Improvement in Consistency and Overall Yield of Magnetic and Thermal Performance in New Range of MCCB of Lower Rating (16A-100A) with FTFM

Major Project Report

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology in Electrical Engineering

(Electrical Power Systems)

Submitted By

DHRUVIL B. PATEL

(16MEEE12)

Guided By

Prof. Swapnil N. Jani

Mr. K Vetrivel

Department of Electrical Engineering

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

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CERTIFICATE

This is to certify that the Major Project Report entitled **"Improvement in Consistency and Overall Yield of Magnetic and Thermal Performance in New Range of MCCB of Lower Rating(16A-100A) with FTFM"** submitted by **Mr. Dhruvil Patel (16MEEE12)**, towards the partial fulfillment of the requirements of Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by her under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date:

Industry Guide
Mr. K Vetrivel
Manager-Design,
SDDC, L&T
Electrical & Automation
Powai

Institute Guide
Prof. Swapnil N. Jani
Assistant Professor
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Head of Department
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Director
Institute of Technology
Nirma University
Ahmedabad

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I, **Dhruvil B. Patel**, Roll . No. **16MEEE12** , give undertaking that the Major Project entitled **Improvement in Consistency and Overall Yield of Magnetic and Thermal Performance in New Range of MCCB of Lower Rating(16A-100A) with FTFM** submitted by me, towards the fulfillment of the requirements for the degree of Master of Technology in Electrical Power Systems of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made.I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Acknowledgement

With immense pleasure, I would like to present this report on the dissertation work related to "Improvement in Consistency and Overall Yield of Magnetic and Thermal Performance in New Range of MCCB of Lower Rating(16A-100A) with FTFM".
I am very thankful to all those who helped me for the successful completion of the first phase of the dissertation and for providing valuable guidance during the project work.

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Dhruvil Patel
(16MEEE12)

Abstract

Circuit breakers are the switchgear devices which are used for different electrical applications .MCCB is one of the switchgear devices having the current carrying capacity from 16A to 1600A with breaking capacity from 25kA to 250 kA.The main aim of this project is Magnetic and thermal yield as well as consistency improvement of new range of MCCB with FTFM. This MCCB will be used for the lower rating applications having thermal and magnetic release (TMR) which provides the protection against the overload condition and short circuit fault condition with rated breaking and making capacity. The overall performance of the MCCB is better but the issues consist in the magnetic and thermal release on production line.The project demonstrates the improvement in yield and consistency of the MCCB. The work involves the improvement by using the tools DFMEA, DOE, DMAIC, 6 SIGMA and FISH BONE DIAGRAM.

Key words : MCCB, Magnetic ,Thermal, Overload , Short circuit , Breaking capacity , Making capacity ,FTFM,DFMEA, DOE, DMAIC,6 SIGMA and FISH BONE DIAGRAM.

Abbreviations

MCCB	Moulded Case Circuit Breaker.
TMR	Thermal Magnetic Release.
DFSS	Design For Six Sigma
DMAIC	Design Measure Analyze Improve and Control.
DOE	Design Of Experiment.
DPMO	Defects Per Million Opportunities
FTFM	Fix Thermal Fix Magnetic.
OT	Over Travel.
CP	Contact Pressure.
IS	Indian Standards.
IEC	International Electro-technical Commission.
ms	Millisecond
PCN	permanent Change Note
SOP	Standard Operating Process
CTQ	Customer To Quality
QC	Quality Check

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Chapter 1

Introduction

- This is to introduce a new range of MCCB, into LT, Electrical business Group under manufacturing program.
- This project was undertaken with the objective of developing new range of MCCBs, addressing both IEC and UL markets with cutting edge features and performance. This range addresses ratings from 16A to 1600A through nine Frame sizes, with breaking capacities up to 200kA at 415 V AC and 100kA at 690 V AC.
- The range will cater to: 1. Premium market segment - Demanding higher breaking capacities. 2. Mass market segment - Cost effective Frames.
- This 100A Cost effective MCCB with designation as Frame 0 and has been designed to address IEC market.

1.1 Ratings Ordering Suffixes:

- Nominal current ratings, In: 16A, 20A, 25A, 32A, 40A, 50A, 63A, 80A, 100A.
- Maximum Rated Operational Voltage (Ue): 415 V AC at 50/60 Hz.
- Impulse withstand voltage (Uimp): 8kV .
- Overload protection (Ir):2 In
- Fixed Short Circuit protection settings: 10 In Fixed

Voltage	Version				
	P	E	U	G	D
	Ultimate Breaking Capacity Icu				
220/230 V	25 kA	25 kA	25 kA	25 kA	45 kA
400/415 V	10 kA	14 kA	10 kA	18 kA	36 kA
220/230/400/415 V	Service Breaking Capacity Ics (% of Icu)				
	50%	50	100%	100%	50%

Table 1.1: Icu & Ics rating of MCCB

1.2 Application and limitations:

- Frame 0 has been designed to address mass market segments such as building, Utilities, OEMs (like DG sets, Telecom, etc.,) and other retail markets where the requirements for breaking capacities (Icu) are typically between 10kA and 36 kA.
- The compact design, especially depth of 60 mm will make Frame 0 suitable for Distribution Board applications.

1.3 Salient features:

- Compact 100 A MCCB with rated ultimate short circuit breaking capacities up to 36 kA at 415 V AC.
- Option for simultaneous use of under-voltage release and shunt release in 4 pole version.
- Offers the following termination types - Front terminals - Spreader link - Box clamp termination
- Suitable for isolation and No Line - Load bias

1.4 Conformity with Standards:

- This MCCB confirm to the following standards:

  - IS/IEC 60947-2: 2003 - IEC 60947-2: 2006 +A1:2009 - EN 60947-2: 2006 +A1:2009
  - Low voltage directive-2006/95/EC

1.5 Constructional details:

- This MCCB has a single break contact system, designed with optimized current path having least copper content equivalent MCCBs. The number of current carrying components per pole is minimized to 7 nos. as against 9 to 11 nos. of a typical single break MCCB. The net to gross ratio of copper has been maximized to 81% by using the scrap of the fixed contact as moving contact. A special cold forming operation profile has been developed on the moving contact, which is copper sheet of 1.5 mm thick, provides larger brazing/supporting area for contact button and also facilitates as arc runner leading to reduced contact button erosion.

- Contact system uses optimum silver contact buttons (Ag-WC) for superior anti-weld properties and better electrical life. The 10kA version has open type arc chute construction and whereas 36kA version has encapsulated arcing system to withstand high pressure developed during short circuit. The moving contact assembly and the thermal release assembly are assembled on a drive shaft as a click-fit operation for ease of assembly. All the components are common with 3 pole and 4 pole accepts housing, main cover, top cover, shaft and trip plate.

- The mechanism is modular in construction and common for all breaker variants. The cold formed protruding emboss features, in the mechanism sheet metal components acts as pins and thus avoiding the need of separate pins (turn parts). The mechanism has enhanced latching system providing large latching area to prevent nuisance tripping/de-latching. The mechanism as sub-assembly can be separately tested in isolation for its deliverable before integrating with the breaker.

- The thermo-magnetic release offers fixed overload protection (Ir) of 1 In and fixed short circuit protection of 10 In. The short circuit protection covers the basic requirements of the generator and motor protections. The thermal release uses bottom tripping philosophy which eliminates the need of an additional braid, a press component and a joining operation. The magnetic release is designed for drop-down assembly which reduces the sub-assembly variants for different current ratings requirements. The release has been designed with provision of hot calibration of thermal release to minimize calibration time.

- The internal accessories are housed in main cover by means of click fit with additional screw fixing arrangement.

1.6 Operation

- The primary function of MCCBs is to protect downstream circuit elements in the event of an over current. A MCCB automatically isolates the electrical circuit under sustained overloads or short circuit. In Molded Case Circuit Breakers, the molded housing is made up of an insulating material of high mechanical, thermal and electrical properties. The cover also provides solid interface barriers, thereby reducing the overall dimensions.

- The circuit breaker comprises of fixed and movable contacts. The contacts can be opened and closed by a mechanism from the release assembly to moving contacts, the current carrying conductors known as braids that are to be brazed.

- To the other ends of the braids, heating elements are fixed. Current flows from moving contacts through braids to heating element. During overload current, the bimetal which is fixed to the heating element gets deflected.

- When short circuit occurs, the magnet is energized due to the magnetic force formed due to high rush of current through the breaker due to the short. And the release assembly is energized. Both these operations results in the movement of trip plate and consequently tripping of the breaker, opening the contacts and breaking the circuit. The breaker has to reset before switching it on again.

1.7 Problem Identication

- MCCB is one of the switchgear device having the current carrying capacity from 16A to 1600A with breaking capacity from 25KA to 250 KA. The main aim of this project is Magnetic and thermal yield as well as consistency improvement of new range of MCCB with FTFM. This MCCB will be used for the lower rating applications having thermal and magnetic release (TMR) which provides the protection against the overload condition and short circuit fault condition with rated breaking and making capacity. The overall performance of the MCCB is better but the issues consists in the magnetic and thermal release on production line.The breakers mostly failed with late tripping (After 1200A) so that fault does not clear within a time which is implemented for MCCB.In case of thermal the breakers failed with Early tripping and Late tripping(After the declared time period implemented for MCCB as per standards. The project demonstrate the improvement in yield and consistency of Magnetic and Thermal tripping of MCCB. The work involves the improvement by using the tools DFMEA, DOE, DMAIC,6 SIGMA and FISH BONE DIAGRAM.

1.8 Scope of the Work

- MCCB tripping by means of methods 1.Thermal Release 2.Magnetic Release In thermal, IS tripping NT for 1.05 In followed by tripping in 1.3 In within 2 hours In Magnetic, Tripping band as per standard NT- bellow 800A and Tripping band is above 1200A

1.9 Organisation of Thesis

Work details available in this thesis are sectioned in various chapters. The details are as follows.

- chapter 2

  Chapter 2 gives the brief introduction about, the literature survey of the MCCB, In which the different patents as well as the IEEE papers are introduced in brief . It also contains the refereed standards and catalogue.

- Chapter 3

  Chapter 3 introduce the future strategy for the project work, Some how like Identification of problems in Magnetic & Thermal as well as the study of tools which will use in Analysis.

- Chapter 4

  Chapter 4 introduces the over all improvement in Magnetic from the 0.66 SIGMA level to 3 SIGMA level.It also contains the different analyzed things by using 6 SIGMA(DMAIC) tool.

- Chapter 5

  Chapter 5 conclude the improvement in Thermal yield from 50% to 93 % by using Six Sigma tool DMAIC.

- Chapter 6

  Chapter 6 introduce the conclusion and future scope of the project work.

- Chapter 7

  Chapter 7 gives the brief about, the references which contains some IEEE transaction papers and patents & other study material.

Chapter 2

Literature Survey

2.1 Patents of MCCB & IEEE Papers

2.1.1 Patent no: US9425013B2

Method for calibrating the magnetic release of a magnetic tripping device in Circuit Breaker.

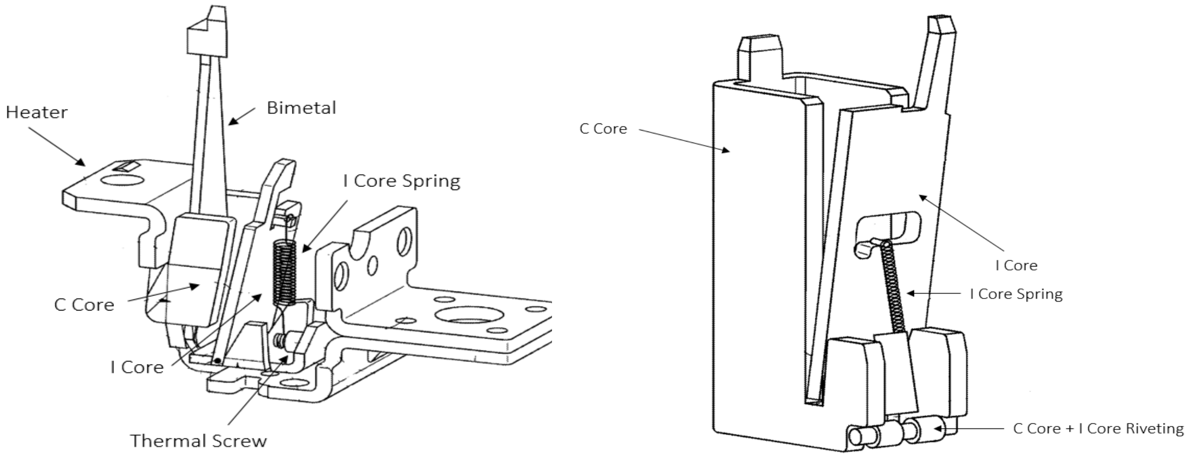
Inventor: Zbynek Augusta ,Frank Himmelein,Filip Musil.

Original Assignee Siemens AG

Field of the Invention: This patent introduces the magnetic tripping device of moulded case circuit breaker which provides the protection against the short circuit faults.

Summary: The magnetic release is disclosed in the case of MCCB. Which contains at least one hinge part and one yoke part which produces the magnetic field during short circuit. At the time of short circuit, the movable or hinge part attract towards fixed part of magnetic release.

- The movable element is arranged in such a way that it attract towards to the yoke element with opposite force. This opposite force creates by using spring, which is try to hold the movable element during absent of fault.



(a) Magnetic Release

(b) C Core and I Core

Figure 2.1: Proposed Design of Magnetic release

2.1.2 Patent no: US6218917 B1

Method and arrangement for calibration of circuit breaker thermal trip unit.
Inventor: Joseph Criniti, Javier I. Larranaga, Volkman Henschel, Manfred Schulz, Walter Felden.
Original Assignee General Electric Co
Field of the Invention: This patent shows the arrangement of thermal tripping device of MCCB. Which provides the protection during overload condition having adjustable or calibration method to interrupt the fault.

Summary: = In thermal tripping device the bimetal connects to the heater element directly. The thermal calibration screw is provided to the other end of the bimetal, which is adjustable. During overload condition bimetal gets heat and provides deflection towards tripping unit.

