Development of 100 A Frame MCCB with Magnetic Threshold I_i of 10 I_n for Short Circuit Protection of Motor

Major Project Report

Submitted in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING
(Electrical Power Systems)

By

Jainil B. Trivedi
(13MEEE24)

DEPARTMENT OF ELECTRICAL ENGINEERING
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY
AHMEDABAD-382481
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Undertaking for Originality of the Work

I, **Jainil Trivedi**, Roll. No.13MEEE24, give undertaking that the Major Project entitled **"Development of 100 A Frame MCCB with Magnetic Threshold I_i of $10I_n$ for shortcircuit protection of Motor"** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Electrical Engineering (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.

Signature of Student

Date:

Place: Nirma University, Ahmedabad

Endorsed By:

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CERTIFICATE

This is to certify that the Major Project Report (Part-II) entitled **"Development of 100 A Frame MCCB with Magnetic Threshold I_i of $10I_n$ for shortcircuit protection of Motor"** submitted by Mr. Jainil Trivedi (13MEEE24) towards the partial fulfillment of the requirements for Semester-IV of Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by him/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:

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Jainil Trivedi

ABSTRACT

The project will be initiated by studying in detail the concepts of motor protection and Type2 Co-ordination scheme. At present L&T MCCB (up to 100 A) has instantaneous setting (Ii) of 9In. To increase the safety margin against peak inrush current drawn by three phase Induction motor, there is requirement of MCCB with Ii = 10In. The concept for new electromagnetic tripping mechanism will be developed and analysed using the Pro-E software. Proposed design of electromagnetic tripping mechanism will be simulated in the FEA tools like JMAG/ANSYS. Based on the findings of the technical study & simulation results prototype will be ordered. Validation of the prototype samples will be done on the product & after successful completion proposed design will be freezed & released.

Nomenclatures

FEM .... Finite Element Method
NEC .... National Electrical Code
MCCB .... Molded Case Circuit Breaker
IEC .... International Electrotechnical Comission
SCPD .... Short Circuit Protective Device
JMAG .... A software used for FEM analysis

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Chapter 1

Introduction

1.1 Arc extinction : Basics

When a short circuit or overload fault occurs in the power system it is required to disconnect the important installation from the power system as soon as possible. Here due to a high current passing through the device the disconnection will be quite a difficult task as due to disconnection an arc produces the arc has to be quenched as soon as possible. The device which is able to quench the arc is known as circuit breaker. The moulded case circuit breaker is also basically a disconnecting means with arc quenching apparatus.

The arc quenching is done by mainly two theories

- High resistance theory
- Low resistance theory

i.) High resistance theory: In this theory the resistance for the arc is increased till such a level so that the arc extinguishes itself. The main disadvantage of this theory is that the amount of energy generated during the arc quenching is enormous so this theory is basically used in d.c. circuit breaker and low voltage circuit breaker. This can be done by Lengthening the arc , reducing the cross section of the arc , cooling the arc , splitting the arc.

ii.) Low resistance theory: In this theory the resistance of the arc is kept as low as possible so the voltage drop between the contacts will be as less as possible so there will be no restriking voltage and due to that the arc will be extinguished naturally.

1.2 Why motor protection is required?

Motor load is around 70 % of the total load. So we can say that motors are the spinal cord of the industry if there is any fault in the motor than the whole industry is affected by it. Most of the industry required mechanical movements motors are used to convert the electrical energy into mechanical energy . So if the motors are not well protected whole power sector gets affected.

1.3 100 A frame motor protective MCCB

Motor mainly require protection from two phenomena

1. Short Circuit Protection
2. Overload Protection

The overload protection is provided by the overload relay and the short circuit protection is provided by the MCCB.The MCCB consists of many different parts like the tripping unit, frame, etc they are explained as given.

- FRAME: It provides insulated housing to mount CB components. Material used: Thermal set plastic such as Glass polymer. Insulation of material is based on rating of CB. Frame ratings indicate several important information such as ; maximum voltage, ampere rating, interrupting rating, and physical size.

- CONTACTS: It mainly consists of two parts i.e. upper and lower contact. In abnormal condition it is used to break the circuit and limit the current at zero value. The contacts are only opened by the mechanical operation of the circuit breaker spring.
  - Straight through contacts
  - Blow apart contacts

  1. Straight through contacts: Some conventional circuit breakers use a straight-through contact arrangement. The electrical path through the contacts is a straight line. The magnetic fields developed around the contact arms of a straight-through contact arrangement have little or no effect on the contacts arms. During a fault, the contacts are only opened by the mechanical operation of the circuit breaker spring.

2. Blow apart contacts: The two contact arms in this type of contacts are positioned parallel to each other. The blow-apart contact design helps to open the contacts faster than the straight-through arrangement.

- ARC CHUTE ASSEMBLY: In abnormal condition if short circuit occur then the contacts of CB open a live circuit, but current continues to flow for a short time between the contacts in the form of an arc. When the contacts open far enough the arc is extinguished and the current flow limits to zero value. This arc may burn other components of CB, hence to quench this arc arc-chute are placed just after the contacts of CB. This assembly is made up of several U shaped steel plates.

- OPERATING MECHANISM: Operating handle is provided to manually on/off CB. means to open and close contacts of CB. Moulded case circuit breakers are trip free, it means they can't be prevented from tripping by holding or blocking the operating handle in ON position. There are three positions of the operating handle: ON(contacts closed), OFF(contacts open) and TRIPPED (mechanism in tripped position). The operating handle is connected to the moveable contact arm through an operating mechanism. To open the contacts, the operating handle is moved from the ON to the OFF position. In this process a spring begins to apply tension to the mechanism. When the handle is directly over the centre the tension in the spring is strong enough to snap the contacts open. As in closing the CB contacts, contact opening speed is independent of how fast the handle is operated.

- TRIP UNIT: it sense if current exceed the rated value and give command to CB. In overload: It sense by bimetal strip. Bimetal consist of two different metal (i.e steel & copper usually) with different thermal expansion characteristics. In short circuit: it sense current value by an electromagnet which is connected with bimetal strip.

- TRIP MECHANISM: A trip mechanism is held in place by the tripper bar. As long as the tripper bar holds the trip mechanism, the mechanism remains in locked position. The operating mechanism is in ON position by the trip mechanism. if any case trip is activated, Trip mechanism releases the operating mechanism, which opens the contacts.

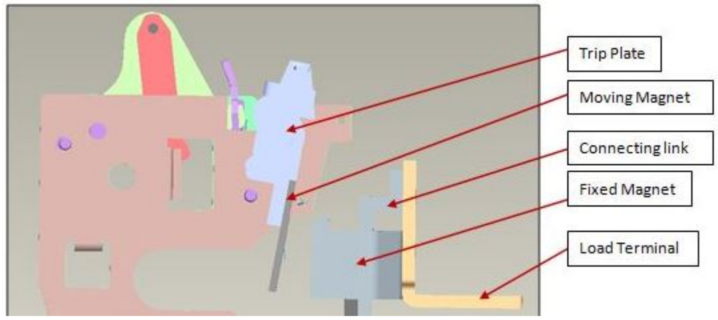

Figure 1.1: Tripping mechanism

The main difference between the standard MCCB and the MCCB used for the short circuit protection of motor is that in MCCB used for short circuit protection there is no overload detection unit in it. As it is only used for the short circuit detection there is no requirement of the bimetallic strip which senses the overload. The figure shows the representation of a 100 A frame MCCB with it's each parts visible.

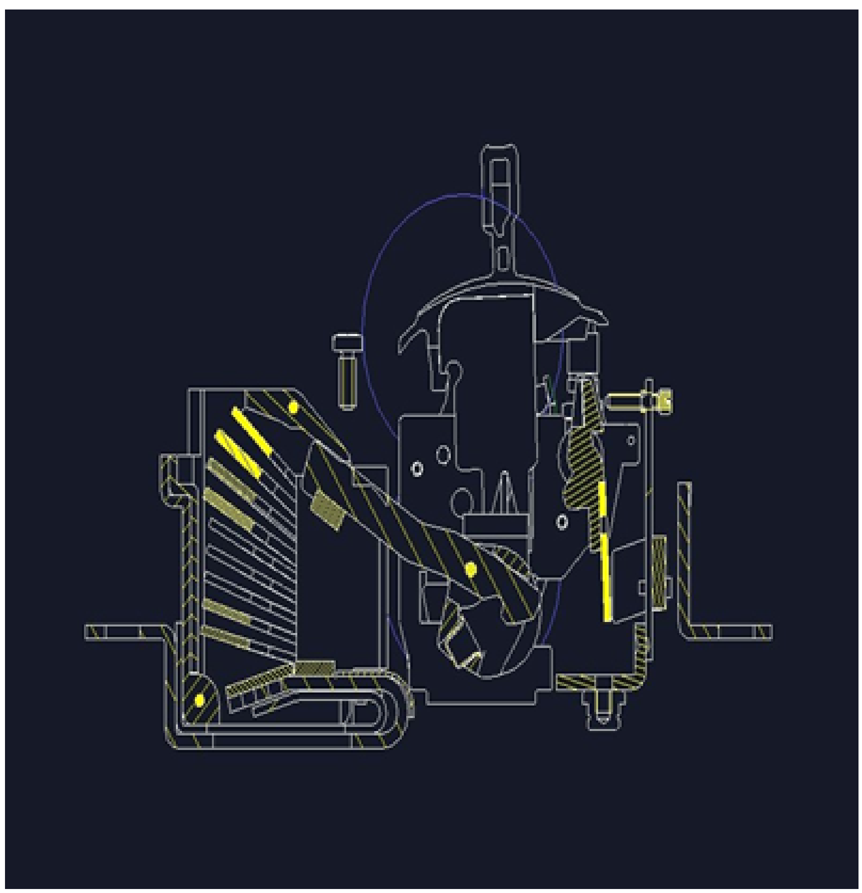

Figure 1.2: Mechanism of 100 A frame MCCB

1.4 Literature Review

Paul Alwin [1]discussed the concept of Type-2 co-ordination applies to any type of motor starter and any type of SCPD the most typical starter include : magnetic starter,integrated starter and co-ordinated protected starters.

