Dynamic Analysis of Spring Operated Drive Mechanism in Circuit Breaker

By

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09MME001

DEPARTMENT OF MECHANICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

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Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Mechanical Engineering (CAD/CAM)

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Declaration

This is to certify that

i The thesis comprises my original work towards the degree of Master of Technology in CAD/CAM at Nirma University and has not been submitted elsewhere for a degree.

ii Due acknowledgement has been made in the text to all other material used.

Bhatt Priyank V.

Certificate

This is to certify that the Major Project entitled "**Dynamic Analysis of Spring Operated Drive Mechanism in Circuit breaker**" submitted by **Bhatt Priyank V. (09MME001)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (CAD/CAM) of Nirma University of Science and Technology, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

In any power system, Circuit breaker is used to operate any electrical equipment in, on load condition as well as in case of severe short circuit faults, which require handling of large mechanical stresses. Hence, the drive used to operate the Circuit breaker shall have sufficient energy to overcome the said stresses and open or close the circuit breaker in reliable manner maintaining adequate operating times (opening and closing) within permissible limits.

The objective of this dissertation is primarily to study the dynamic behavior of the drive used to operate the Circuit breaker during opening and closing operations. The analysis of dynamic stresses imposed on different component of the drive during closing and opening operations is performed using Multi-body Dynamics (MD) software-ADAMS. As outcome of above study it is possible to reduce (4.8 %) the opening time of circuit breaker by changing the preload condition of opening spring of the drive, maintaining other requirement as per applicable standards.

Keywords: circuit breaker , short circuit, dynamic

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Chapter 1

Introduction

1.1 Preliminary Remark [1]

A circuit breaker shown in Figure[1.1] is an apparatus in electrical systems that has the capability to, in the shortest possible time, switch from being an ideal conductor to an ideal insulator and vice versa. It is a crucial component in the substation, where it is used for coupling of bus bars, transformer, transmission line, etc. The most important task of a circuit breaker is to interrupt fault currents and thus protect electric and electronic equipment. The interruption and the subsequent reconnection should be carried out in such a way that normal operation of the network is quickly restored, in order to maintain system stability. For maintenance or repair of electrical equipment and transmission lines, the circuit breakers together with the disconnectors, earthing switches will ensure personnel safety.

It can be manually opened and closed, as well as automatically opened to protect conductor or equipment from damage caused by excessive temperature from over current in the event of short circuit. For that important consideration to above said event is the breaking and making time which is customarily design for few milliseconds to avoid prolonged arcing and pre-arcing time that overheats and thus melting moving and fixed contacts.

Figure 1.1: 72.5 kV Circuit Breaker with drive [1]

Breaker is operated by spring operated mechanism which supplies required mechanical energy to it. Drive is a heart of the circuit breaker. If it fails, breaker could not perform its intended function and even if delaying to provide energy within few milliseconds breaker fails to perform its intended function. Thats why drive have to be precise to give adequate energy at all time through its life cycle.

1.2 Objective

Objective of this project is

- To study dynamic behavior of the drive.
- To investigate dynamic loading experience on drive components during operating condition.
- To find sensitivity of opening spring with respect to initial condition.

1.3 Motivation

From past few years, demand of power increases exponentially so proper and safe distribution of power demand of distribution and protection equipment also increases. Circuit breaker is switching device used for protection of electric equipment whenever fault occurs in supply line. Reliability of breaker depends on circuit breaker drive which provide sufficient energy to operate it. If drive fails to perform its intended function, over current will damage electric equipments and breaker. Energy should be sufficient to operate it in millisecond therefore drive components experience high stress during operating cycles and also Spring operated mechanism drive was developed 30 years back so consistent operation of drive dynamic analysis need to be carried out for further improvement.