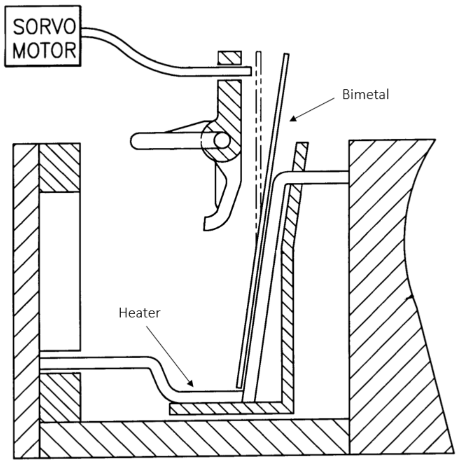


Figure 2.2: Calibration of circuit breaker thermal trip unit

- The tripping is almost depending on the bimetal deflection and the gap between bimetal and tripping mechanism, which gap is maintaining by calibrating the thermal screw on the bimetal, which is also known as the calibration screw.

2.1.3 Patent no: US5821839

"A Improved calibration means for a circuit breaker

Inventor: James Arthur Heise, Duane Lee Turner, Dennis William Fleege, Eugene Walter Wehr.

Original Assignee Square D Company

Field of the Invention: = This patent introduces the improved thermal tripping device particularly the calibration unit of the thermal tripping device.

Summary: The bimetal is directly connected through the heater element which is produces the heat whenever it senses the overcurrent. the bimetal get deflection through that heat of heater.

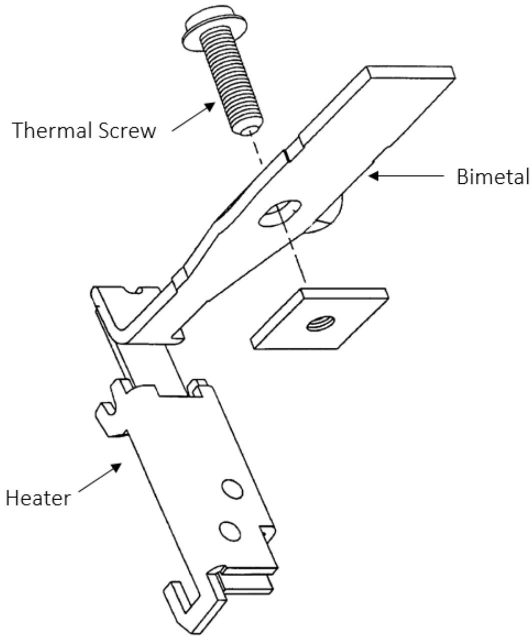


Figure 2.3: Improved calibration means for a circuit breaker

- As shown in fig 2.3 the screw which is with square nut is placed on the strip. The calibration is done by using the tightening of the screw.
- The strip gets the bending due to tightening of screw and provide appropriate gap between the bimetal and tripping mechanism.
- The calibration through that screw is adjustable. The calibration plate horizontally slides and bend as the calibration screw tightening with square nut.
- Circuit breaker having an improved calibration arrangement for calibrating and maintaining the pre-determined current level at which the circuit breaker interrupts the current.

2.1.4 Patent no: US5300907 A

Operating mechanism of a molded case circuit breaker

Inventor: Jean-Pierre Nereau, Philippe Perrier.

Original Assignee BiBTeX

Field of the Invention: The objective of this paper is to achieve the MCCB mechanism holding the knob and latch bracket in the ON position, when nuisance tripping happened.

Summary: The mechanism contains different components as shown in fig 2.4 , During the ON position of MCCB the latch bracket holds the knob as shown in figure 2.4.

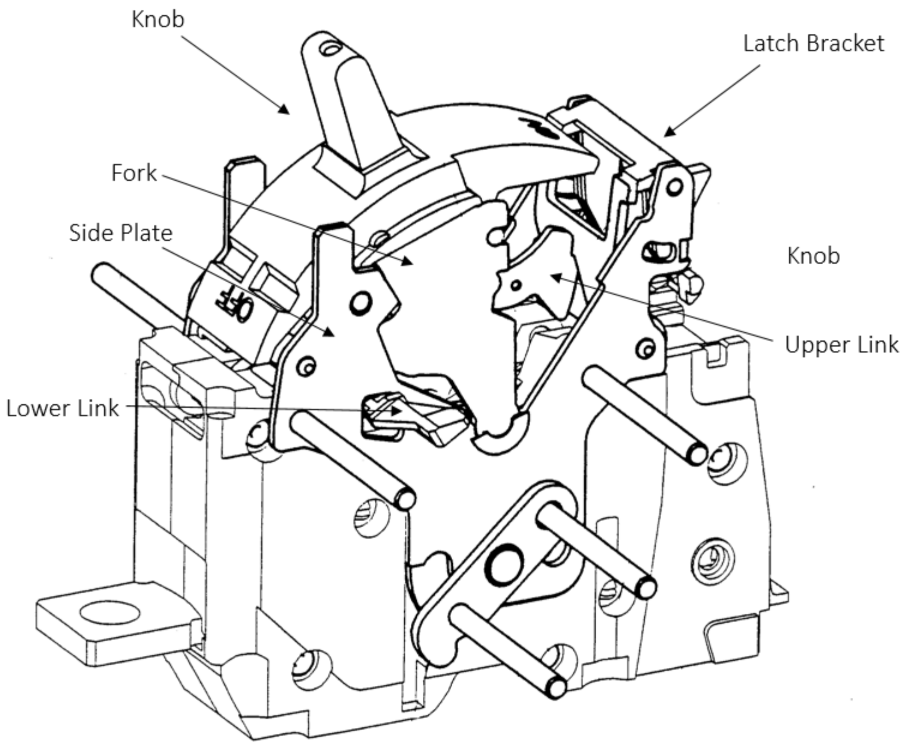


Figure 2.4: Operating mechanism of a molded case circuit breaker

- The knob position holds by using the main spring charging, which is connected from lower link floating pin to the fork of the mechanism.
- During the faults on the system the latch bracket of the MCCB release the latch link, and MCCB gets trip and main spring gets discharge.

2.1.5 Patent no: US20100164676A1

Trip device

Inventor: Young Min Jun

Original AssigneeLSIS Co Ltd

Field of the Invention: This paper introduces the thermal tripping unit which trips the MCCB during the overload condition having the bimetal directly connected with heater element and the magnetic release having one yoke part and one armature part which provides the protection during short circuit faults.

Summary: MCCB contains the fixed contacts at outgoing side terminals and having moving contacts at incoming side of MCCB.

- The moving contacts are connected through the copper braids and the other end of the braids are connected at the end of bimetal. The arrangement over here is the direct heating application.
- In magnetic release, the yoke part is fixed which is mostly of mild steel and produce the magnetic field whenever fault current passing through it. The armature part of magnetic release is hinged at one end and the other part of armature element is providing the tripping.

2.1.6 D. D. ROYBAL, "Weighing high interrupting capacity and short-time current ratings, IEEE INDUSTRY APPLICATIONS MAGAZINE, JULY-AUG 2005. WWW.IEEE.ORG/IAS.

- The MCCB having two type of release 1. Thermal release and 2. Magnetic release.
- The MCCB trips in case of overload (2 to 3 times of rated current) and trips in case of short circuit condition (10 to 12 times of its rated current).
- The current verses time characterises of both are inverse. But the characterises of magnetic unit is instantaneous, which provide the tripping in milliseconds (instantaneous). The characterizse of thermal unit is not instantaneous but its take some seconds to trip the MCCB.

2.2 Standards

- IS/IEC 60947-1: 2003 (Low voltage switch gear and control gear)
- IEC 60947-2: 2006 +A1:2009 (Low voltage switch gear and control gear)

2.3 Shivalic catalogue for Bimetal Selection

It includes the basic information of Bimetal and provide inforamtion about different properties of bimetal as well as the procedure to selection of Bimetal according to the requirements.

Chapter 3

Strategy for Project

Based on the previous discussion, for the requirement of proposed work for project the different strategy is adopted, which is given in the following sections.

3.1 MCCB

The MCCB has a single break contact system,Which is designed with optimized current path having least copper content. The number of current carrying components per pole is minimized to 7 nos. as against 9 to 11 nos. of a typical single break MCCB. The net to gross ratio of copper has been maximized to 81% by using the scrap of the fixed contact as moving contact. A special cold forming operation profile has been developed on the moving contact, which is copper sheet of 1.5 mm thick, provides larger brazing/supporting area for contact button and also facilitates as arc runner leading to reduced contact button erosion.MCCB provide the protection against the short circuit faults as well as the overload conditions.In case of the short circuit fault, the MCCB provides the protection by the Magnetic tripping and in case of overload condition the MCCB provides the protection by using the thermal tripping, Mostly by bi metal and protect the equipment's or network by isolation from the fault.The magnetic release gives the instantaneous tripping or fault clearing, It takes certain millisecond time. In case of thermal release take required time to trip in seconds which is depend on the rated current.The time current characteristics for both is shown as following.

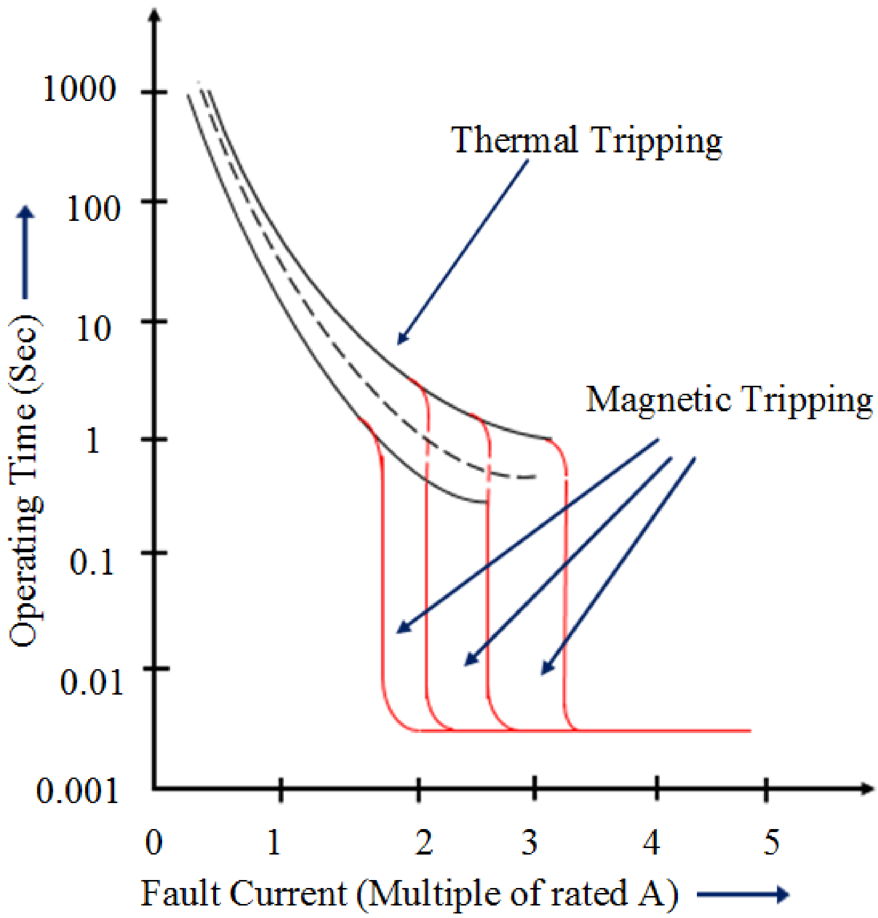


Figure 3.1: Characteristics of Magnetic and Thermal Tripping

3.2 Strategy for Analysis

In order to analyze the improvement of magnetic and thermal yield improvement of new range of MCCB, Ensure the material used for the MCCB as well as the component assembly.The analysis is done as following manners.

- Define the main problem of Magnetic and the thermal failure
- Find out the root causes by using required method
- Make an action plan

  Details of each analysis are given in the chapter 4

3.3 Analysis Tools

Selection of the Analysis tools are mainly based on the requirement of the work. In the proposed work, analysis will be done, considering various experimental and statically conditions in the system. There are number of tools available on which the analysis. can be performed.The main tool which is mostly required for analysis purpose is 6 SIGMA.Six Sigma has acquired a strong perspective stance with practices often being advocated as universally applicable. Six Sigma has a major impact on the quality management approach, while still based in the fundamental methods tools of traditional quality management. Six Sigma as a program aimed at the near elimination of defects from every product, process and transaction.Six Sigma focusing on process outputs that are of critical importance to customers. So it can be used for any analysis.

DMAIC is a data-driven quality strategy used to improve processes.

- The DMAIC methodology contains the Define, Measure, Analyze, Improve and Control.
- While the DMAIC methodology presented below may appear linear and explicitly
- In which the Scope of the work as well as the main objective should be define.

Chapter 4

Magnetic improvement by Six Sigma Tool (DMAIC)

4.1 DEFINE

4.1.1 Scope

The scope of the project is to improve magnetic yield.

4.1.2 Requirements

- Tripping band as per standard
  Non Tripping below 800A & Tripping above 1200A
- Tripping band as defined on Shop floor.

Magnetic testing (Non-Tripping below 850 A & Tripping above 1150A).

4.1.3 Project Objective

- Breaker Magnetic yield to be increased from 20% to 90%.

4.1.4 Problem Statement

- The overall performance of the 100A MCCB is better but the issues consists in the magnetic release on production line.
- 80% of breakers failed in Magnetic Testing.

4.1.5 Passing Criteria is bellow

1. Till 800A(8In) breaker remains NON TRIP up to 200 ms.
2. Beyond 1200A(12In)breaker have to TRIP in minimum ms.

4.2 MEASURE

Magnetic Testing data of 15 Nos 100A MCCB.