Lorraine K. Paden [2] discussed that the combination starter must have a short circuit rating adequate for the available short circuit current on the supply side.

Frank W Kussy et.al. [3] discussed how the total motor branch circuit protection with instantaneous trip type circuit breakers an high fault circuit protectors is done.

Paul Alwin [1] Type-2 Co-ordination means that motor starters will be suitable for use after a short circuit fault current.

Lorraine K. Padeen [2] discussed that the false tripping of instantaneous trip circuit breaker is an occasional problem when motors are starting . The asymmetric starting current causes the breaker to trip without a fault condition . In some cases the maximum setting permitted by the NEC is not high enough to allow the starting current to flow without tripping the instantaneous trip circuit breaker.

James Wilson [4] discussed how the moulded case circuit breakers can be applied to the motor control centres and how it affects the control centres.

George Gegory[5] discussed how the right size moulded case circuit breaker is chosen for the motor starters.

Weiong Tong et al. [6]discussed how dynamic simulation of operating mechanism for moulded case circuit breaker is done.

Lorraine K. Padeen [2] discussed false tripping of instantaneous trip circuit breaker is an occasional problem when motors are starting The asymmetrical starting current causes the breaker to trip without a fault condition. In some cases the maximum setting permitted be the NEC is not high enough to allow the starting current to be flow without tripping the instantaneous trip circuit breaker.

Paul Alwin [1] discussed if a SCPD with high let through current and energy was used to protect a starter the likelihood that the starter could be damaged or even totally destroyed by a short circuit was great.

National Electric Code article 110-9 [7] discussed that equipment intended to break current at fault levels shall have an interrupting rating sufficient for the system voltage and the current which is available at the line terminals of the equipment.

National Electric Code article 110-10[7]discussed that the let through energy of a short circuit protective device must be lower than the withstand rating of the down-stream equipment.

Underwriters Laboratory 508 [8] discussed that the circuit breaker with a lower interrupting rating may be used if the combination is evaluated and subjected to appropriate requirements of the standards for the circuit breaker and circuit breaker enclosures.

1.5 Magnetic threshold definition

The current limit at which the magnetic release will actuate the tripping mechanism to trip the circuit breaker is known as the magnetic threshold.

The magnetic threshold is defined by a range of values of current in between the MCCB should operate.

The band or range is defined between 80% of magnetic threshold (Minimum value) to 120% of magnetic threshold (Maximum value) .

Here in the range the minimum value of current is known as the "Non-Trip" value, which suggest that the MCCB should not trip till that particular current value.

1.6 Problem Identification

- The magnetic threshold is the limit which defines which combination of the contactors, overload relay and MCCB to be used to fulfil the protection of the motor as well as the person who is operating the motor.
- The current magnetic threshold limit of the 100 A frame is 9In.
- Now as the magnetic threshold limit is low the requirement of the contactors , overload relay and MCCB for some particular rating is higher
- As the magnetic threshold value of the MCCB will be increased the size of the Contactors , overload relay and MCCB for the same particular rating will decrease which will affect the starter panel size an due to the reduction in the size it will be more economical.
- Hence by increasing the magnetic threshold value of the MCCB the starter apparatus will be more economical without sacrificing the require safety and protective standards.

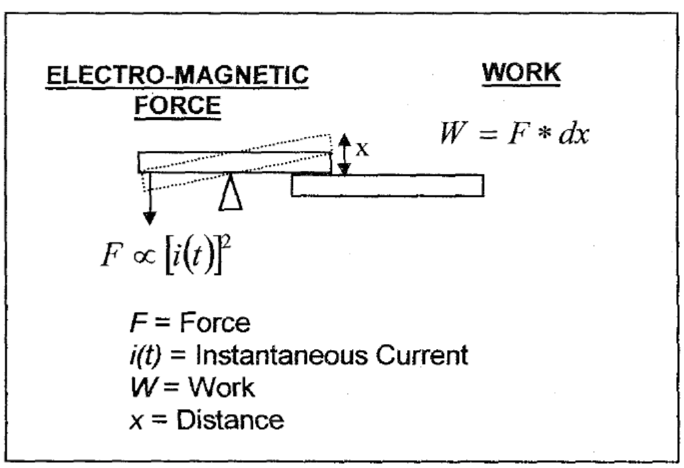

Figure 1.3: Basic working of Magnetic release

1.7 Methodology

- Literature Survey.
- Simulation study of present design of electromagnetic tripping mechanism of 100 A MCCB.
- Development of mathematical model for theoretical calculation of magnetic pull generated by fixed magnet on moving magnet.
- Identification of different parameters affecting the magnetic threshold of 100 A frame motor short circuit protection MCCB.
- Simulation study and theoretical calculation for the modification of various key parameters.
- Practical testing and validation of developed prototypes for modified electromagnetic tripping mechanism.

1.8 Scope of work

The scope of the project is to analyse the present electromagnetic tripping mechanism and increase the magnetic threshold of the electromagnetic tripping mechanism for 100 A frame motor short circuit protection MCCB. The main factors that affect the magnetic threshold of 100 A frame motor short circuit protection MCCB are air gap, size of fix magnet, size of moving magnet, spring force, saturation etc

- Study of various parameters affecting magnetic threshold of 100 A MCCB
- Analyzing key parameters affecting the electromagnetic tripping mechanism by finite element software and theoretical calculation
- Selection of modified electromagnetic tripping mechanism from the results of the analysis of the key parameters
- Prototyping and validation of the modified electromagnetic tripping mechanism

1.9 Outline of the Thesis

- **Chapter 1** introduces to the basic construction of a MCCB. A brief introduction about the problems associated with present magnetic threshold of MCCB thus defining the motivation behind this project. This chapter also comprises of literature studied, problems identified and scope of the work.
- **Chapter 2** gives a brief introduction about the co-ordination between the overload protection relay and the short circuit protection MCCB.
- **Chapter 3** comprises of the theoretical and finite element analysis of the present electromagnetic tripping mechanism, moreover various parameters like spring force and design data for the present tripping mechanism are given.
- **Chapter 4** comprises of different modifications in electromagnetic tripping mechanism and their theoretical and FEM analysis.
- **Chapter 5** gives a brief introduction about the validation and testing procedure for the motor short circuit protection MCCB.
- **Chapter 6** comprises of conclusions drawn and the future work.

Chapter 2

Co-ordination studies between overload relay and SCPD

- In case of motor protection the overload protection and the short circuit protection both are provided by two different apparatus so a co-ordination between the characteristics of both is required. According to the IEC standards there are mainly two type of co-ordination

2.1 Why Type-2 Co-ordination is required?

In any industry the safety of the operator an installation is the main concern. Type-1 & Type-2 co-ordination both provide safety to operator as well as the machine . Type-1 co-ordination however does not provide protection to the starter apparatus i.e. after the short circuit has occurred there is a requirement of maintenance of starter or to change the whole starter which is very time consuming as compared to the type-2 co-ordination starter as the maintenance requirement after the short circuit is less so the economic losses are also less and the same starter can be used in future without replacing any part. So the Type-2 co-ordination is preferred very much as it provides the safety of the personnel and increases the productivity.

Table 2.1: Type-1 & Type-2 Co-ordination

Type-1 Co-ordination	Type-2 Co-ordination
Under short circuit condition the contactors or starters shall cause no damage to the installation or operator and may not be suitable for further service without repair and replacement of the parts.	Under short circuit condition the contactors or starters shall cause no danger to installation or operator n shall be suitable for further use. The risk of contact welding is recognized in which case the manufacturer shall indicate the measures to be taken in regards to the maintenance of the equipment

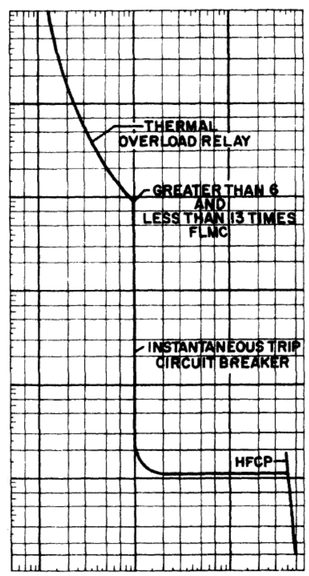

Figure 2.1: I-T characteristics of Overload Relay and MCCB

2.2 Summary

This chapter gives us a brief introduction about the co-ordination of the overload relay and the motor short circuit protection MCCB and how it affects the protection of the device and the operating personnel.

Chapter 3

Analysis and calculation for magnetic release

3.1 FEM analysis : Basics

The numerical methods for approximating the solutions of mathematical models is known as finite element method. Mathematical models represents some aspects of physical reality as mathematical equations.The characterization of finite element method is done by a variational formulation, a discretization strategy, one or more solution algorithms and post-processing procedures.

Examples of variational formulation are the Galerkin method, the discontinuous Galerkin method, mixed methods, etc.

A discretization strategy is understood to mean a clearly defined set of procedures that cover (a) the creation of finite element meshes, (b) the definition of basis function on reference elements (also called shape functions) and (c) the mapping of reference elements onto the elements of the mesh. Examples of discretization strategies are the h-version, p-version, hp-version, x-FEM, isogeometric analysis, etc. Each discretization strategy has certain advantages and disadvantages. A reasonable criterion in selecting a discretization strategy is to realize nearly optimal performance for the broadest set of mathematical models in a particular model class.

There are various numerical solution algorithms that can be classified into two broad categories; direct and iterative solvers. These algorithms are designed to exploit the sparsity of matrices that depend on the choices of variational formulation and discretization strategy. Postprocessing procedures are designed for the extraction of the data of interest from a finite element solution. In order to meet the requirements of solution verification, postprocessors need to provide for a posteriori error estimation in terms of the quantities of interest. When the errors of approximation are larger than what is considered acceptable then the discretization has to be changed either by an automated adaptive process or by action of the analyst. There are some very efficient postprocessors that provide for the realization of superconvergence.