1.4 Lay-up of the report

The lay-up of this report is as follows:

- Second chapter covers literature review in that give brief idea about various research have been done in the field of dynamics.
- Third chapter includes breaker standard and various factor which should consider while designing drive.
- Fourth chapter contains basic input needed for simulation, simulation results and validation with experiment results.
- Fifth chapter consists flexible analysis of drive components during operation and it includes stress and strain history over a period of time.
- Sixth chapter covers Conclusion and Future scope.
- References.

Chapter 2

Literature Review

2.1 Spring operated drive [1]

Spring operated drive shown in Figure[1.2] is spring operated mechanism which pumps energy to breaker. It is high speed actuating mechanism that provide energy to perform closing operation in 52 $\pm$5 millisecond and opening operation in 29 $\pm$4 millisecond. During closing and opening operation drive has to accelerate and in the end of operation absorb energy. For such high speed activation and rapid breaking of a circuit breaker demands that member of the operating mechanism be tough, durable and safe to withstand incoming power supply so that in situation of system breakdown, they function as required.

2.1.1 Design features

The operating mechanism consists primary of two tension springs. The closing spring generate the required driving force to close the circuit breaker and charge the opening spring. The opening spring is directly connected to the circuit breakers link system. This means that the mechanical energy needed for the vital opening operation is always stored in the opening spring when the circuit breaker is in closed position. In other words, a closed circuit breaker is always prepared for immediate opening.

Universal motor drives the spring charging gear, which automatically charges the closing spring immediately after each closing operation. The springs are kept in charged state by a latch that is released when the circuit breaker is being closed. This enables rapid reclosing of the circuit breaker after a dead time interval of 0.3 second.

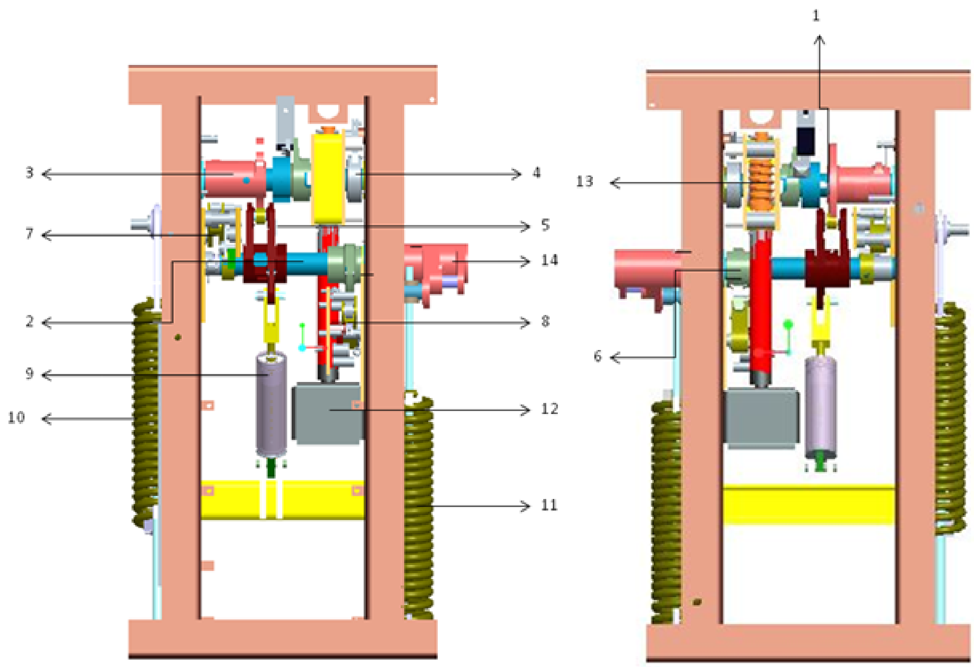

Figure 2.1: Spring operated drive

1 Motor shaft	8 Tripping latch
2 Output shaft	9 Hydraulic damper
3 Cam	10 Closing spring
4 Stop lock disc	11 Tripping spring
5 Transmission lever	12 Gear Box
6 Retention lever	13 Worm gear box
7 Closing latch	14 Output lever