MCCB	Br 1	Br 2	Br 3	Br 4	Br 5	Br 6	Br 7	Br 8	Br 9	Br 10	Br 11	Br 12	Br 13	Br 14	Br 15
R	1230	870	910	870	790	890	1238	1048	1180	845	1078	860	980	940	1135
Y	860	910	940	930	930	1236	1278	1098	1110	1238	1080	910	1214	965	1235
B	1190	950	1100	1236	1065	1120	1163	1210	1310	1165	1206	1045	1180	1280	1138

Table 4.1: Magnetic test data before 6 Sigma

4.2.1 Graphical representation of above data

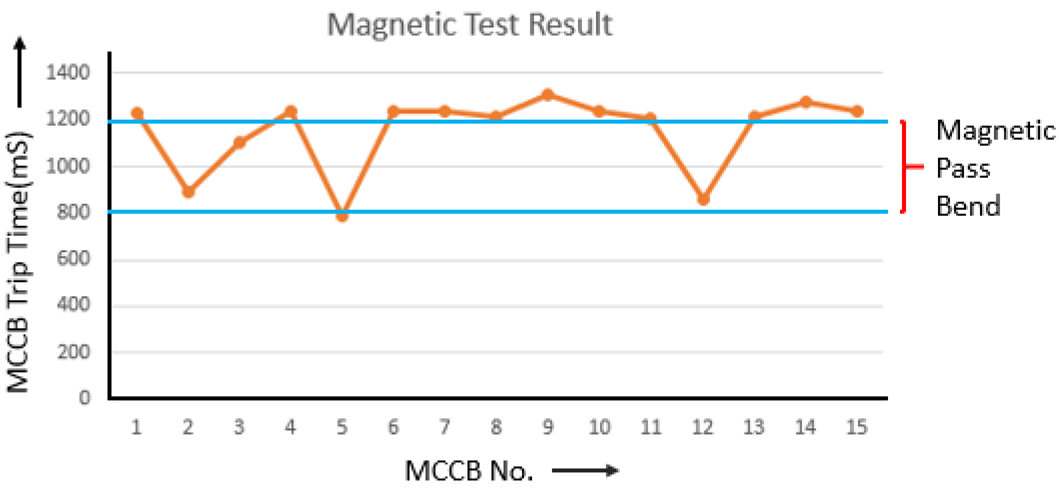


Figure 4.1: Graph of above results of breakers

- From the above graph we can easily see that most of the breakers failed above 1200A. The meaning is that "Within a bend of 800A to 1200A breaker should not TRIP".

Before DMAIC	**Value**
opportunities	15
Defects	12

Table 4.2: Breakers Pass Fail Details

Before 6 SIGMA (DMAIC) the SIGMA level as well as the values are shown in bellow table

Before DMAIC	**Value**
Defects%	80
Yield%	20
SIGMA level	0.66

Table 4.3: Results before 6 SIGMA

4.3 ANALYZE

The tool used here is DMAIC, Which is the part of 6 SIGMA(DFFS)

4.3.1 Process Flow

The above problem solution as well as goal of yield should be achieved by preparing process flow.

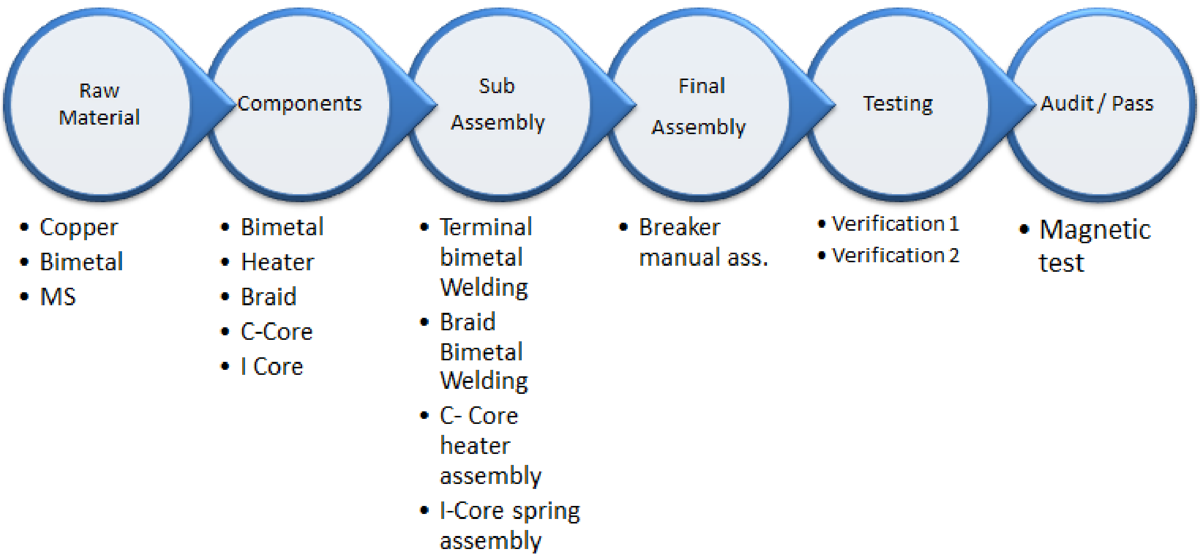


Figure 4.2: Process Flow of Analysis

- The beginning of flow is starting from the basic step of Raw material and the Component level.
- The second step is to assemble the components with proper stacking limit with appropriate torque.
- Final assembly should be complete by using other components of breaker.
- The final testing done on test bench of Magnetic Testing.
- On the test bench it should be pass in both bends.
  1. Audit
  2. Shop

4.3.2 Process Flow Micro With Scope

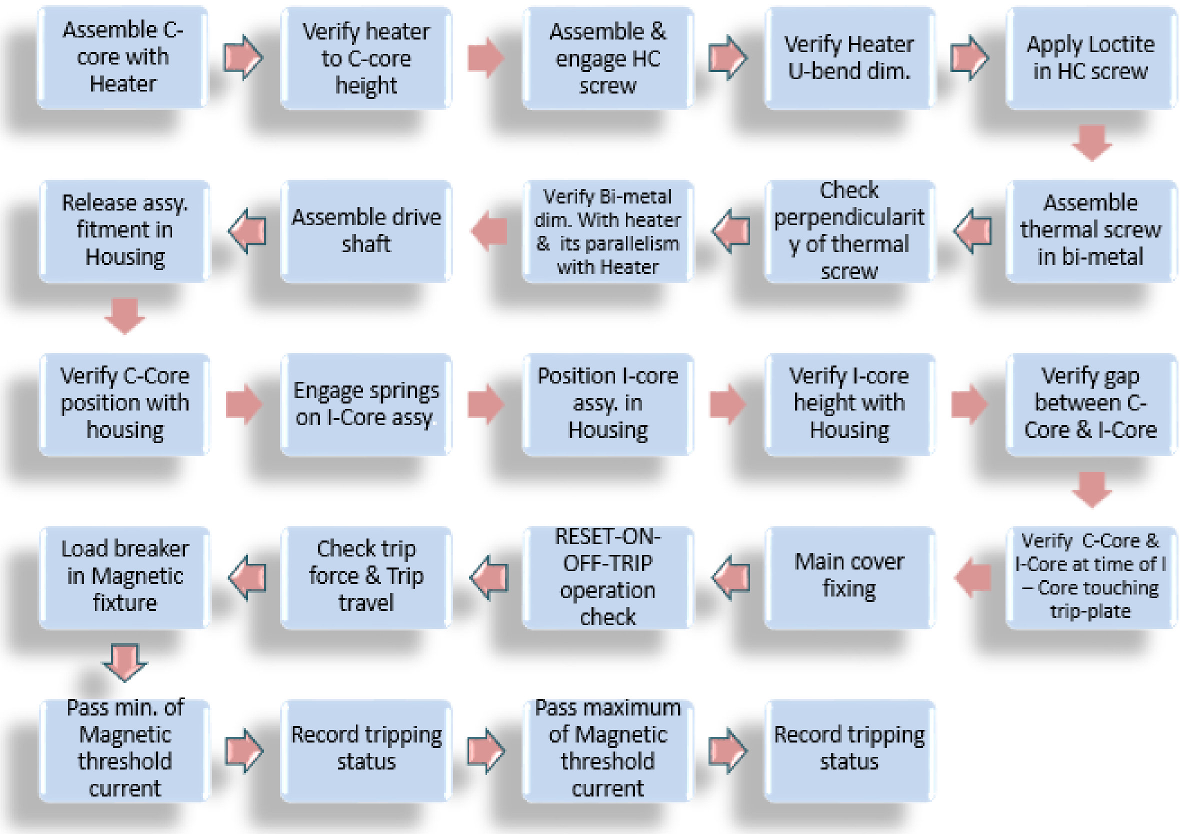


Figure 4.3: Process Flow (Micro)of Analysis

4.3.3 Fish bone Diagram

- Fish bone diagram is also known as the cause effect diagram and ishikawa diagram.Fish bone diagram shows the possible causes of the problem. In which the problem is taken at the head of the fish.
- The problem or effect is displayed at the head or mouth of the fish.
- Possible contributing causes are listed on the smaller bones under various cause categories.
- Agree On the major categories of causes of the problem (written as branches from the main arrow).The major categories often include like, equipment or supply factors, environmental factors, rules, and people/staff factors.

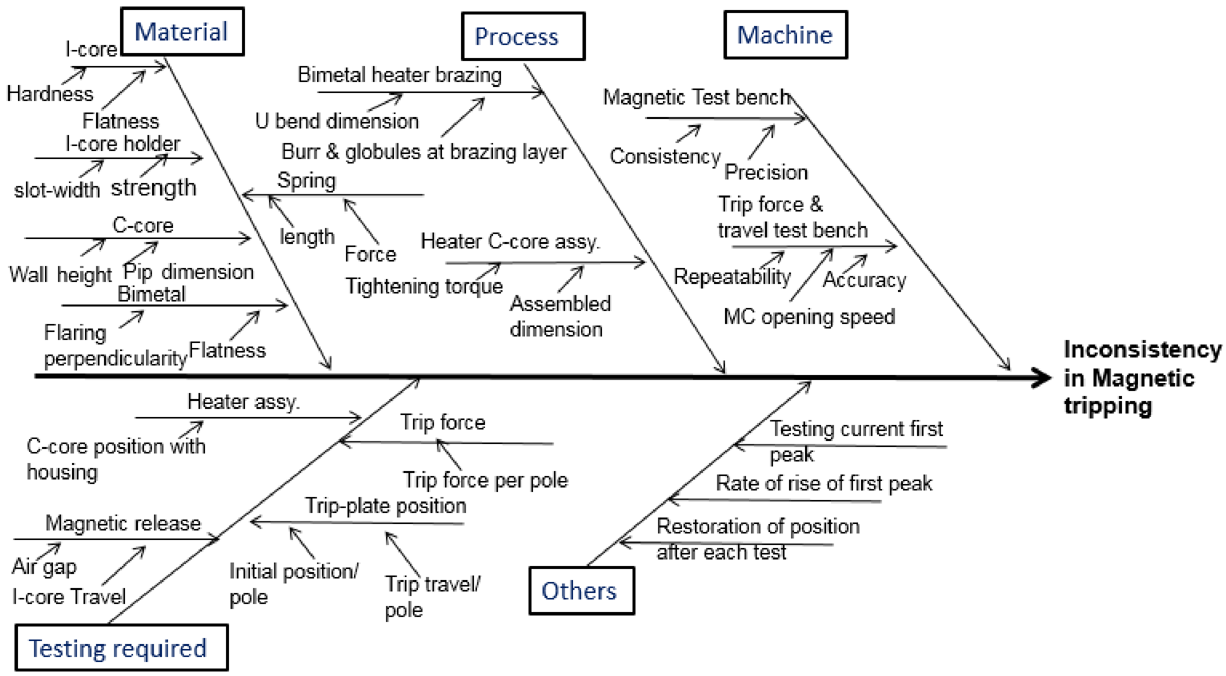


Figure 4.4: Fish bone diagram of magnetic

4.3.4 Tolerance stack up for Air gap

The appropriate air gap between the C Core and I Core must be required.

Description		Stack Direction	Target Dimension	Limit Dimension		Tolerance
From	To			Upper limit	Lower limit	
I core inner Surface	I core outer surface	-	1.2	1.27	1.13	0.14
I core holder surface	I core holder surface(Housing)	-	2	2.09	1.91	0.18
Housing slot for I core	Housing slot for heater	+	11.95	12.05	11.85	0.2
C core heater surface	C core surface (I core)	-	8.5	8.65	8.35	0.3