3.2 Analysis of Present electromagnetic tripping mechanism

The analysis of dynamic characteristic of MCCB during short circuit protection is necessary, and building of corresponding simulation model is also required, so the optimization of design and protection parameters setting of MCCB can be done. The breaking of short circuit current is a complex physical process which is coupled with mechanical movement, electric circuit, magnetic field and electric arc. The protection characteristics of MCCB are mainly dependent on the mechanical movement characteristic of magnetic trip.

Here, firstly the mathematical models of instantaneous acting trip and switching arc are studied. The analysis of electromagnetic torque characteristics on armature in the trip which varies with the current and air gap is done using JMAG. The analyzed results are integrated with mechanical motion equations to build a simulation model of MCCB.

Here a motor protection MCCB whose rated current is 100A is taken for example, the fig. shows the 3-D model of instantaneous acting magnetic trip. This is a typical electromagnetic tripping mechanism where iron core is not present is used. The main magnetic path consists of yoke and armature. The conductor passing through the yoke and armature is of irregular shaped.

The Fig. shows that when current flows through the conductor,it will generate an electromagnetic torque on armature. Because of the electromagnetic torque the armature spins in the decreasing direction of air gap. There also exists a counter torque which affects the armature such that it will prevent it from rotating.

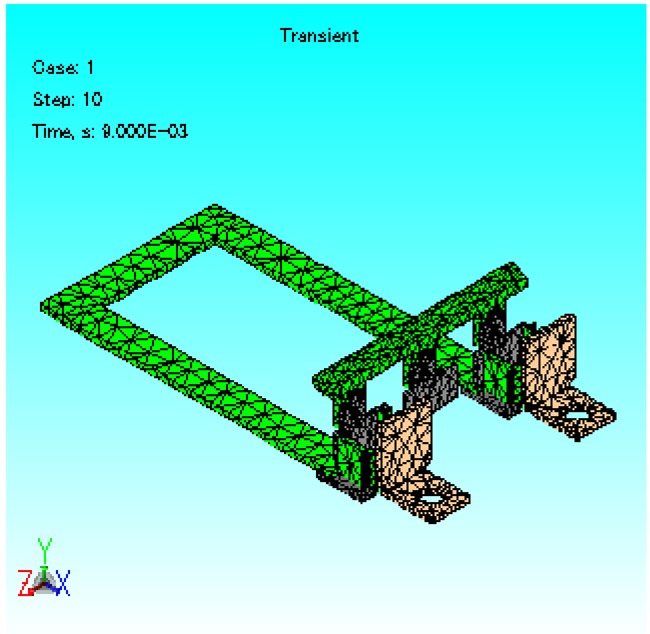

Figure 3.1: 3-D model of the electromagnetic tripping mechanism with meshing

It can be seen from Fig that when current flow through the conductor, an electromagnetic torque on armature will be generated. The effect of the electromagnetic torque is to spin the armature in the decrease direction of air gap. Meanwhile, counter torque on the armature will prevent rotation of armature. So the motion equation of the armature can be written as

$$d\omega/dt = 1/J[T_e - T_f]$$

$$d\theta/dt = -\omega$$

where θ is the angle between the yoke and armature shown in fig.5.2

ω is angular velocity of armature,

T_e is the electromagnetic torque on armature,

T_f is the counter torque,

J is rotation inertia of armature.

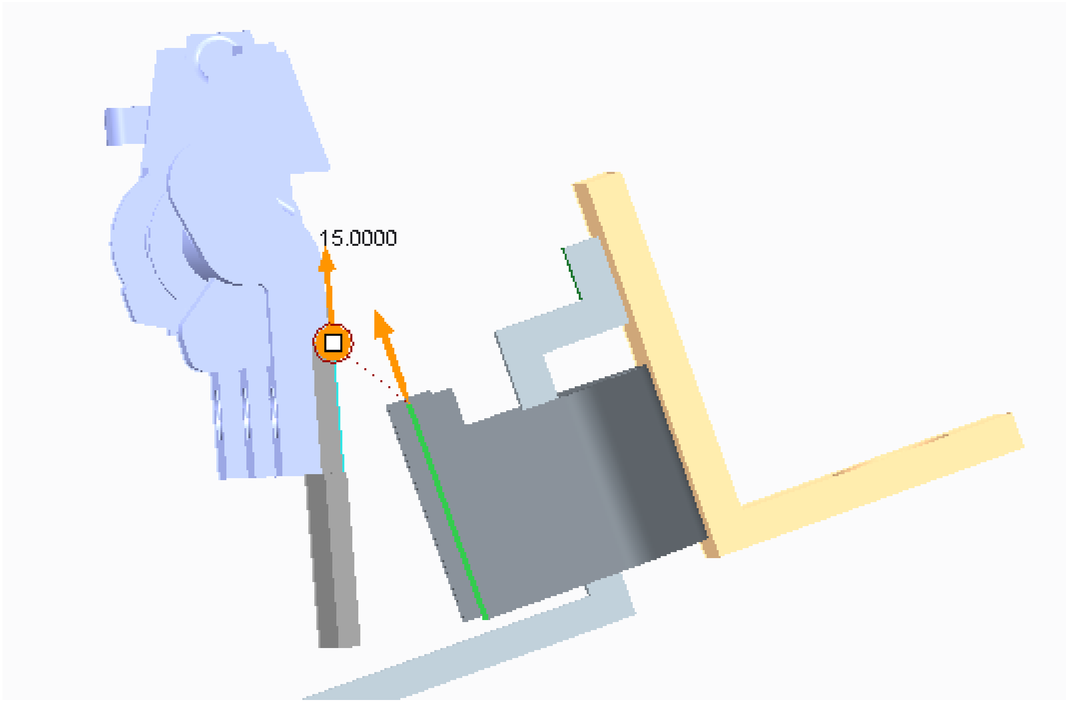

Figure 3.2: Angle between the armature and yoke

The counter torque consists of three components which are

(i) torque of reaction spring

(ii) frictional resistance moment

(iii) trip torque

The torque generated when the armature knocks the tripping shaft which will then trigger the actuating mechanism to pull apart main contact of circuit breaker is known as the trip torque. So when the armature rotates at a certain angle range in which the armature has contact with tripping shaft the trip torque will work. The equation of counter torque can be written as.

$$T_f = M(\theta_m - \theta + \theta_0) + T_m$$

where

M is rigidity of torsion spring,

T_m is the frictional resistance moment,

θ_m is the maximum value or initial value of

Here for the simulation of the dynamic behavior of instantaneous acting trip based on the above motion equation, the calculation of variable Te needs to be accurately done. For that the finite element analysis software JMAG is used .The 3-D model of magnetic trip shown in Fig, is imported into JMAG, and the electromagnetic characteristics of the instantaneous acting trip are analyzed using transient magnetic analysis of JMAG.Magnetic flux density vector distribution in armature and yoke of trip calculated by JMAG when the excitation current through the conductor is up to 800A is shown in Fig.

As we know the main parameters which affect , the flux density and the electromagnetic torque of the armature are the excitation current and air gap between the yoke and armature. And the measurement of air gap can be done by the angle . So the electromagnetic torques Te under different current of conductor i and angle are calculated using JMAG.

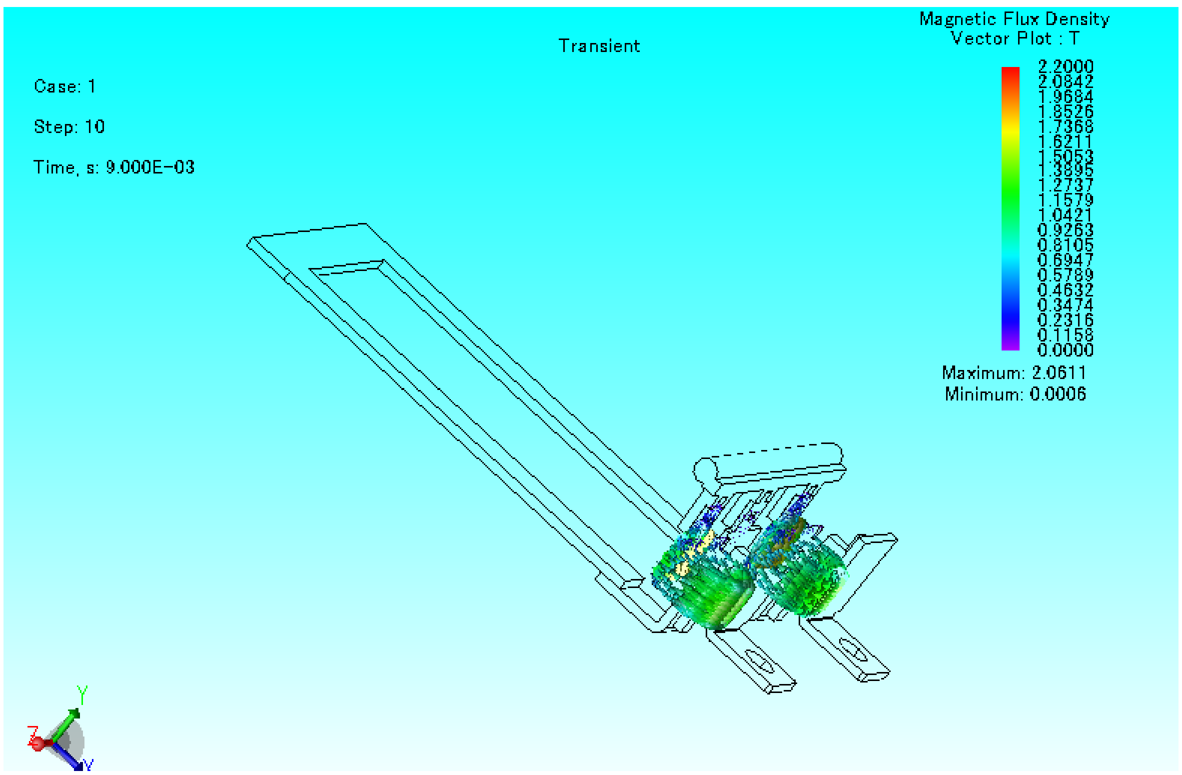

Figure 3.3: Magnetic Flux Density

3.3 Force Calculation For The electromagnetic tripping mechanism

The electromagnetic tripping mechanism consists of a U Shaped fixed magnet and a moving magnet. Whenever a current through the breaker exceeds the magnetic threshold of the release the fixed magnet is energized which attracts the moving magnet & leads to unlatching of operating mechanism due to movement of the trip plate. The electromagnetic tripping mechanism will trip the breaker when the force produced by the magnet is greater than the force exerted by the trip-plate springs.

