8.81 | BAD |
| 9 | GOOD | 8.8 | BAD |
| 8.99 | GOOD | 8.8 | BAD |
| 8.97 | GOOD | 8.8 | BAD |
| 8.88 | GOOD | 8.8 | GOOD |
| 8.85 | GOOD | 8.78 | BAD |
| 8.82 | GOOD | 8.78 | BAD |
| 8.80 | GOOD | 8.75 | BAD |

**Table 4:** Analytical Summary of Counts

| Count | Concentricity | Length | Inner Dia. | Outer Dia. | Hole Dim. |
|---|---|---|---|---|---|
| Top | 8 | 0 | 1 | 8 | 7 |
| Bottom | 8 | 0 | 1 | 8 | 3 |
| Total | 16 | 0 | 2 | 16 | 10 |

Now, as per the summary stated in table 4, the confidence level is found out for the various parameters.

**Table 5** Percentage confidence level as per count

| Count | Confidence Level |
|---|---|
| 6 | 90% |
| 7 | 95% |
| 10 | 99% |
| 13 | 99.90% |

Rule: If total count is >= 6, then it is concluded that 90% confidence level that this quality parameter is leading to the problem. Hence, from Table 4 Total Count of Concentricity, Outer Diameter and Hole Dimensions is 10 and more than 10. Hence it shows 99.90% confidence level that this parameter is leading to the quality issue.

Now, in order to reduce the loss in the production of contactors the possible solution is to be implemented. The solution is found out with the help of prioritization. Following are the identified problems and their solutions.

Solution Prioritization:

I. Outer Diameter:
   Reason: Diameter specification not mention on top side of


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moving magnet rubber bush
Solution:
a) Sorting of rubber bush for freeness in moving magnet
b) Mould to be corrected for outer diameter
c) Gauge to be implemented for outer diameter

II. Concentricity:
Reasons: Misalignment of mould punch
Solution:
a) Visual inspection of moving magnet rubber bush
b) Mould to be corrected for 0.05mm concentricity
c) Gauge to be implemented for concentricity

III. Hole Dimensions:
Reasons: Misalignment of punch with respect to die.
Solution:
a) Gauge to be implemented
b) Eliminate reaming operation based on result

The solutions found out are implemented on the process and the result is observed by again performing the testing on a batch of 10 contactors. Fig. 5 shows the comparative graph of change in DOV before and after implementation of Six sigma. It is very clear from the graph that the DOV has reduced which in turn reduce FTY losses of power contactor, thus improving the productivity.

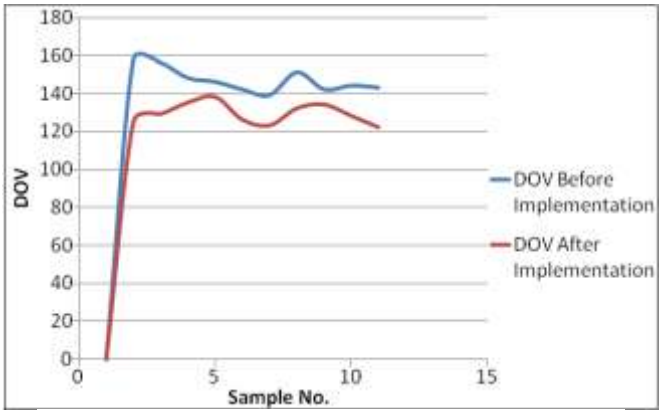


**Figure 4:** DOV before and after implementation of Six Sigma

## 4. Conclusion

This paper presents the implementation of Six Sigma tools in order to improve the production rate of power contactors by reducing the FTY losses. Various tools are used in order to identify the root causes of the failure and rejection of the contactors and then the exact reasons and solutions are found out. These solutions are then implemented and the productivity results are compared on the basis of before and after implementation test results. It is found that the six sigma methodology reduces the production losses and improves the quality of the product.

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