Table 4.4: Stack up data of magnetic release

4.3.5 Importance of air gap sensitivity proven by Calculation

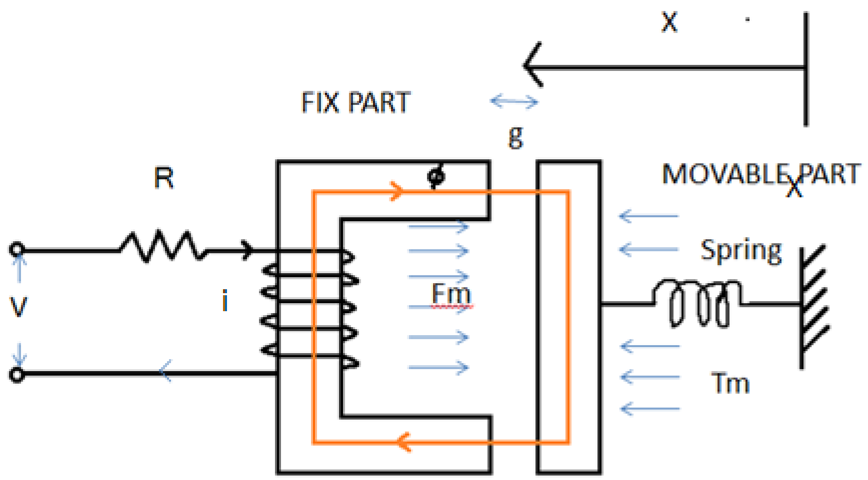


Figure 4.5: Magnetic tripping Circuit

Where,

V= Applied Voltage

R= Resistance

g= Air Gap

I= Applied Current

Fm= Mechanical Force

Tm= Mechanical Torque of Spring

X= Distance from Referance

$\phi = Flux\ produced\ by\ fixed\ part$

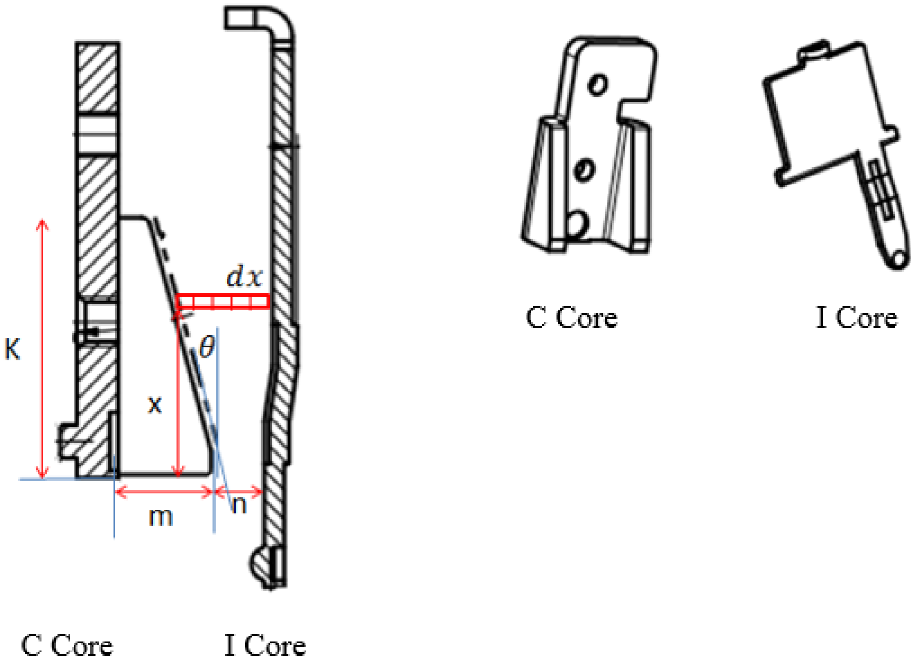


Figure 4.6: C Core & I Core of Magnetic release

Where,

A= Area of assumed strip

L= Length of air gap

$\mu = Permeability\ of\ material$

$Area\ of\ C\ Core = t * dx.$

$t = Thickness$

$l = n + x \sin\theta$

$$
\begin{aligned}
P &= \mu \frac{A}{l} \\
&= \int_0^k \mu \frac{t * dx}{n + x \sin\theta} \\
&= \mu \int_0^k \frac{t * dx}{n + x \sin\theta} \\
&= \mu t \int_0^k \frac{1}{n + x \sin\theta} dx \\
&= \mu t \frac{1}{\sin\theta} \ln\left[n + x \sin\theta\right]_0^{17.5} \\
&= \frac{t}{\sin\theta x} [\ln(\sin\theta + n)]_0^{17.5} \\
&= \frac{2.5}{0.25} [\ln(0.25 * x + 0.5)]_0^{17.5} \\
&= \frac{2.5}{0.25} \ln(4.375) - \ln(0.5) \\
&= \frac{2.5}{0.25} (1.4759) - (0.6931) \\
&= 10 * (2.169) \\
&= 21.69 \ H
\end{aligned} \tag{4.1}
$$

Here the permeance 21.69H is due to the 0.5mm air gap between C Core and I Core.

Sr No.	Air Gap	Permeance
1	0.2mm	30.14H
2	0.3mm	26.33H
3	0.4mm	23.69H
4	0.5mm	21.69H
5	0.6mm	20.00H
6	0.7mm	18.77H

Table 4.5: Permeance with respect to Air gap

The different values of permeances w.r.t air gap is above table,

- From the above table , It is clearly see that

  Air Gap (Increase) Permeance (Decrease)

  Reluctance (Increase) Flux(Decrease)

$$
\begin{aligned}
&PermeanceP = \mu\frac{A}{l} \qquad AirGap \propto \frac{1}{Permeance} \\
&ReluctanceR = \frac{F}{\phi}
\end{aligned} \tag{4.2}
$$

- Required torque to attract the I Core (Increase)

  - For less air gap less torque required - For more air gap more torque required

- The I Core can attract easily by C Core with less air gap **Appropriate air gap required between C Core / I Core for exact tripping during faults**

4.3.6 List of Significant Factors

Sr. No.	Factors	Effects
1	Thermal screw flaring on bimetal	It makes an interfere with other parts
2	Heater U Bend Dim.	Change bi metal position & I Core Motion
3	C Core side wall dimension	Changes in air gap between I Core & C Core
4	C Core pip dimension	C Core position changes & reduces the air gap
5	I Core dimension	I Core position shifts & travel required to touch trip plate reduces
6	I Core fixing	I Core position shifts & travel required to touch trip plate varies
7	I Core slot dimension	I-Core rubs with the I-core holder while actuating
8	Spring load	Spring load was insufficient
9	Spring stress	Spring stress was improper
10	Trip-plate initial position	Leads to variation of relative gap for I-Core
11	Trip travel	Trip-travel different for various poles

Table 4.6: Significant factors and its effects

4.4 IMPROVEMENT

4.4.1 Improvement Action

The Table shown bellow which contains the Causes,Actions as well as the Benefit.

- In this method of DMAIC, The consideration of respective department which would take actions to improvement the Magnetic yield is required

Sr. No.	Cause	Action	Benefit	Resp.
1	Trip plate transnational Movement	PCN on housing for trip plate holding slot	Trip plate has rotational movement only	Design
2	Continuity between C Core & I Core	Removal of C Core additional pip dia.	Gap of 0.5-0.9mm between C Core & I Core	Design
3	C Core improper position	Removal of bur & globules which formed at bimetal & heater welding	To achieve C Core intended position	Quality
4	Sticking of I Core	Step at hte I Core holder to be removed	Slot width increased (Clarence increased from 0.35-0.85mm) & smooth movement of I Core	Design
5	Sticking of I Core	Thermal screw threshold flaring slot perpendicularity with bimetal	To avoid the interference between thermal screw & I Core	Design
6	Insatiability of I Core holder	Housing Slot reduced (interference fit) used for holding I Core holder	Non variability of I Core position	Design

Table 4.7: Actions for Improvement

4.4.2 Improvement Done

1. Problem: Interference in Drive shaft rotation during tripping & I Core holder should not place proper in slot.

Causes: 1. Shaft tilting 2. Late tripping in magnetic

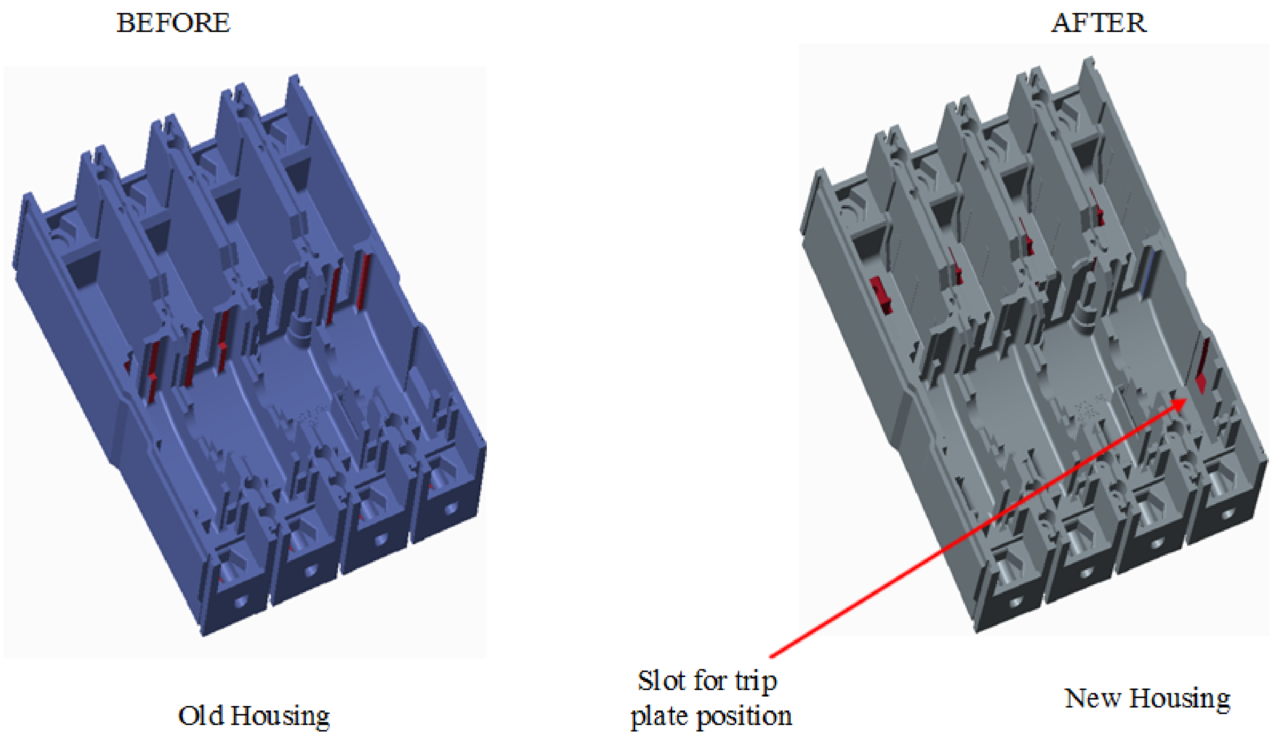


Figure 4.7: Modification in Housing

- After improvement the trip plate moves very free as well as the I Core holder completely place into its slot in Housing by increasing the Slot dimension up to 3.9mm.
- The magnetic tripping happens during the short circuit faults within a tripping bend.

2. Problem: Less Air gap between the C Core & I Core causes late tripping.

Causes: 1. Late tripping in magnetic   2. I Core cannot rotate.

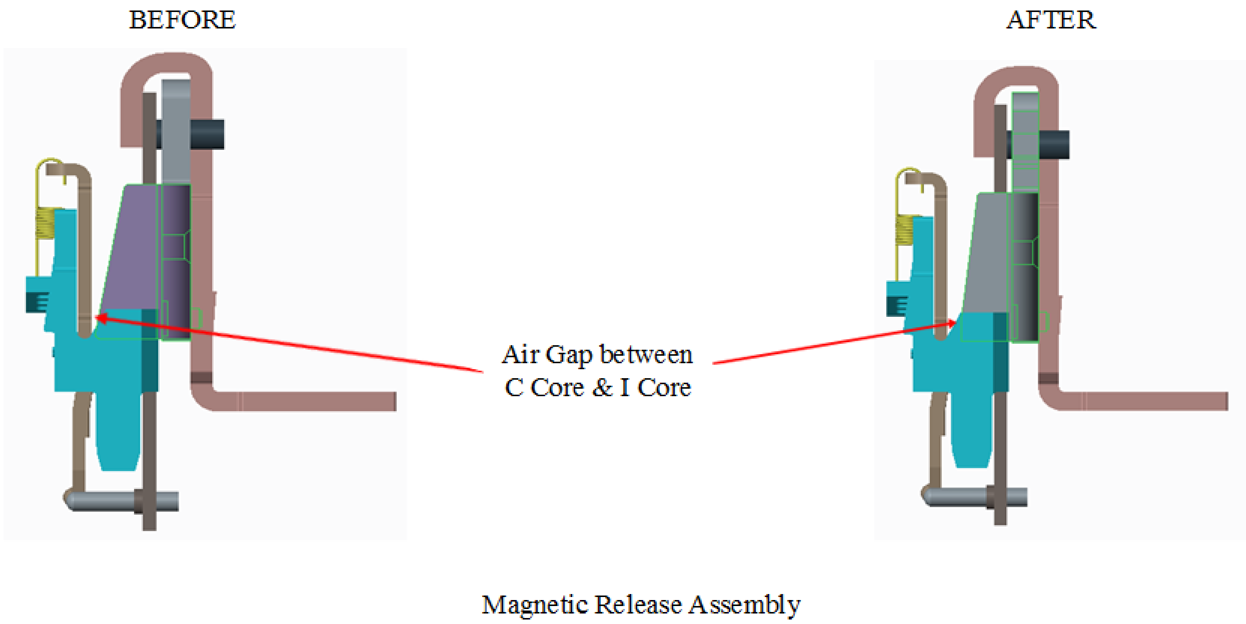


Figure 4.8: Modification in C Core wall

- After reducing the C Core wall at bottom side the Air gap between the C Core and I Core should be maintain.

- The magnetic tripping happens during the short circuit faults within a tripping bend by increasing the Air gap.

3. Problem: Extra dimension of I Core interfere the rotation of I Core in the I Core holder.

Causes: 1. Late tripping in magnetic 2. I Core cannot rotate freely.

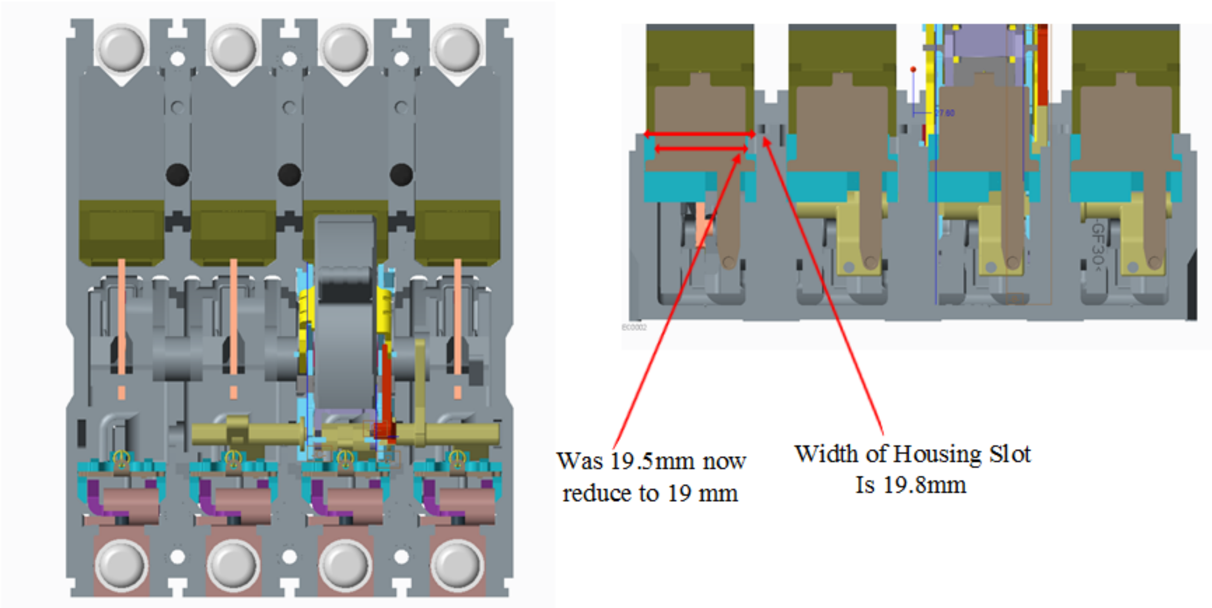


Figure 4.9: Modification in I Core Dimensions

- After reducing the I Core dimension from both sides the I Core should be rotate freely without any interfere.