Force exerted by electromagnets

Let us derive an electromagnetic force produced by the fixed magnet.

Let us assume

$F =$ The magnetic pull or force exerted by the fixed magnet on the flapper in Newton

$B =$Flux density in air gap,Wb/m^2

$A =$ Cross-sectional area of each pole facing the air gap,m^2

Let work done $= F * dx$ joule where

$dx =$rate of change of distance

Thus the work done creates change in stored magnetic energy = (Magnetic energy Stored/m^3) * Change in volume

Magnetic energy stored in the solenoid$= \frac{1}{2} * L * I^2$

$L =$ self inductance

$$L = \frac{N^2 * \mu_0 * A}{l}$$

$N =$no of turns of solenoid

$l =$ length

$$B = \mu_0 * H$$

$H =$field strength inside the solenoid

$$H = \frac{N * I}{l}$$

Substituting L,B,H in magnetic energy $= \frac{1}{2} * L * I^2$

$$\frac{1}{2} * L * I^2 = \frac{B^2 * V}{2 * \mu_0}$$

Therefore,

$$F * dx = \frac{B^2 * A * dx}{2 * \mu_0}$$

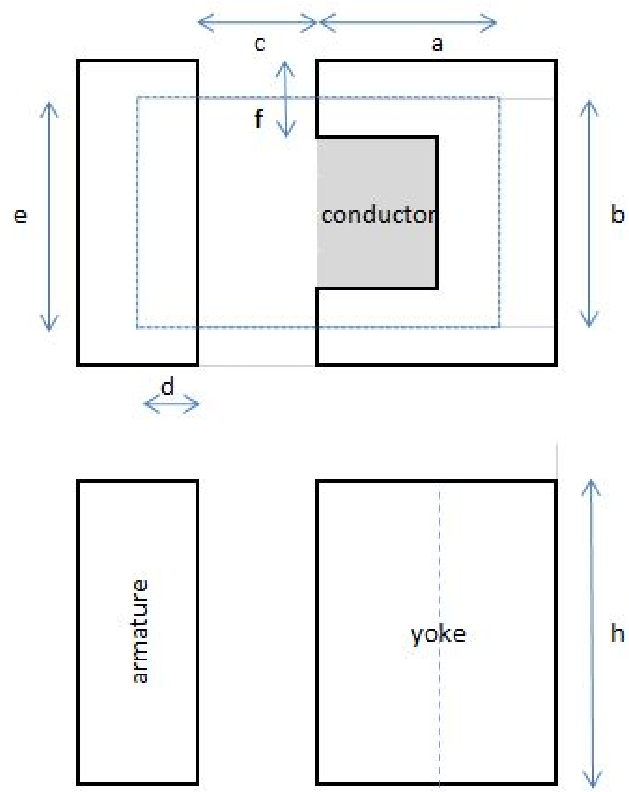

Figure 3.4: C-Shaped fixed and moving magnet

So, The electromagnetic force in Newton

$$F = \frac{B^2 * A}{2 * \mu_0}$$

The force in grams is

$$F = \frac{B^2 * A}{19.62 * \mu_0}$$

Table 3.1: Attributes of present magnetic circuit

Dimensions of Fixed Magnet			
height of core	h	mm	12.5
relative permeability			2000
for one limb			
mean length	a	mm	14.2
width	f	mm	2
area of cross section		mm^2	25
Back portion of core			
mean length	b	mm	6.4
width	f	mm	2
area of cross section		mm^2	25
Air gap dimensions			
mean length	c	mm	3.2
area of cross section		mm^2	25
permeability in free space		henry / metre	1.25664E-06
Moving Magnet			
thickness of Moving Magnet		mm	1.2
height of Moving Magnet		mm	8.6
relative permeability			2000
mean length	d	mm	0.6
area of cross section		mm^2	17.2
mean length	e	mm	6.4
area of cross section		mm^2	10.32

Calculation of reluctance of flux path

Total Reluctance of magnetic circuit = Reluctance of fixed magnet + Reluctance of Flapper + Reluctance of air gap

$$S = \frac{l * 10^{-3}}{\mu_0 * \mu_r * A * 10^{-6}}$$

Here

S is the reluctance

l is the length of the part

μ_0 is the permiability of air

μ_r is the relative permiability

Reluctance of fixed magnet

$$S_1 = \frac{32.8 * 10^{-3}}{2 * 10^{-3} * 25 * 10^{-6} * 1.256 * 10^{-6}}$$

$$S_1 = 522028.2133 \frac{AT}{Wb}$$

Reluctance of moving magnet

$$S_2 = \frac{8.2 * 10^{-3}}{2 * 10^{-3} * 17.2 * 10^{-6} * 1.256 * 10^{-6}}$$

$$S_2 = 206140.6078 \frac{AT}{Wb}$$

Reluctance of air gap

$$S_3 = \frac{6.4 * 10^{-3}}{4 * 3.14 * 10^{-7} * 25 * 10^{-6}}$$

$$S_3 = 203718327.2 \frac{AT}{Wb}$$

Total Reluctance

$$S = S_1 + S_2 + S_3$$

$$S = 204514866.8 \frac{AT}{Wb}$$

Table 3.2: Reluctance claculation of present magnetic circuit

Reluctance calculations			
For core limbs			
reluctance	2 * a	AT/Wb	420169.0498
For back core			
reluctance	b	AT/Wb	101859.1636
Total reluctance of core (S1)	2*a+b	AT/Wb	522028.2133
Air gap reluctance (S2)	2 * c	AT/Wb	203718327.2
For flapper			
Reluctance (2*d)	2 * d	AT/Wb	27759.5831
Reluctance (e)	e	AT/Wb	246751.8498
Reluctance of flapper (2*d+e) (S3)	2*d+e	AT/Wb	274511.4329
Total reluctance of whole magnetic circuit	S1+S2+S3	AT/Wb	204514866.8

Table 3.3: Force Calculation

Force calculations		
Flux produced	AmpTurns / S	0.000005531
Flux density in Fixed Magnet	Wb / m^2	0.22124553
Flux density in Mov Magnet	Wb / m^2	0.535963008
Flux density in air gap	Wb / m^2	0.22124553
Force (N)	Newtons	0.486910519

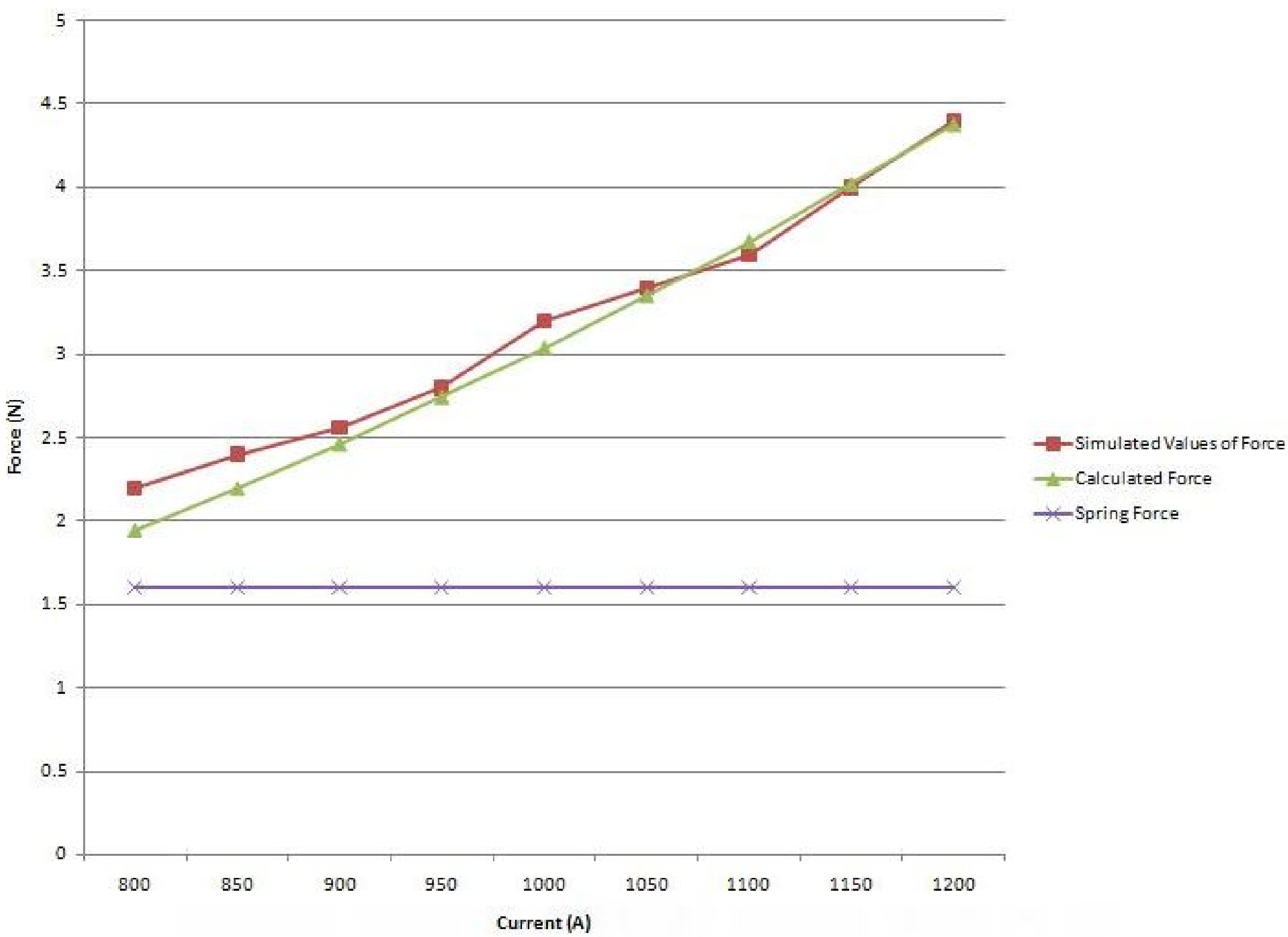

Figure 3.5: Force Comparision for present release

Table 3.4: Spring Data

Rates & Loads	
Spring Rate (or Spring constant), k :	0.8551 N/mm
Maximum load possible, Fmax :	3.0990 mm
Maximum load possible Considering Hook Stress, FmaxHS :	2.4705 N
Initial Tension, Tensioninit :	0.3517 N
Safe Travel	
Maximum Safe Travel, Travelmax :	3.2129 mm
Maximum Safe Travel Considering Hook Stress, TravelmaxHS :	2.4778 mm
Physical Dimensions	
Diameter of spring wire, d:	0.300 mm
Outer diameter of spring, Douter :	3.000 mm
Inner diameter of spring, Dinner :	2.400 mm
Mean diameter of spring, Dmean :	2.700 mm
Length Inside Hook (Free length) , Lfree :	9.200 mm
Number of active coils, na :	4.767
Body length, Lbody :	1.730 mm
Hook length 1:	4.150 mm
Hook length 2:	3.320 mm
Total Hook Length:	7.470 mm
Type of Hooks:	extended hooks
Spring index, C :	9
Material Type	
Material type:	Hard Drawn ASTM A227
Weights & Measures	
Weight of one spring, M :	0.0000 Kgs
Weight of one thousand springs, M :	0.0318 Kgs
Length of wire required to make one spring,Lwire :	56.0665 mm
Stress Factors	
Material shear modulus, G :	79,236,434,108.527 Pa
Maximum shear stress possible, tmax :	917.072 Pa
Wahl correction factor, W :	1.162

3.4 Summary

This chapter gives us the mathematical modelling of the present electromagnetic tripping mechanism and the finite element analysis of it, moreover it also gives us information about how the key parameters like spring force, air gap and the size of fixed magnet affect the electromagnetic pull force generated by the fixed magnet on the moving magnet.

Chapter 4

Proposed modification for magnetic release

The magnetic force can be varied by adjusting

1.) **Spring Force**: As the force exerted by the fixed magnet on the moving magnet is used against the spring force we can say that spring force is the main parameter which affects the magnetic threshold performance of MCCB. By modifing the spring we can change the force exerted by the fixed magnet on the moving magnet for the same amount of current. The present spring gives a spring force of 0.8N and there are two springs whics are connected with the tripplate so the total spring force provided by the springs is 1.6N. So when the magnetic pull generated by the current exceeds 1.6 N force the MCCB will trip. So to increase the magnetic threshold a modification was suggested such that the spring force generated by the spring will be **1 N** instead of **0.8 N** so that the current required to generate the magnetic pull will increase which will in order increase the magnetic threshold of the MCCB. Here the modification suggested depends on the active number of turns in the spring and the wire diameter. From theoretical calculation point of view increasing the spring force increases the magnetic threshold but here as the number of active coil increases and due to that the size of the spring also increases because of that the spring does not get fixed in the grove provided on the tripplate. Because of this reason during the practical testing of the MCCB the spring failed its operation several times and due to that the operating consistency of this modification was low as there was approximately **28%** failure of springs noticed during practical testing. So, this modification was not accepted.

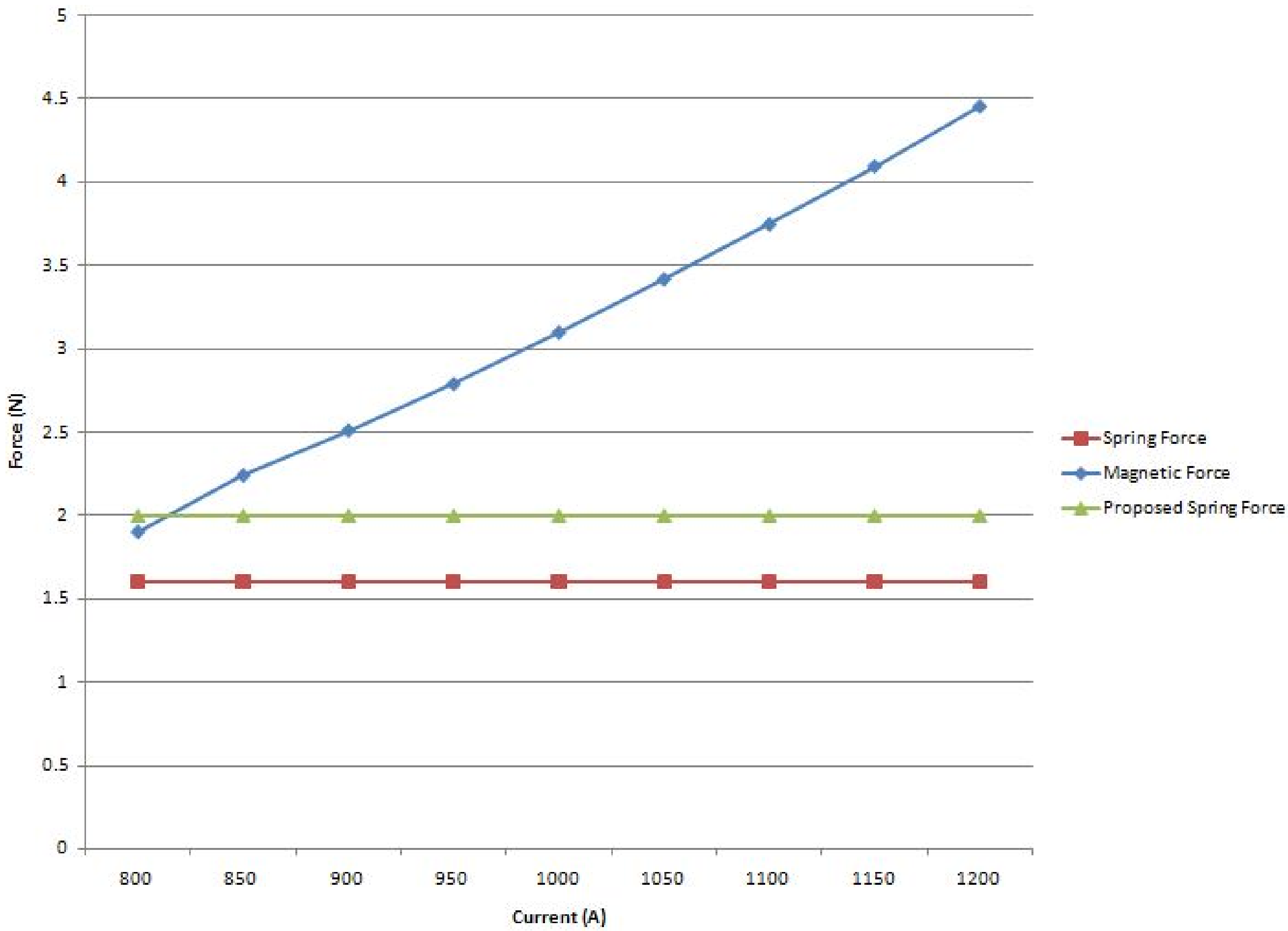

Figure 4.1: Spring Force Comparision

As it is easy to conclude from the graph that for the present spring design the magnetic force generated by 800 A current is very higher than the spring force, and for the modified spring the force generated by 800 A current is less than the spring force. So it is evident that by increasing the spring force the magnetic threshold of the MCCB can be increased.

Table 4.1: New Spring Data sheet

Rates & Loads	
Spring Rate (or Spring constant), k :	1.0277 N/mm
Maximum load possible, Fmax :	3.7471 mm
Maximum load possible Considering Hook Stress, FmaxHS :	2.9809 N
Initial Tension, Tensioninit :	0.4797 N
Safe Travel	
Maximum Safe Travel, Travelmax :	3.1793 mm
Maximum Safe Travel Considering Hook Stress, TravelmaxHS :	2.4338 mm
Physical Dimensions	
Diameter of spring wire, d:	0.320 mm
Outer diameter of spring, Douter :	3.000 mm
Inner diameter of spring, Dinner :	2.360 mm
Mean diameter of spring, Dmean :	2.680 mm
Length Inside Hook (Free length) , Lfree :	9.200 mm
Number of active coils, na :	5.25
Body length, Lbody :	2.000 mm
Hook length 1:	4.100 mm
Hook length 2:	3.100 mm
Total Hook Length:	7.200 mm
Type of Hooks:	extended hooks
Spring index, C :	8.375
Material Type	
Material type:	Hard Drawn ASTM A227
Weights & Measures	
Weight of one spring, M :	0.0000 Kgs
Weight of one thousand springs, M :	0.0384 Kgs
Length of wire required to make one spring,Lwire :	59.5059 mm
Stress Factors	
Material shear modulus, G :	79,236,434,108.527 Pa
Maximum shear stress possible, tmax :	917.072 Pa
Wahl correction factor, W :	1.175

2.) **Area of Cross Section**: The main parameter which affects the force exerted by fixed magnet on moving magnet is reluctance. The reluctance is inversely proportional to the area of cross section. If the area of cross section is changed then the reluctance will also change and in turn it will change the force exerted on the moving magnet by the fixed magnet. But there are some constraints which do not allow the implementation of this modification. As seen from the theoretical modelling for the electromagnetic tripping mechanism the area of cross section needs to be decresed to increase the magnetic threshold of the release. Now as seen from the given data sheet for the changing the area of cross section a change in height of fixed magnet is required. But in practise if a change in height is implemented than fixing the fixed magnet on the terminal connector becomes a problem as the height of the fixed magnet is reduced it gets deformed at the time of fixing it to the terminal connector. So this modification was not implemented due to the fixing issues of the fixed magnet. The calculation for the fixed magnet with less height is as provided.