- The magnetic tripping happens during the short circuit faults within a tripping bend by decreasing the dimensions of I Core.

- Avoid the late tripping.

4. Problem: Extra dimension of I Core interfere the rotation of I Core in the I Core holder.

Causes: 1. Late tripping in magnetic 2. I Core cannot rotate freely.

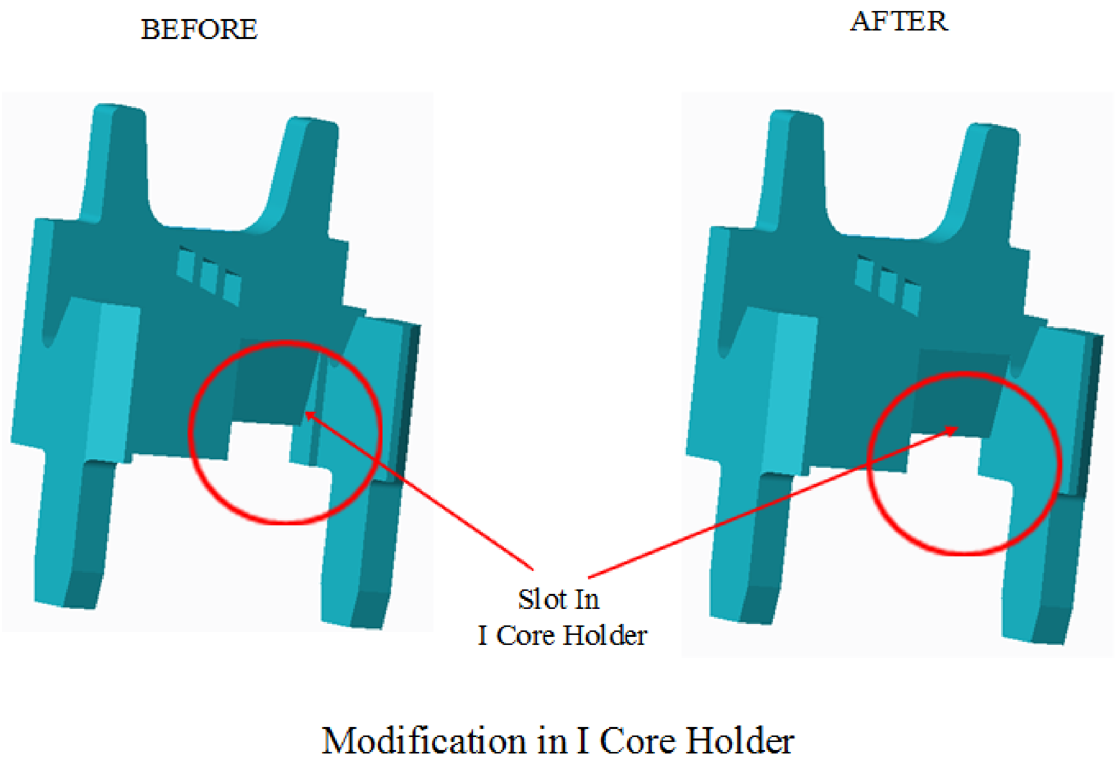


Figure 4.10: Modification in I Core Holder dimensions

- After reducing the I Core dimension from both sides the I Core should be rotate freely without any interfere.
- The magnetic tripping happens during the short circuit faults within a tripping bend by decreasing the dimensions of I Core.
- Avoid the late tripping.

5. **Problem:** Thermal screw inter meddle the I Core leg during tripping.

Causes: 1. Late tripping in magnetic 2. I Core cannot rotate freely.

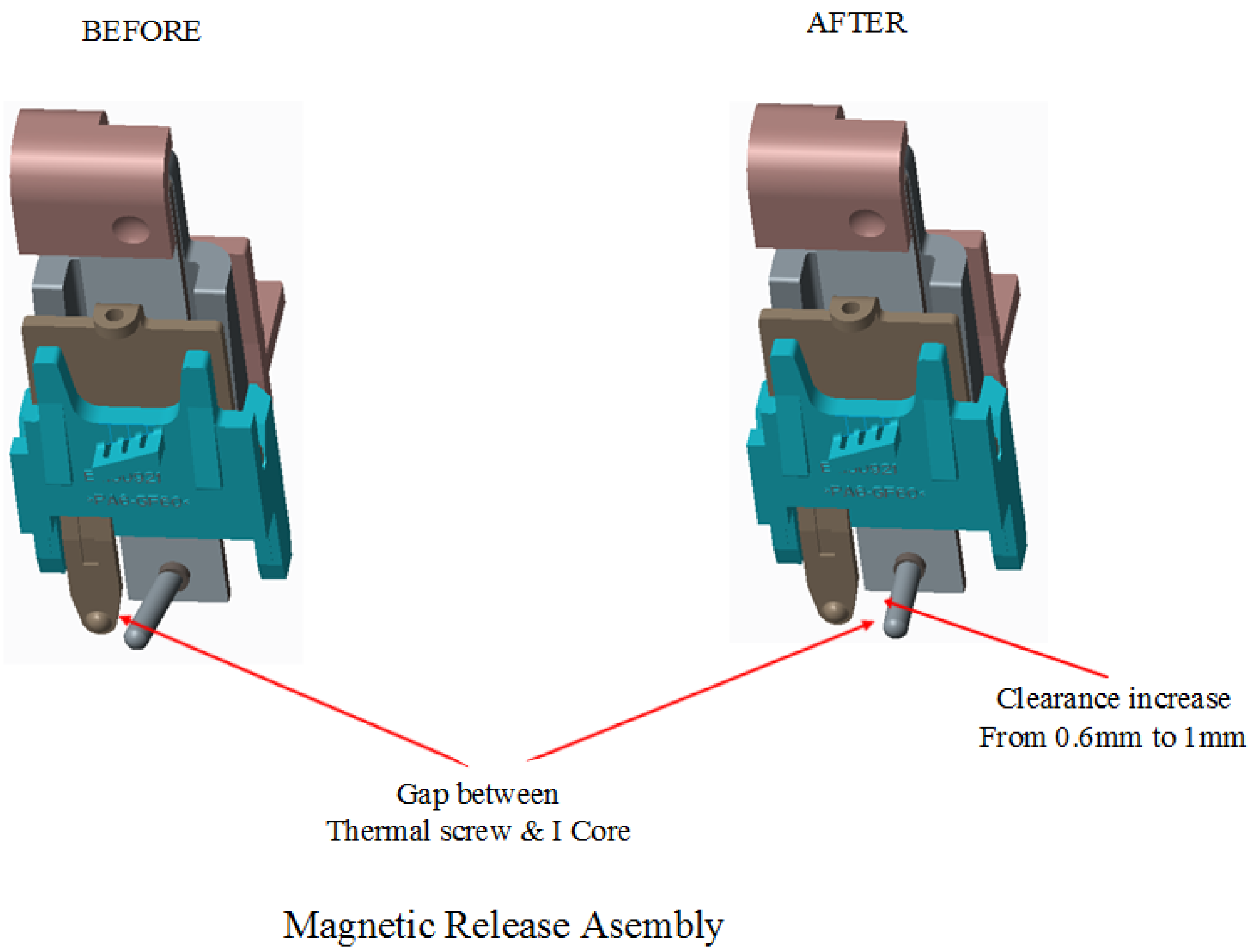


Figure 4.11: Modification of the location of thermal screw on bi metal

- After relocation of the thermal screw the interference of I Core leg should be neglect.
- The magnetic tripping happens during the short circuit faults within a tripping bend by relocation of the thermal screw from 0.6mm to 1mm.
- Avoid the late tripping.

4.5 CONTROL

4.5.1 Control actions after improvement

Sr. No.	Re commanded Action	Action Taken
1	For constraining Trip-plate transnational movement in the Housing	PCN implemented in housing
2	Tip-travel upper limit defined & measurement to be done in every Breaker	CD sheet (test instruction sheet) updated for trip travel.
3	C Core having additional pip dia. to be rejected & CTQ added in the C-core Pip dia	PCN implemented for machining C Core wall
4	C Core side wall end, closer to I Core to be machined.	Fixture to be made to measure C Core side wall height at sub assay.
5	Note addition in drawing of Heater sub assembly for removal of Bur& globules at bimetal & heater brazing region	PCN implemented
6	Step at the I Core holder to be removed & slot width increased.	PCN implemented
7	Thermal screw threaded flaring slot perpendicularity with bimetal specified in drawing	CTQ added for measuring flaring perpendicularity & paralleling.
8	Bi-metal paralleling with Heater specified	Fixture for measuring dimension at the sub assay. Level

Table 4.8: Control actions after improvement

4.6 Test Data after Improvement

- After all type of modification and improvement the testing data are as bellow.

MCCB	Br 1	Br 2	Br 3	Br 4	Br 5	Br 6	Br 7	Br 8	Br 9	Br 10	Br 11	Br 12	Br 13	Br 14	Br 15
R	890	910	928	890	850	952	870	1005	865	913	956	840	856	930	982
Y	980	1065	1076	1056	952	980	1143	1095	1025	1049	995	926	1047	982	1038
B	1024	1095	1035	1119	1045	1083	1182	1108	1195	1225	1186	976	1105	1048	1129

Table 4.9: Magnetic test data after 6 Sigma

4.6.1 Graphical comparison of Magnetic data before & after 6 SIGMA

Graphical representation of Magnetic data before 6 SIGMA

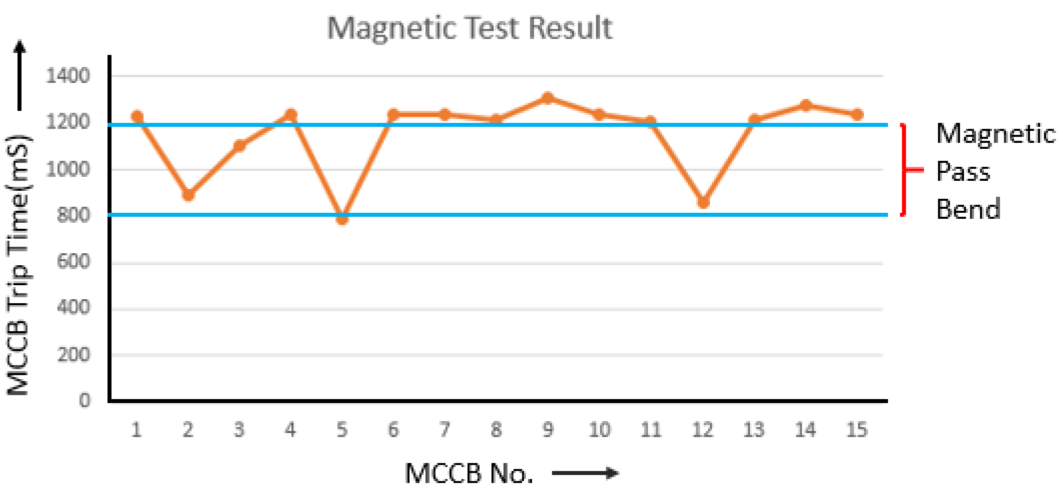


Figure 4.12: Magnetic TRIP Testing results of 100A before 6 SIGMA

Graphical representation of Magnetic data before 6 SIGMA

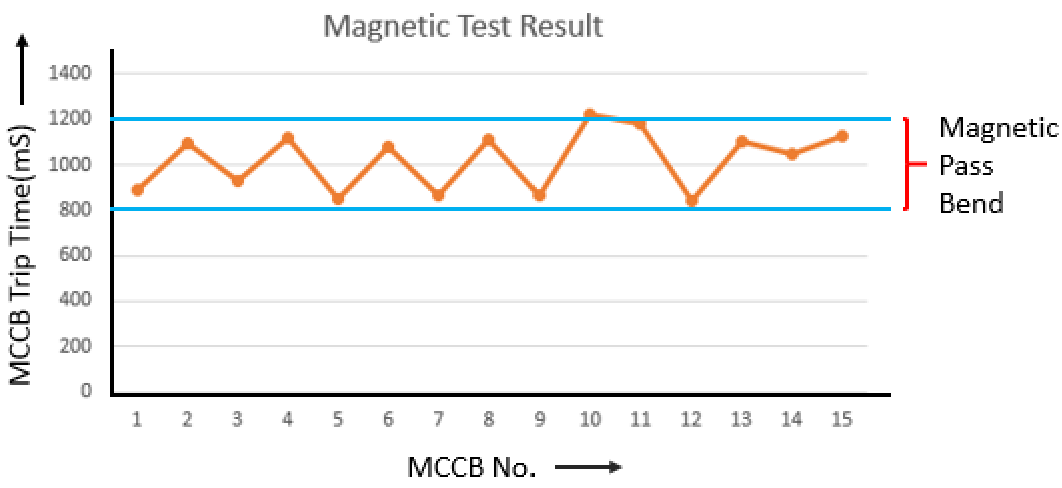


Figure 4.13: Magnetic TRIP Testing results of 100A after 6 SIGMA

4.7 SIGMA level after 6 SIGMA process

After all type of modification and improvement the testing data are as bellow.