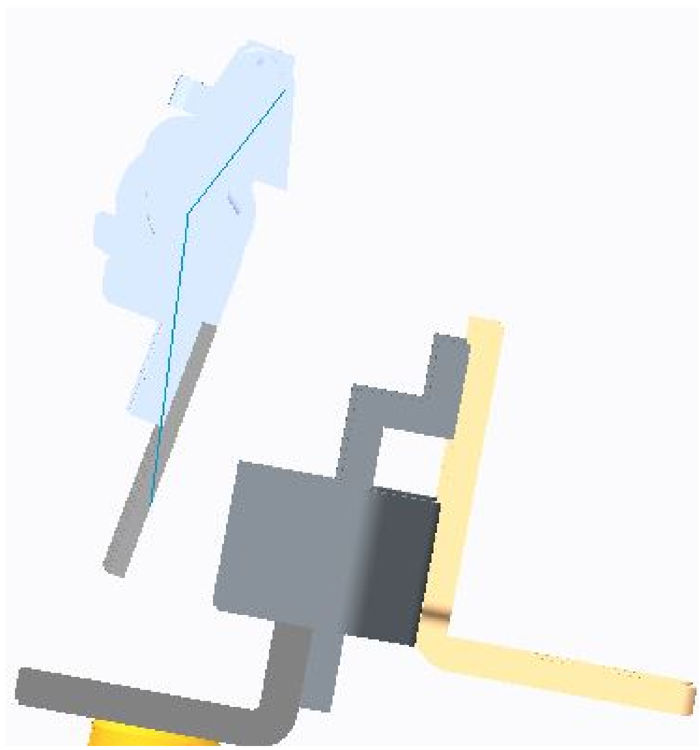

Figure 4.2: Modification in area of fixed magnet

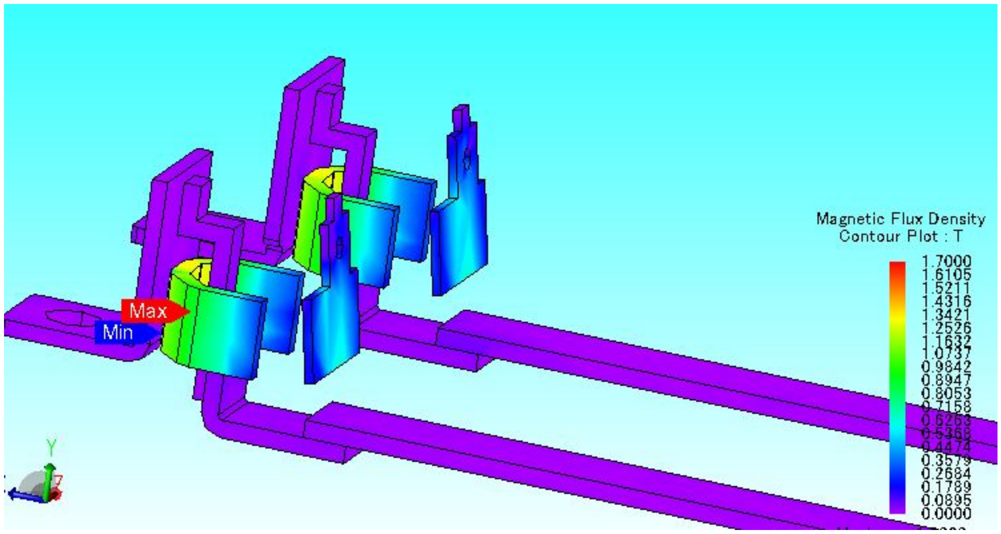

Figure 4.3: Magneic Flux Density in modifies release

From the above image it is evident that the flux which links with the armature decreases as the height of the yoke is reduced so beacuse of that the current required to generate the same flux density increases therefore the magnetic threshold limit of MCCB increases.

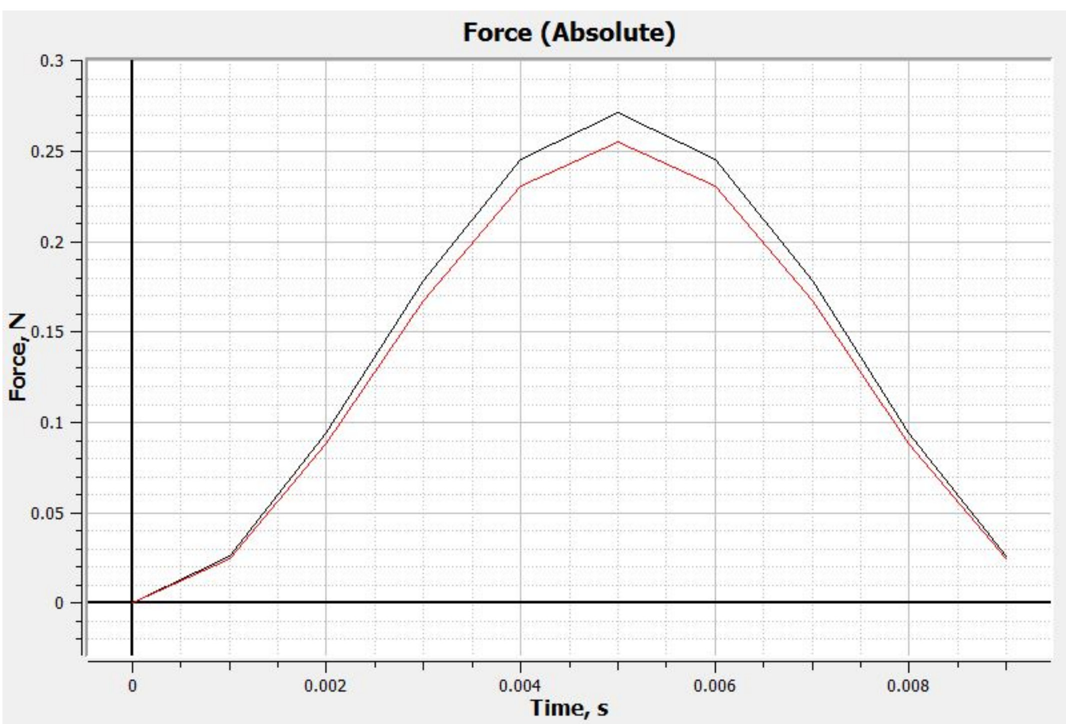

Figure 4.4: Magnetic force in FEM software for change in area

Table 4.2: Force Claculation for change in area

Dimensions of Fixed Magnet			
height of core	h	mm	9
relative permeability			2000
for one limb			
mean length	a	mm	14.2
width	f	mm	2
area of cross section		mm^2	18
Back portion of core			
mean length	b	mm	6.4
width	f	mm	2
area of cross section		mm^2	18
Air gap dimensions			
mean length	c	mm	3.4
area of cross section		mm^2	18
permeability in free space		henry / metre	1.25664E-06
Moving Magnet			
thickness of Moving Magnet		mm	1.2
height of Moving Magnet		mm	8.6
relative permeability			2000
mean length	d	mm	0.6
area of cross section		mm^2	17.2
mean length	e	mm	6.4
area of cross section		mm^2	10.32
Reluctance calculations			
For core limbs			
reluctance	2 * a	AT/Wb	583568.1247
For back core			
reluctance	b	AT/Wb	141471.0605
Total reluctance of core (S1)	2*a+b	AT/Wb	725039.1852
Air gap reluctance (S2)	2 * c	AT/Wb	300626003.6
For flapper			
Reluctance (2*d)	2 * d	AT/Wb	27759.5831
Reluctance (e)	e	AT/Wb	246751.8498
Reluctance of flapper (2*d+e) (S3)	2*d+e	AT/Wb	274511.4329
Total reluctance of whole magnetic circuit	S1+S2+S3	AT/Wb	301625554.2
Force calculations			
Flux produced		AmpTurns / S	0.000003750
Flux density in Fixed Magnet		Wb / m^2	0.20835252
Flux density in Mov Magnet		Wb / m^2	0.363405559
Flux density in air gap		Wb / m^2	0.20835252
Force (N)		Newtons	0.310906758

3.) **Air gap**: As from calculation it is revealed that the main parameter which affects the force is reluctance and from the calculation it is also seen that the reluctance which affects the most is the air gap reluctance. So by increasing the length of the air gap we can change the force exerted by the fixed magnet on the moving magnet. Here this is the most suitable way to change the electromagnetic force because the fixed magnet assembly used for the short circuit protection MCCB of the motor is different than the other MCCB of the same frame. So due to this reason the direction chosen for the increase in magnetic threshold was to change the length of the air gap. Here to use this change in air gap we have to either change the length of the fixed magnet or the length of the moving magnet. By this modification we can increase the magnetic threshold of the motor short circuit protection MCCB without affecting very much the economical constraint. The results of this modification are very promising according to the theoretical calculation and according to the FEM analysis software JMAG. The prototypes for this modification are developed and validated.

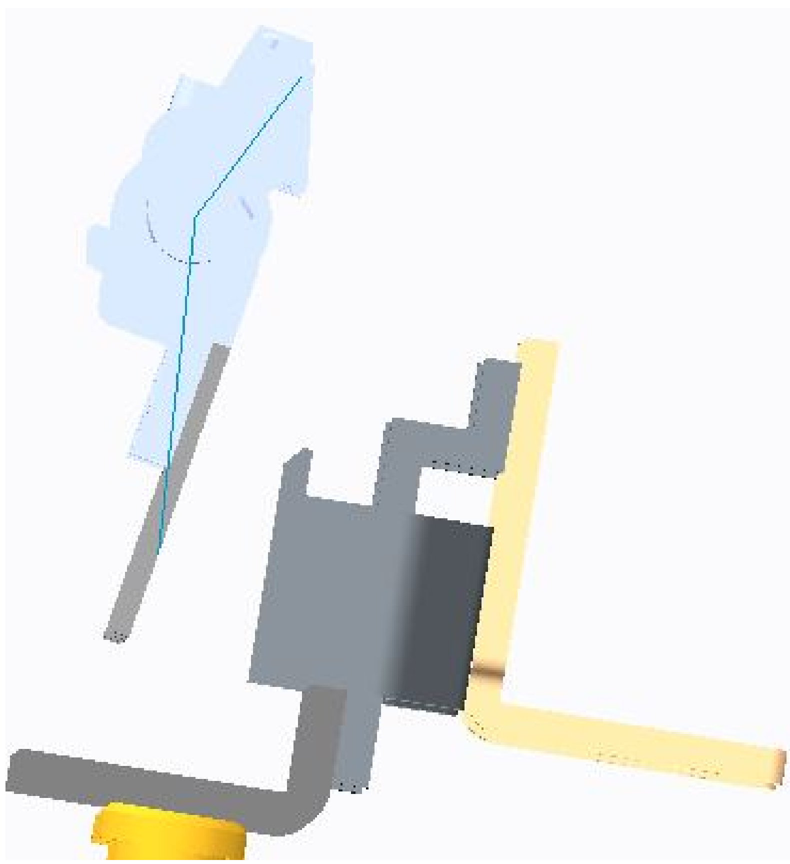

Figure 4.5: electromagnetic tripping mechanism with increased length of air gap

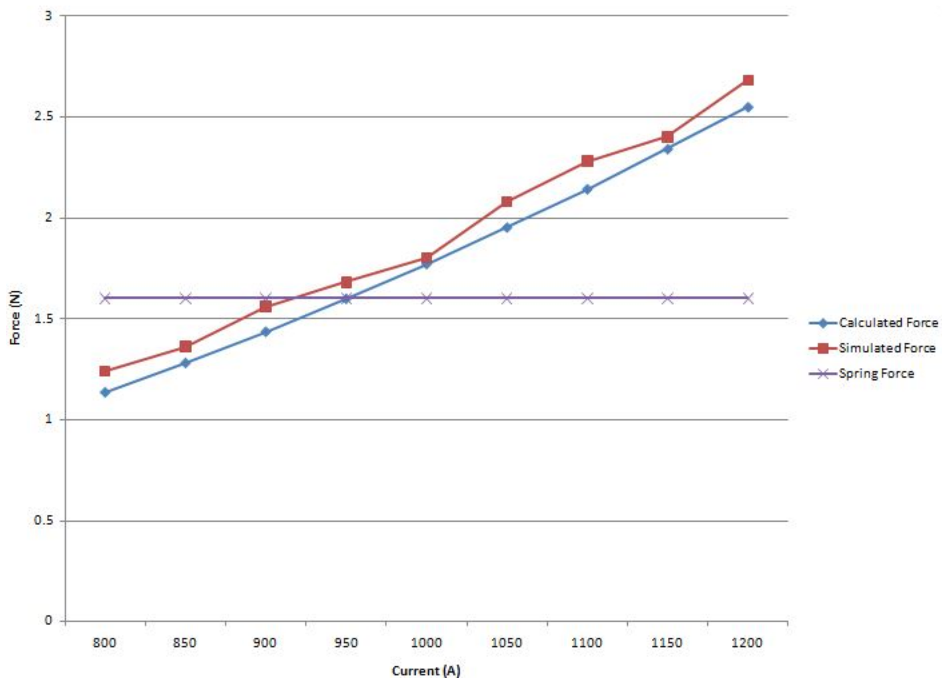

Figure 4.6: Force comparision for release with extended length of air gap

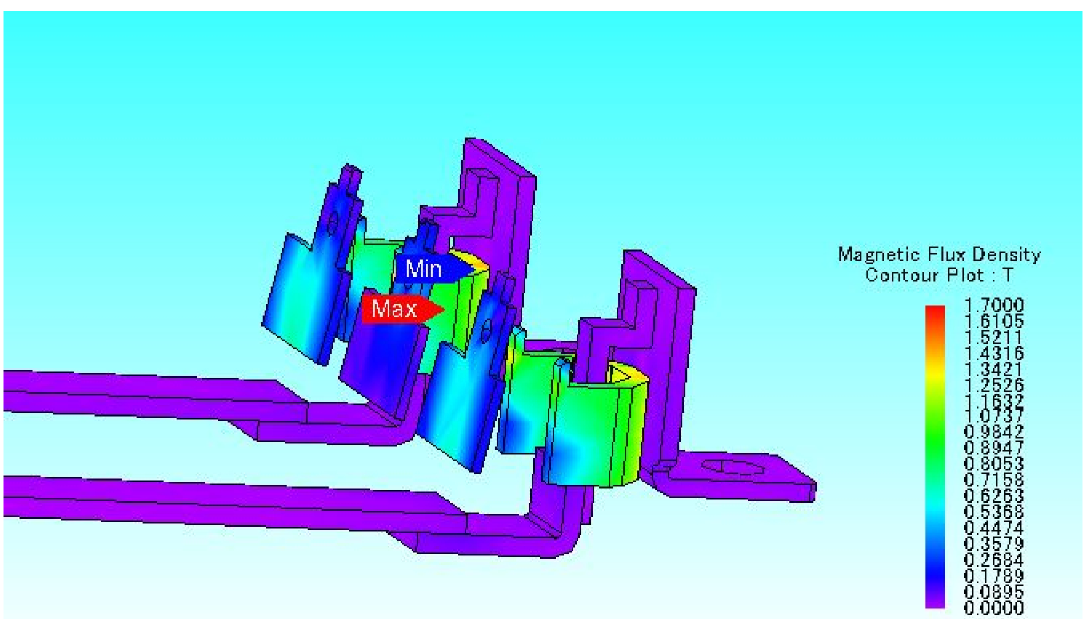

Figure 4.7: Magneti Flux Density of electromagnetic tripping mechanism with increased length of air gap

From the FEM analysis it is evident that as the length of air gap increases the effective or total reluctance of the magnetic circuit increases and due to that the flux linkage with the

Table 4.3: Force Calculation for change in air gap

Dimensions of Fixed Magnet			
height of core	h	mm	12.5
relative permeability			2000
for one limb			
mean length	a	mm	13.2
width	f	mm	2
area of cross section		mm^2	25
Back portion of core			
mean length	b	mm	6.4
width	f	mm	2
area of cross section		mm^2	25
Air gap dimensions			
mean length	c	mm	4.2
area of cross section		mm^2	25
permeability in free space		henry / metre	1.25664E-06
Moving Magnet			
thickness of Moving Magnet		mm	1.2
height of Moving Magnet		mm	8.6
relative permeability			2000
mean length	d	mm	0.6
area of cross section		mm^2	17.2
mean length	e	mm	6.4
area of cross section		mm^2	10.32
Reluctance calculations			
For core limbs			
reluctance	2 * a	AT/Wb	420169.0498
For back core			
reluctance	b	AT/Wb	101859.1636
Total reluctance of core (S1)	2*a+b	AT/Wb	522028.2133
Air gap reluctance (S2)	2 * c	AT/Wb	267380304.4
For flapper			
Reluctance (2*d)	2 * d	AT/Wb	27759.5831
Reluctance (e)	e	AT/Wb	246751.8498
Reluctance of flapper (2*d+e) (S3)	2*d+e	AT/Wb	274511.4329
Total reluctance of whole magnetic circuit	S1+S2+S3	AT/Wb	268176844
Force calculations			
Flux produced		AmpTurns / S	0.000004218
Flux density in Fixed Magnet		Wb / m^2	0.168724485
Flux density in Mov Magnet		Wb / m^2	0.408731796
Flux density in air gap		Wb / m^2	0.168724485
Force (N)		Newtons	0.283175955

yoke decreases which indicate that a higher amount of current is required to generate the same flux density or to generate the same magnetic force. Hence the value of the magnetic threshold is increased.