After 6 SIGMA	Value
opportunities	15
Defects	1

Table 4.10: Breakers Pass Fail Details

After 6 SIGMA	Value
Defects%	6.67
Yield%	93.33
SIGMA level	3

Table 4.11: Results after 6 SIGMA

4.7.1 Sigma Level of Magnetic

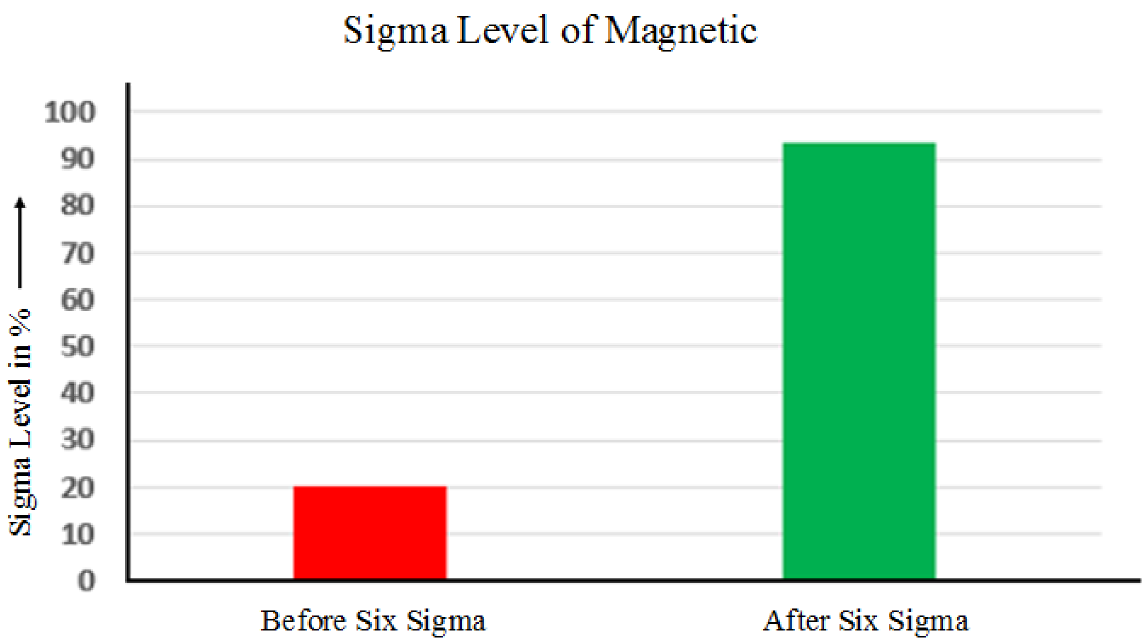


Figure 4.14: Comparison of Sigma level of Magnetic

Formulas behind the Calculated Values

$$
\begin{aligned}
DPMO &= \frac{Total\ Defects}{Total\ Opportunities} * 1,000,000 \\
Defects &= \frac{Total\ Defects}{Total\ Defects} * 100 \\
Yield(\%) &= 100 - (Defects\ in\ \%) \\
ProcessSigma &= 1 - \frac{Total\ Defects}{Total\ Opportunities} + 1.5
\end{aligned}
\tag{4.3}
$$

Chapter 5

Thermal improvement by Six Sigma Tool (DMAIC)

The tool used here is DMAIC, Which is the part of 6 SIGMA(DFFS)

5.1 DEFINE

5.1.1 Scope

Breaker Thermal yield from 50% to 95%

5.1.2 Requirements

- Tripping band as per standard
  1. Non Tripping at 1.05In followed by tripping at 1.3In within 2 hours
  2. Breaker should trip between predefined bend for 100A (50 Sec-70 Sec)
- Tripping band as defined through IS Testing.

5.1.3 Project Objective

- Breaker Thermal yield to be increased from 50% to 95%.

5.1.4 Problem Statement

- The overall performance of the 100A MCCB is better but the issues consists in the Thermal release on production line.

- 50% of breakers failed in Thermal Testing.

5.1.5 Passing Criteria is bellow

1. Non Tripping at 1.05In followed by tripping at 1.3In within 2 hours
2. Breaker should trip between predefined bend for 100A (50 Sec-70 Sec)

5.2 MEASURE

Thermal Testing data of 15 Nos 100A MCCB.

MCCB No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Thermal Trip Sec(50-70)	80	75	65	72	58	90	55	85	65	60	88	64	78	87	66

Table 5.1: Thermal test data before 6 Sigma

5.2.1 Graphical representation of above data

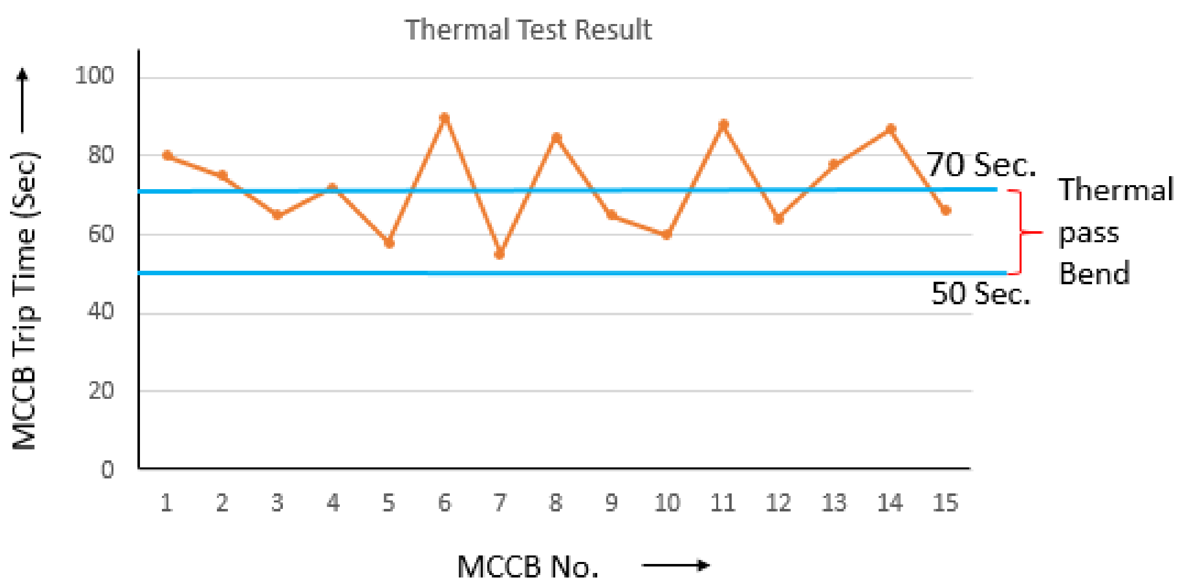


Figure 5.1: Graph of above results of breakers

- From the above graph we can easily see that most of the breakers failed and trip above 70 Sec . The meaning is that "Within a bend of 50 Sec to 70 Sec breaker should not TRIP".

Before DMAIC	Value
opportunities	15
Defects	8

Table 5.2: Breakers Pass Fail Details

Before 6 SIGMA (DMAIC) the SIGMA level as well as the values are shown in bellow table

Before DMAIC	Value
Defects%	53.33
Yield%	46.67
SIGMA level	1.42

Table 5.3: Results before 6 SIGMA

5.3 ANALYZE

5.3.1 Process Flow

The above problem solution as well as goal of yield should be achieved by preparing process flow.

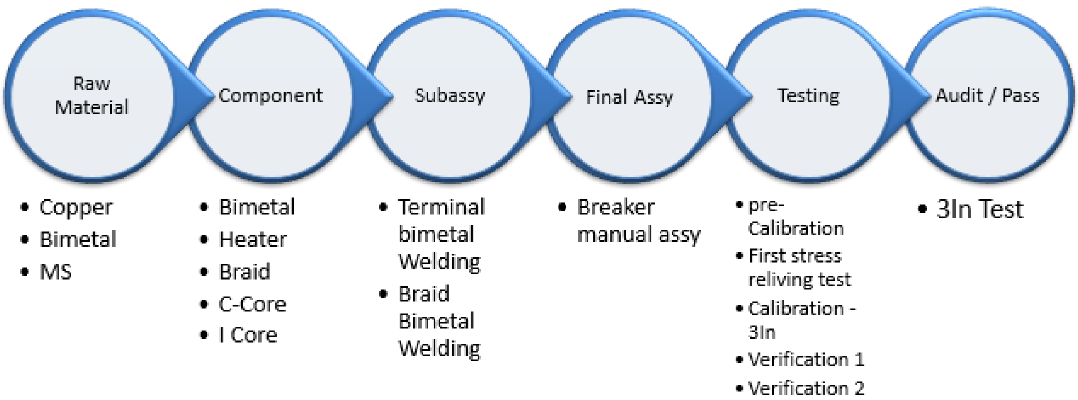


Figure 5.2: Process Flow of Analysis

- The beginning of flow is starting with dimensions of Raw material and the Component level
- The second step is to assemble the components with proper stacking limit with appropriate torque.
- Final assembly should be complete by using other components of breaker.
- The final testing done on test bench of Thermal testing.
- On the test bench it should be pass in both bends.
  1. Audit (55 Sec-65 Sec)
  2. Shop (50 Sec-70 Sec)

5.3.2 Process Flow Micro With Scope

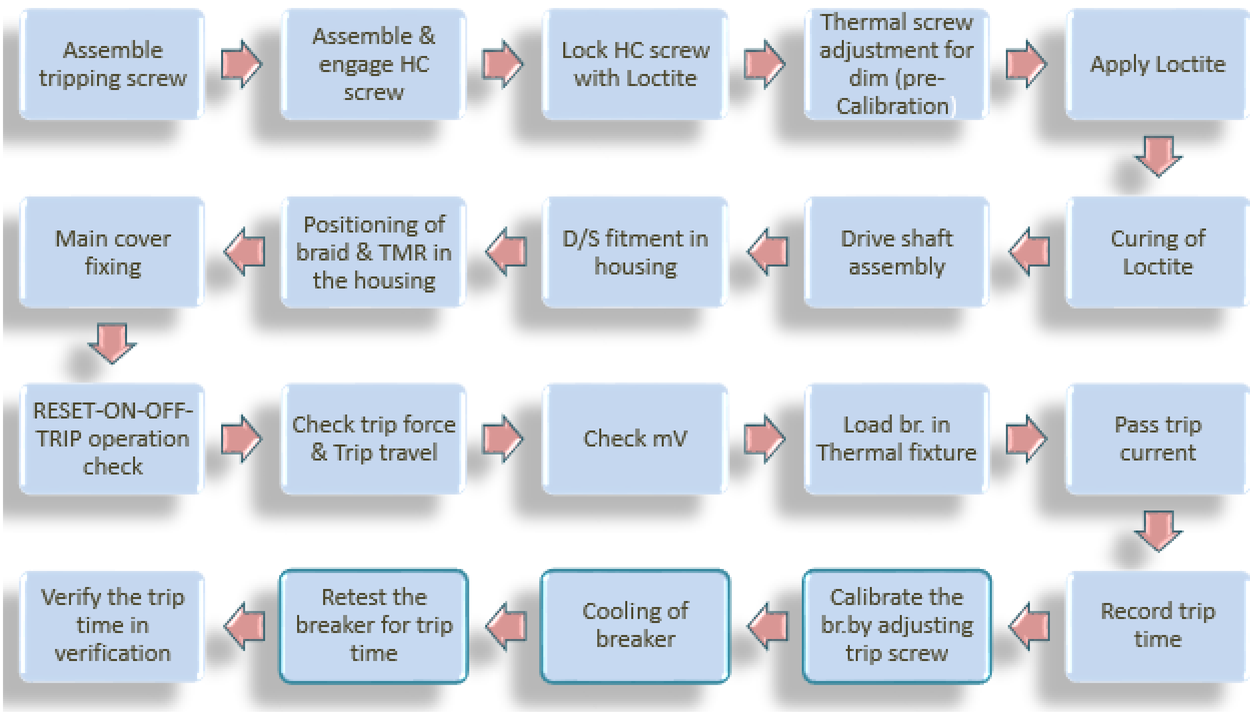


Figure 5.3: Process Flow (Micro)of Analysis

5.3.3 Fish bone Diagram

- Fish bone diagram is also known as the cause effect diagram and ishikawa diagram.Fish bone diagram shows the possible causes of the problem. In which the problem is taken at the head of the fish.
- The problem or effect is displayed at the head or mouth of the fish.
- Possible contributing causes are listed on the smaller bones under various cause categories.
- Agree On the major categories of causes of the problem (written as branches from the main arrow).The major categories often include like, equipment or supply factors, environmental factors, rules, and people/staff factors.

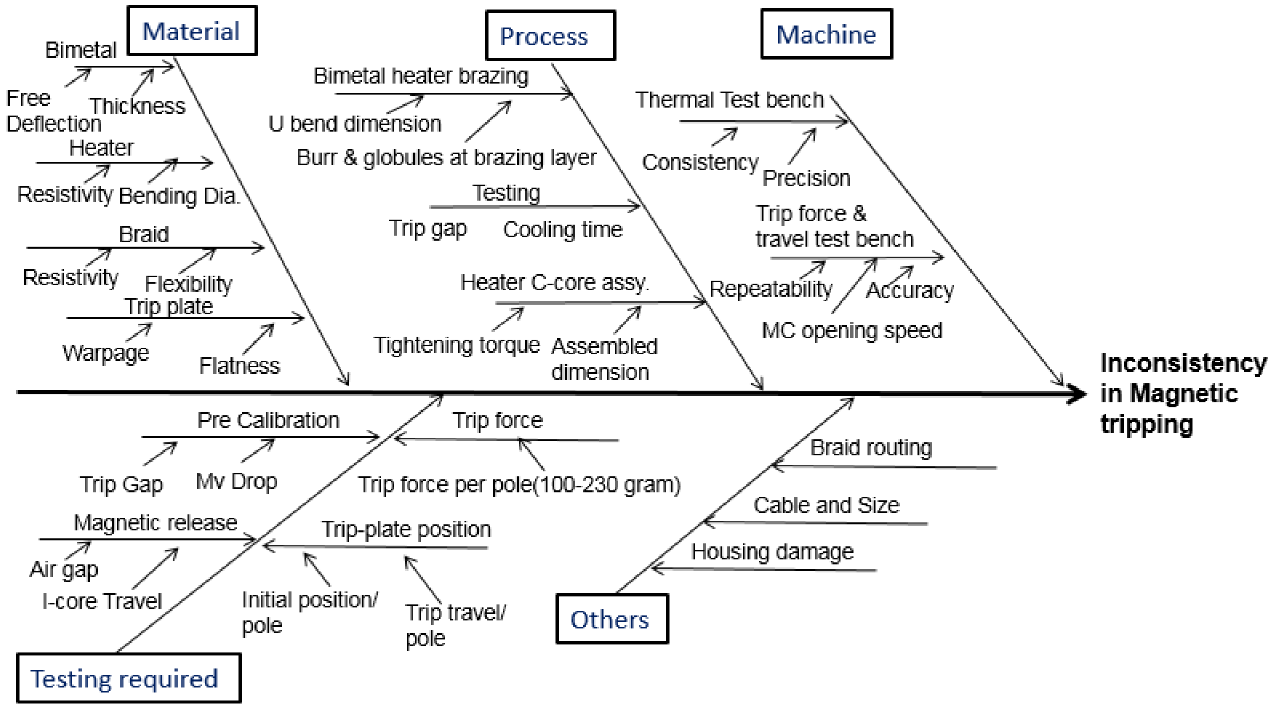
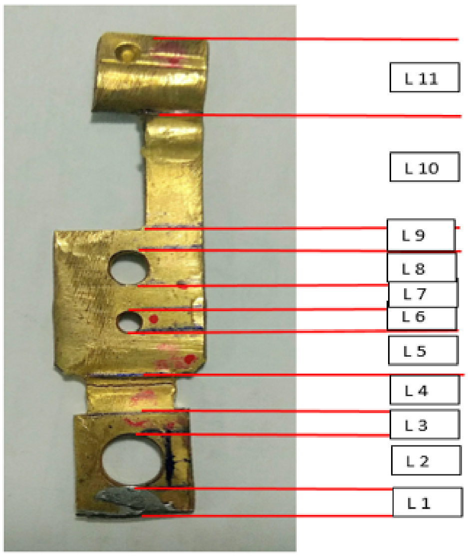


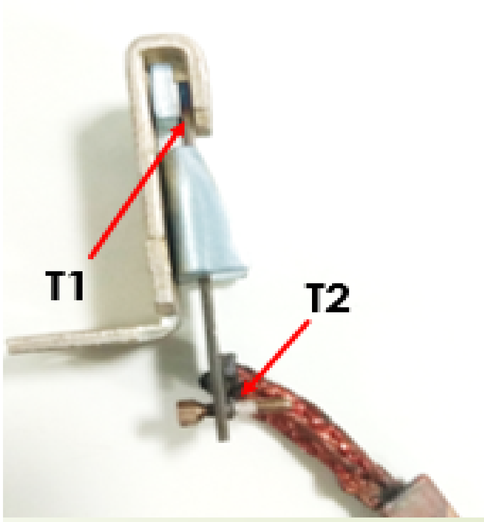
Figure 5.4: Fish bone Diagram for Thermal Improvement

5.3.4 Temperature attains at thermal screw on Bi-metal due to conduction

Purpose: As per defined temperature, Really Bimetal attains its actual temperature during Overload condition or not !!!!!