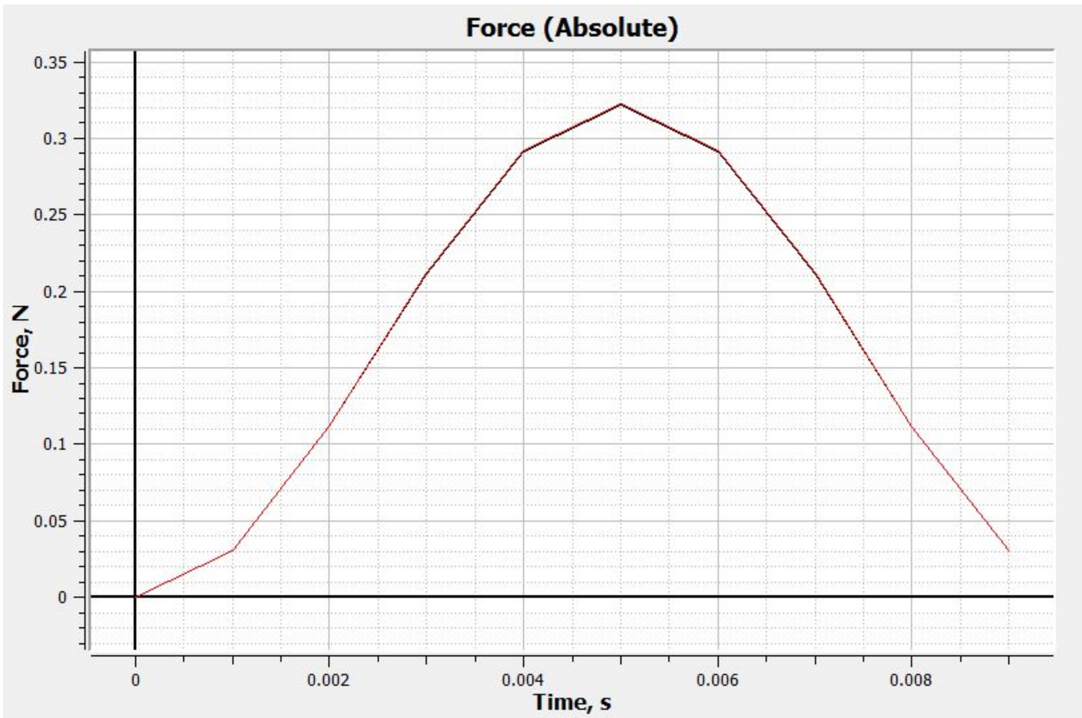

Figure 4.8: Magnetic Force in FEM for extended length of air gap

4.1 Relative comparision of present and modified electromagnetic tripping mechanism

Table 4.4: Relative Comparision for modification

Parameters	**Present design**	**Modified airgap**	**Modified area**	**Modified spring force**
Length of air gap (mm)	3.2	4.2	3.4	3.2
Area of fixed magnet (mm^2)	25	25	18	25
Total Reluctance (Wb)	204514866	268176844	301625554	204514866
Spring Force (N)	1.6	1.6	1.6	2
N.T. current (Theo.) (A)	720	900	850	850
N.T. current(Sim.) (A)	700	900	830	850
N.T. current(Prac.) (A)	750	885	Not Possible	835

4.2 Summary

This chapter comprises of the analysis of the applied modifications to the electromagentic tripping mechanism and how it affects the magnetic pull force generated by it. This chapter also comprises of the relative comparision between present and modified electromagnetic tripping mechanism.

Chapter 5

Practical Testing and Validation

The main purpose of the motor short circuit protection MCCB is to get tripped during any kind of short circuit condition. So to test the magnetic threshold of the MCCB it is required to apply a short circuit condition to the MCCB and to check the value of the "Non-Trip" value of the current. Here the test is Two Pole in Series Test. In this test a short circuit condition is created by connecting the two poles of MCCB in series and applying the current source to one pole. Here the duration of the test is 200ms. So if the MCCB does not trip for 200ms for a particular current value it is known as "Non-Trip" value for that MCCB.

The testing for both the modification were done for 10 MCCBs for the validation process. It should be noted that during the practical testing it was found that for the modification in spring force the failure rate was as high as 28% so this modification was not validated due to its higher failure.

For the modification in air gap the failure rate is very less and as the failure rate is less this modification was validated and this modification was accepted for the implementation for the increase in magnetic threshold from $9 * I_n$to $10 * I_n$.

Here the two pole in series test is done for two practically feasible modifications for ten no. of breakers and the graph shows the number of failures for the ten no. of breakers for ten no. of operations.

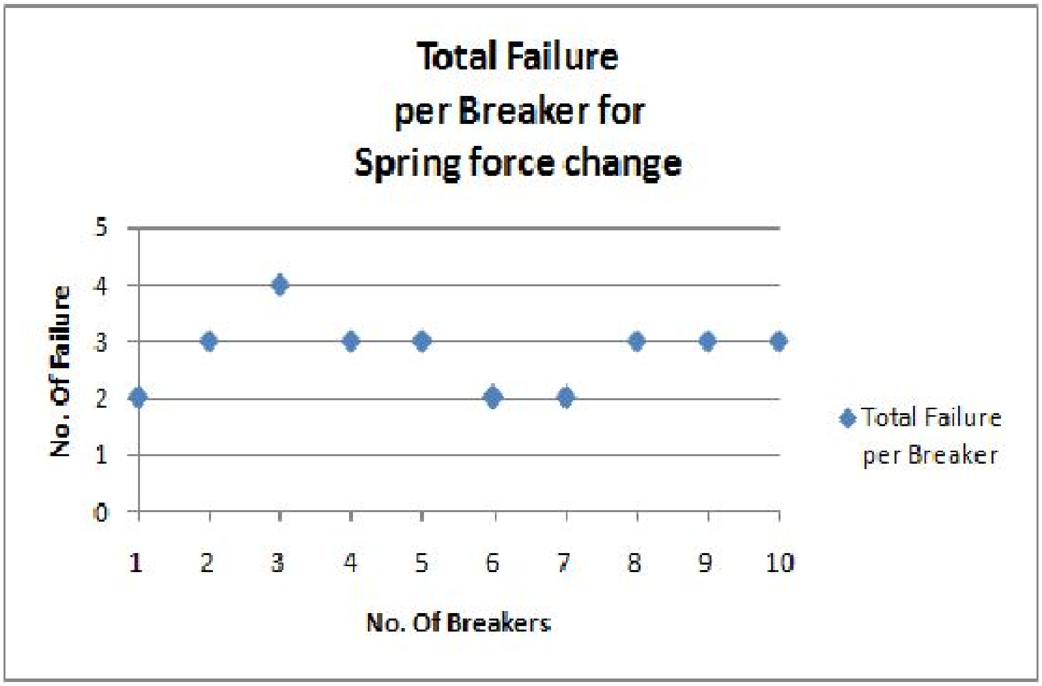

Figure 5.1: Total Failure per Breaker for Spring Force Change

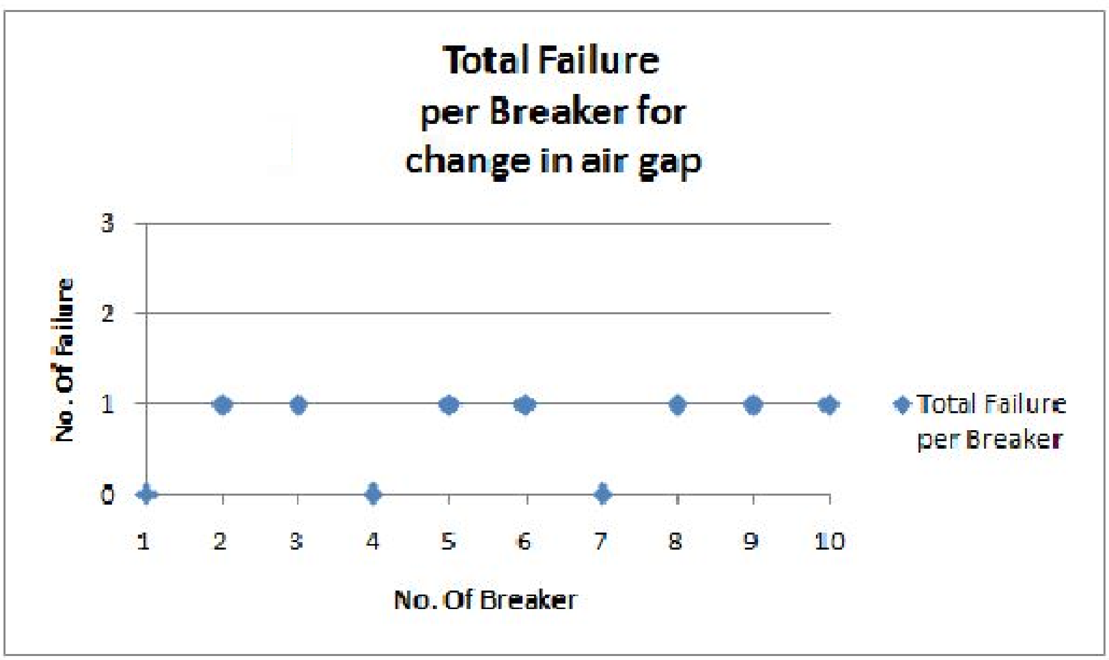

Figure 5.2: Total Failure per Breaker for Air gap change

Chapter 6

Conclusion

The problem with the present design is the present magnetic threshold of the release cannot provide adequate co-ordination with the overload relay. After the detailed analysis of the electromagnetic tripping mechanism using FEM software - JMAG and theoretical model, the key parameters were identified such as air gap, size of fix magnet, size of moving magnet spring force, saturation etc. By the detailed study of various selected parameters and constraints in design using FEM software and theoretical model, new modification in design were developed. There are two acceptable modifications for practical testing based on study carried out. The practical tests are performed on number of breakers to get the number of failure. The number of failure is less in the proposed modification in design with change in air gap length and the magnetic threshold limit is increased from the present value to the required value in this proposed modification which is accepted and validated.

Bibliography

[1] Paul Alwin, *"Short circuit protection on motor starters – IEC type-2 co-ordination"*,IEEE transaction paper on industry application January/February-1993.

[2] Lorraine K. Padden, *"Testing and applying instantaneous trip circuit breaker in combination motor starters"*, IEEE copyright material paper no. PCIC-98-05.

[3] Frank W. Kussy et al., *"Total Motor Branch Circuit Protection with Instantaneous Trip Type Circuit Breakers and High Fault Circuit Protectors"*, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. IA-1l, NO. 4, JULY/AUGUST 1975.

[4] James Wilson et al., *"Application of Motor Control Centers with Moulded-Case Circuit Breakers in Systems with High Fault Capability"*, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. IA-10, NO. 1, JANUARY/FEBRUARY 1974.

[5] George D. Gregory, *"Short circuit rating an application guidelines for moled case circuit breaker"*, IEEE transactions on industry application, Vol 35 , No 1 , January/February 1999.

[6] Weixiong Tong et al., *"Dynamic Simulation of Operating Mechanism for Moulded Case Circuit Breaker"*, IEEE transactions on power delivery Vol no 25 no. 1 january 2007

[7] National Electrical Code 1990, Article 110

[8] "Industrial control equipment" UL test standard 508, UL publications , Northbrook Illinois.