(a) Copper Heater



(b) Thermal Release

Figure 5.5: Thermal release of MCCB

- In thermal release the current passes through the heater and bimetal which is welded with heater.
- Here current flow within the total mass of heater so total resistance is required to find out the heat generation 'or' Heat flow.
- From generated heat the temperature on heater obtained .
- By using heater's temperature , the temperature attains on bimetal up to thermal screw should be obtain by using conduction heat formula.

1. Heater Area

Copper Heater					
Section	Length(mm)	Width(mm)	Thickness(mm)	Area(mm2)	Length/Area
1	3.3	12.7	2	25.4	0.129921
2	6.5	6.3	2	12.6	0.515873
3	3.6	12.7	2	25.4	0.141732
4	5.82	10	2	20	0.291
5	5.15	16.7	2	33.4	0.154192
6	2.3	14.4	2	28.8	0.079861
7	4.1	16.7	2	33.4	0.122754
8	3.9	12.7	2	25.4	0.153543
9	3.05	16.7	2	33.4	0.091317
10	12	6.6	2	13.2	0.909091
11	17.7	9.5	2	19	0.915789

Table 5.4: Copper heater data

2.Total Resistance

$$
\begin{aligned}
R &= \frac{\rho l}{A} \\
R &= (1.72 * 10^{-5}) * 1.80507 \\
R &= 3.35159 * 10^{-5}\Omega
\end{aligned}
\tag{5.1}
$$

Where,

R =Resistance (Ω)

$\rho = Resistivity \ (\Omega m)$

$l = Length \ (mm)$

$A = Area \ (mm^2)$

- Total area of copper heater is 270 squaremm
- The resistance of copper heater is =3.35159* 10ˆ5 ohm
- The resistance of Bimetal is = 0.000182 ohm **Total resistance of thermal release is =0.000216 ohm**

3. Heat generated on Heater

$$
\begin{aligned}
Qk &= I^2 Rt \\
Qk &= 200^2 * 0.000216 * 60 \\
Qk &= 518.4 \; Watt \, Sec
\end{aligned}
\tag{5.2}
$$

Where,

I =Thermal test bench current (A)

R= Total resistance (Heater + Bimetal) (Ω)

$t = Time \; (Second)$

1 Watt/Sec = 1 Joule

4. Relation between joule heating & Temperature rise on heater is given by

$$
\begin{aligned}
Qk &= cm(\Delta T) \\
\Delta T &= \frac{Qk}{cm} \\
\Delta T &= \frac{518.4}{0.385 * 12.6} \\
\Delta T &= 106.8645^o C
\end{aligned}
\tag{5.3}
$$

Where,

Qk =Generated Heat (J)

$\Delta T = Temperature\ \ Rise\ \ (^0C)$

$C = Specific\ \ heat\ \ capacity\ \ (J/g^0C)$

- The above calculated temperature is obtained on bimetal in 60 Sec.
- The temperature on bimetal up to thermal screw is find out by using the raised temperature on heater by using the conduction formula.
- Here the heat flow through direct heating system.
- The direct heating process is helpful in the lower rating MCCBs.

Where,

T1	379K	Temperature at Heater in Kelvin
T2	????	Temperature on bimetal up to thermal screw
L1	63.72mm	Length of Heater
L2	35mm	Length of Bimetal
k1	385	Thermal Conductivity(Copper)
k2	160	Thermal Conductivity(Bimetal)
A1	270 square mm	Area of Heater
A2	54 square mm	Area of Bimetal

Table 5.5: Copper Heater Data

$$
\begin{aligned}
Qk &= \frac{T1 - T2}{\frac{L1}{K1*A1} + \frac{L2}{K2*A2}} \\
T2 &= T1 - ((Qk * (\frac{L1}{k1 * A1} + \frac{L2}{k2 * A2})) \\
T2 &= 379 - ((518.4 * (\frac{63.72}{270 * 385} + \frac{35}{54 * 160})) \\
T2 &= 379(518.4 * (6.1298 * 10^{-4}) + 0.004050) \\
T2 &= 379 - (518.4 * 0.004662) \\
T2 &= 379 - 2.147 \\
T2 &= 376.58K(103.58^oC)
\end{aligned}
\tag{5.4}
$$

* The Temperature at Thermal screw is almost 103.58^oC.

* The actual temperature at thermal screw is (103.58 + 33)= 133.58^oC.

* The temperature attains on bimetal during the temperature rise test is also almost nearer to 133^oC.

* Due to Direct heating system the temperature on both the heater and bimetal is same.**Loss in the temperature is due to ambient temperature , Losses are negligible**

5.3.5 Free deflection on bimetal with temperature at 2In current

Purpose : During overload condition the bimetal should have proper deflection or not!!!

- To trip the breaker during overload condition the bimetal should have proper deflection . For Cu5 Bimetal free deflection is follow

$$\begin{aligned} D &= \frac{\alpha \Delta T^2}{t} \\ D &= \frac{1.68 * 10^{-5} * 133 * 39^2}{1.20} \\ D &= 2.83\ mm \end{aligned} \tag{5.5}$$

Where,

$\alpha = Specific\ thermal\ deflection\ in\ per^oC.$

$\Delta T = Temperature\ change\ in\ ^oC.$

$L = Active\ length\ of\ Bimetal.$

$t = Thickness\ of\ bimetal.$

5.3.6 List of Significant Factors

Sr. No.	Factors	Effects
1	Bimetal bending repeat ability	Bimetal deflection bending of 2mm in 2In at 75 sec for repeated testing
2	Bimetal Stress relieving	Removal of stress in the bimetal by heating in Oven for 4 hrs at 250 degree C
3	Bimetal not coming back to start point	Bimetal coming back to its start position after cooling for defined time
4	Braid Solidification area	Solidified portion of braid on bimetal after brazing obstructing with housing wall for bimetal
5	Testing interval (cooling breaker)	Proper cooling of breaker (30 min min) to bring back to atmospheric temperature before next thermal test
6	Ambient correction Factor	Application of ACF & correctness of the same
7	Screw Tip profile	Dome in screw tip for friction less cam with trip plate for tripping
8	Release Annealing	Removal of stress in the bi metal assembly (created during welding) by heating in Oven for 4 hrs at 250 deg C
9	Force more than 270 gram	Trip force of the breaker by pushing trip plate at 12.5mm should be less than 270gram
10	Travel more than 2.3 mm	Trip travel of the breaker by pushing trip plate at 12.5mm should be less than 2.3mm
11	Travel less than 1.7 mm	Trip travel of the breaker by pushing trip plate at 12.5mm should be more than 1.7mm

Table 5.6: Significant factors and its effects

5.4 IMPROVEMENT

5.4.1 Improvement Actions

Sr. No.	Causes	Action	Benefits	Improved By
1	Bimetal deflection bending of >2mm in 2In at 75 sec for repeated testing	Repeat ability test on release assay for >2mm deflection before making breakers	Improved lower tripping bend	control
2	Removal of stress in the bimetal & Assy by heating in Oven for 4 hrs at 250 deg C	Heating of Assy in Oven for 4 hrs at 250 deg C and cooling naturally	Improved trip band & repeat ability in readings	control
3	Bimetal coming back to its start position after cooling for defined time	Cooling of MCCB for 30 min before next thermal test	Repeat ability of thermal time improvement	control
4	Application of ACF	Derivation of ACF in Thermal test bench & IS testing	Elimination of environmental temperature factor for proper calibration	control
5	Dome in screw tip for friction less cam with trip plate for tripping	Assemble screw with smooth surface & dome	Smooth tripping leading to Repeat ability in reading	control

Table 5.7: Actions for Improvement

5.4.2 Improvement Done

1. Problem: Inconsistency in thermal tripping

Causes: 1. Obstacle in bimetal deflection 2. Trip Gap is not maintained

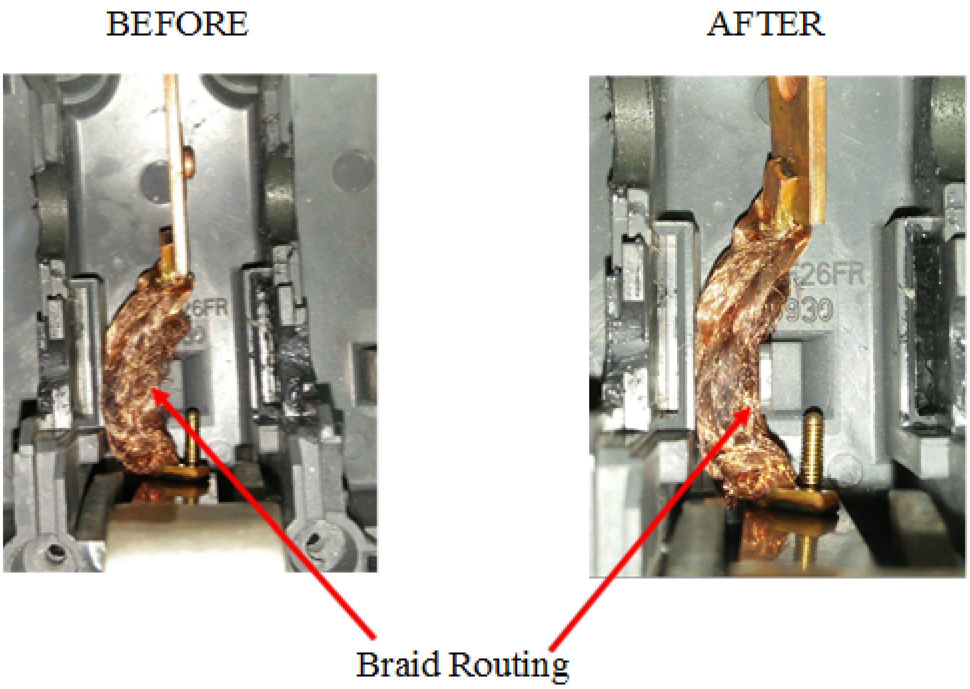


Figure 5.6: Modification in Braid Route

- After routing of braid the problem of thermal screw tilting is almost reduce and there is no obstacle in bimetal deflection

- The trip gap maintain properly, So decided trip time should be achieved.

- No late tripping of MCCB.

2. **Problem:** Thermal Screw Tilting

Causes: 1. Late tripping in Thermal 2. Trip Gap is not maintained

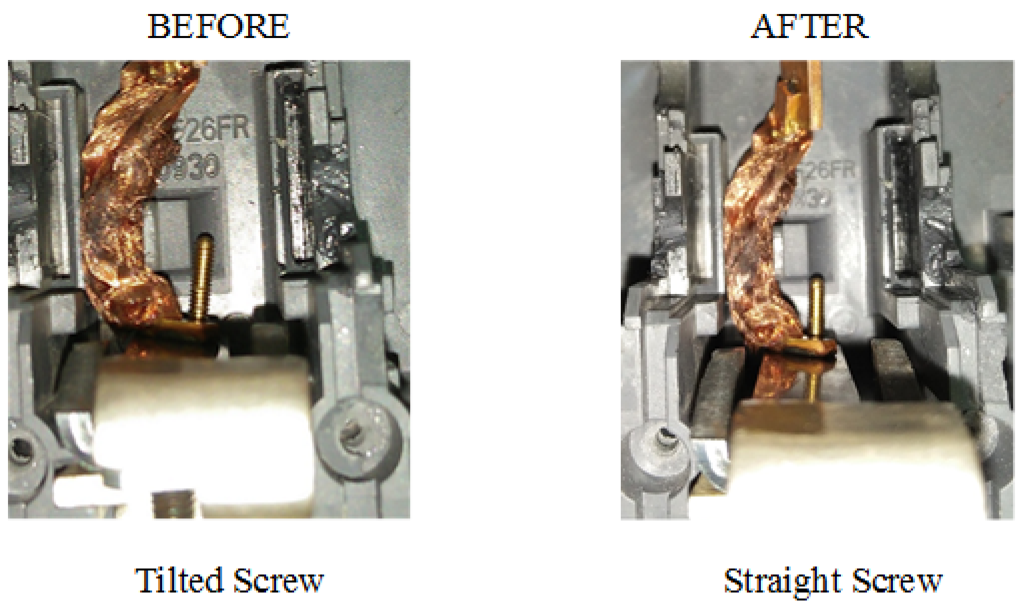


Figure 5.7: Modification in Braid Route

- After routing of braid the problem of thermal screw tilting is almost reduce
- The trip gap maintain properly, So decided trip time should be achieved.
- No late tripping of MCCB.

3. Problem: In consistency in tripping Time

Causes: 1. Trip Gap is not maintained 2. No repeatably in test reading

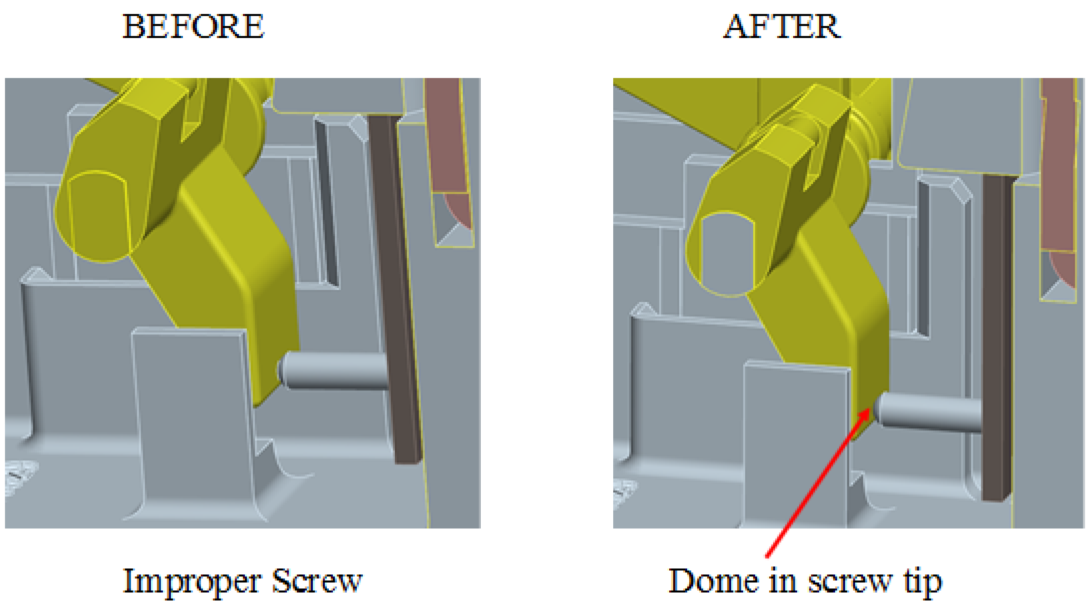


Figure 5.8: Modification in Thermal screw

- Improve in tripping time consistency
- The trip gap maintain properly, So decided trip time should be achieved
- No late tripping of MCCB.

4. Problem: Inconsistency in Trip travel causes variation in thermal trip time

Causes: 1. Trip Gap variation 2. Non trip in thermal testing

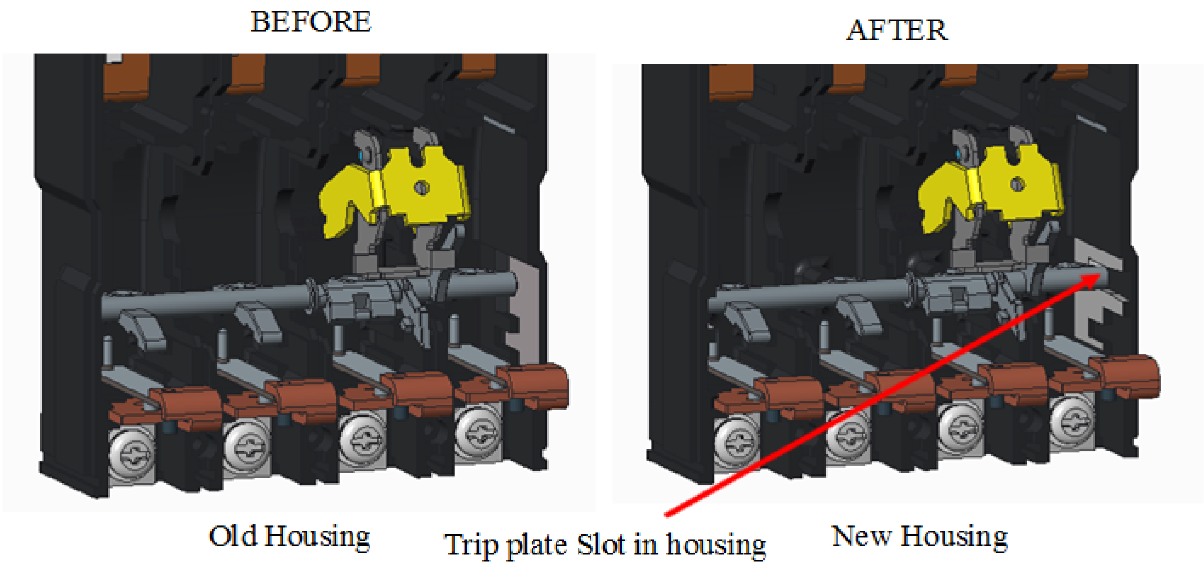


Figure 5.9: Modification in trip plate slot in housing

- Improve in tripping time consistency.
- The trip gap maintain properly, So decided trip time should be achieved during testing.
- Consistency in Trip travel.
- Tripping of MCCB within a decided thermal bend.

5.5 CONTROL

5.5.1 Control actions after improvement

Sr. No.	Recommended Action	Control Action
1	Thermal screw length as per drawing	Thermal screw thread length is mention as CTQ
2	Parallelism between heater and bimetal	CTQ on bimetal heater parallel dim.
3	Proper welding of bimetal and heater	QC on bimetal weld bur (Visually)
4	Sufficient locktite on thermal screw to avoid breakage of thermal screw	Control in Locktite on thermal screw
5	Proper welding of bimetal and heater	Take care of Bimetal welding with heater
6	Proper heater for MCCB	QC on heater assembly as per current rating

Table 5.8: Control actions after improvement

5.6 Thermal test data after 6 Sigma

After all type of modification and improvement the testing data are as bellow.

MCCB No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Thermal Trip Sec(50-70)	55	60	65	72	58	68	55	59	65	60	63	64	67	59	66

Table 5.9: Thermal Test Data

- From above table we can see that only 1 breaker failed during thermal tripping test
- Almost 14 number of breakers pass in the predefined thermal tripping bend

5.6.1 Graphical comparison of Magnetic data before & after 6 SIGMA

Graphical representation of Magnetic data before 6 SIGMA

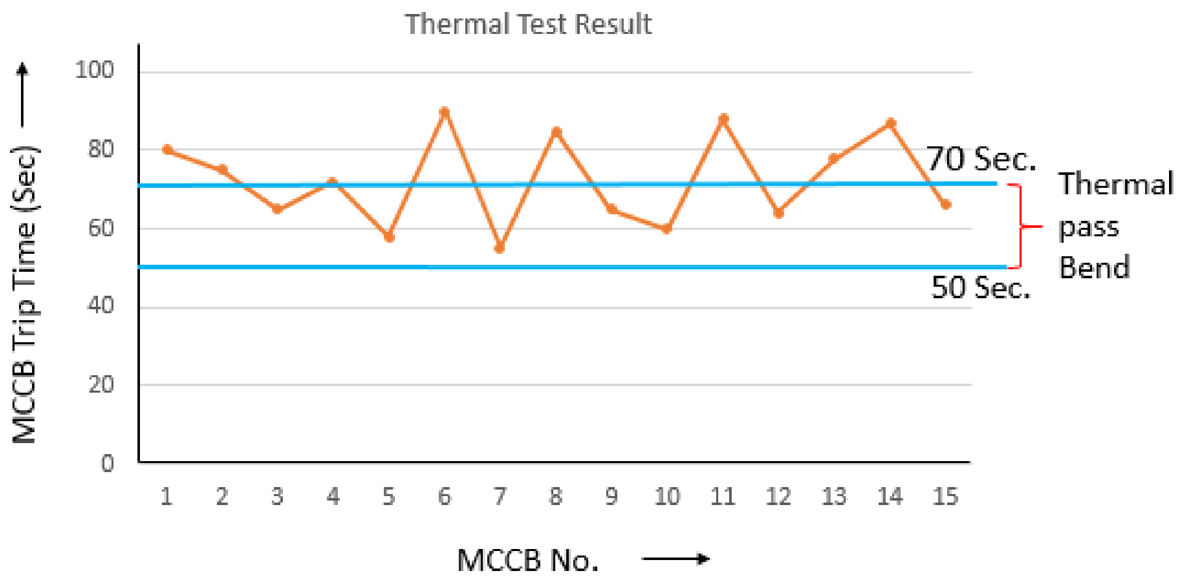


Figure 5.10: Thermal trip testing results of 100A before 6 SIGMA

Graphical representation of Magnetic data after 6 SIGMA

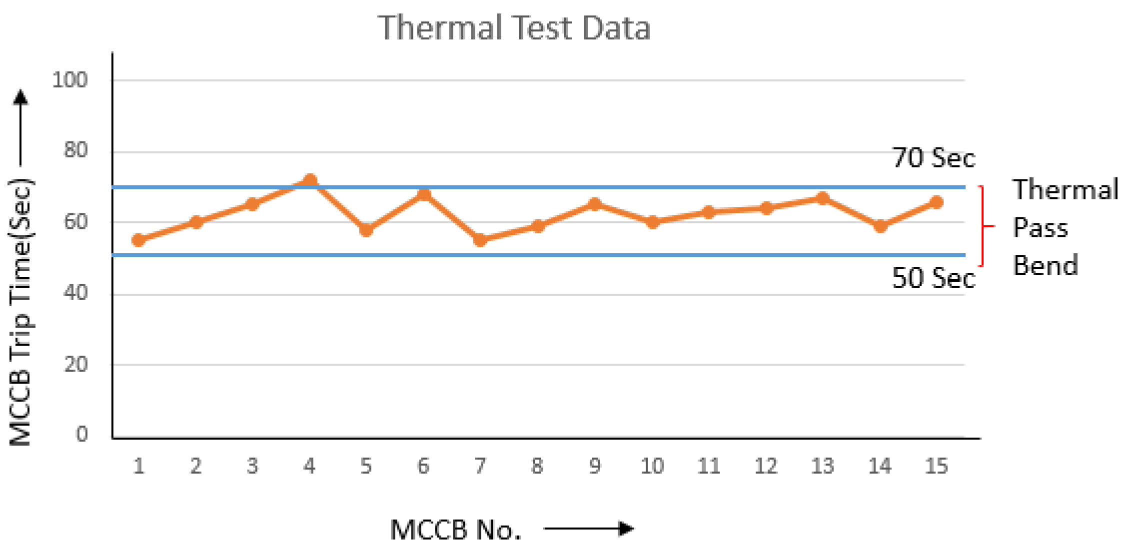


Figure 5.11: Thermal trip testing results of 100A after 6 SIGMA

5.7 SIGMA level after 6 SIGMA process

After all type of modification and improvement the testing data are as bellow.

After 6 SIGMA	Value
opportunities	15
Defects	1

Table 5.10: Breakers Pass Fail Details

After 6 SIGMA	Value
Defects%	6.67
Yield%	93.33
SIGMA level	3

Table 5.11: Results after 6 SIGMA

5.7.1 Compression of Sigma level

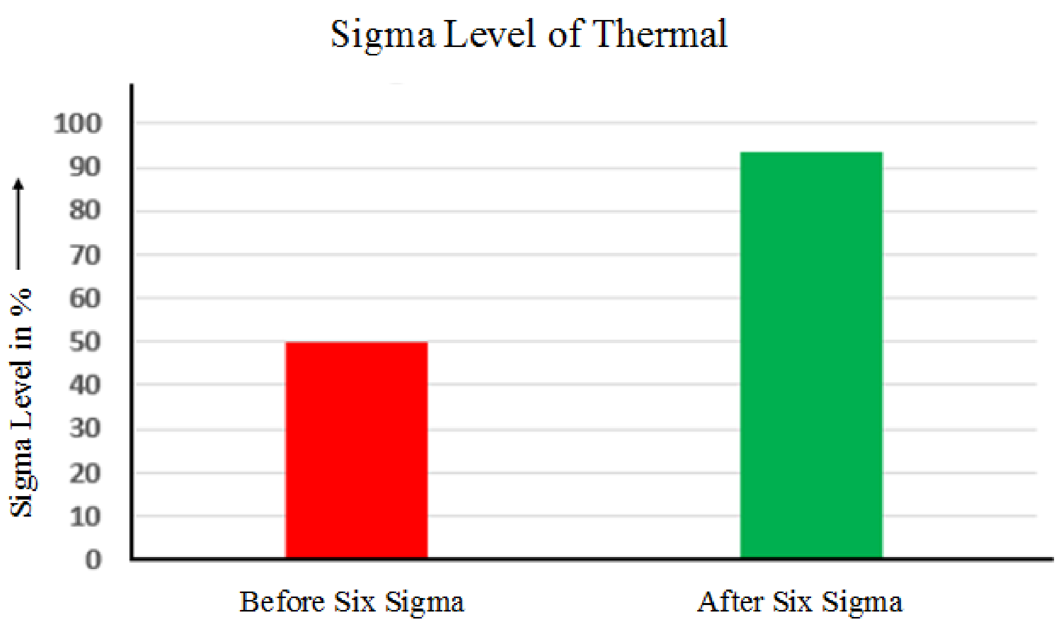


Figure 5.12: Comparison of Sigma level of Thermal

Chapter 6

Conclusion and Future Scope

6.1 Conclusion

Based on the test results, the possible conclusion can be made about the process yield of magnetic and thermal, The overall yield of magnetic and thermal is improve by using the most power full tool Six Sigma to improve the process level as well as the quality of the product. The DMAIC tool used to improve the yield as well as the consistency of the MCCB.At starting almost breakers failed in magnetic testing, the yield was almost around 20 % in magnetic, after some route cause analysis and improvement actions & some permanent modification the yield improved up to 93 %.In thermal testing the yield was around 50% ,after some analysis and improvements by using Six Sigma (DMAIC) tool the yield improved up to 93%.The overall consistency and the first time product yield also improved through the Six Sigma process.

6.2 Future Scope

The proposed work can be extended for yield up to 98 % to 100% .

- By riveting the I Core & C Core, The constant and same air gap maintains between C Core & I Core in all poles.
- Thermal consistency also improved 100% through Cold calibration heater.

Chapter 7

References

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