Table 2.1: Spring operated drive component list

The spring-type operating mechanism of a circuit breaker when open and close, relies spring force stored in the closing and the tripping springs respectively, to drive the mechanism at specific times and in the required motions. Each spring act on a designated input link, which rotates and initiates the entire sequence. This differs from regular mechanisms where a constant speed motor is generally used as the driving source. Therefore, an area worth researching is the response time of a spring-type operating mechanism, that is the relationship between motion and time of the two operations. Pro-E model of drive shown in Figure[1.2] and its individual component listed in Table 2.1.

2.1.2 Operating mechanism of Spring operated drive

Spring operated mechanism consists of two operation i.e. close and open the circuit breaker is shown in Figure[1.3]. Working of this operation is discussed as follow:

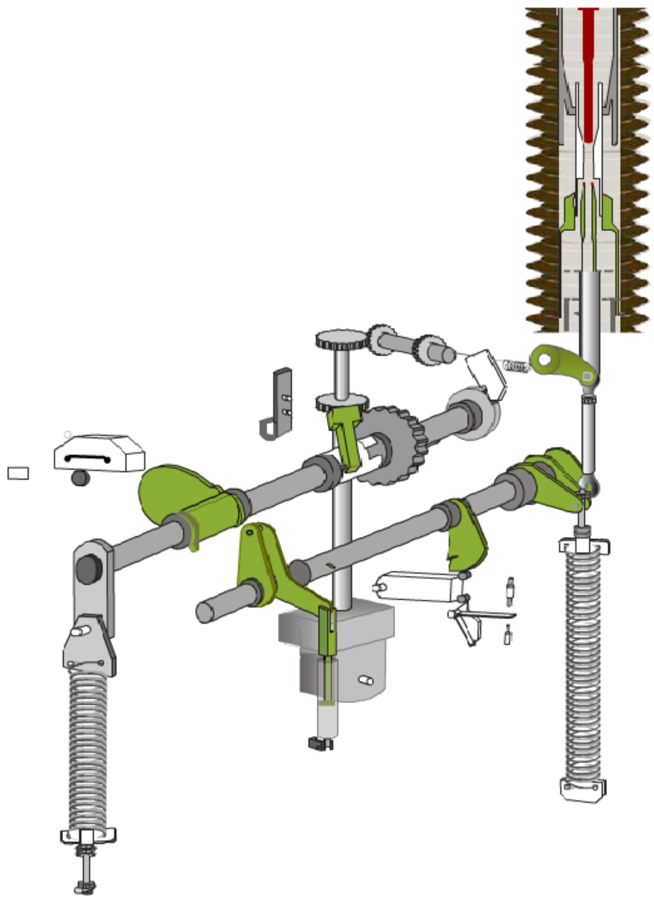

Figure 2.2: Spring operated drive mechanism

Closing operation: When the circuit breaker is being closed, the closing latch is released from the main shaft and the closing spring trips. This means that the cam disc rotates via the closing lever. The switching shaft is put in motion and the circuit breaker closes, at the same time as the trip spring in turn is charged and locked. The motor then charges the closing spring following each closing operation, via the main shaft and worm gear. When the spring is then charged, the circuit is interrupted by the limit switch.

Opening operation: When the signal indicating that the circuit breaker shall open is received, the tripping latch device releases from the switching shaft and the trip spring hereby opens the circuit breaker. A damping device is included to retard the motion of the contact system in the end position at opening. The auxiliary equipment is characterized by the following:

- Robust auxiliary contacts and limit switches.
- Mechanical indication of charged or discharged closing spring.
- All electrical wiring used for external connections is brought to terminal blocks.

Interlocking against unintentional operation: is achieved partly electrically and partly mechanically. Electrical interlocking is achieved by having the circuits of the operation coils connected through the auxiliary contacts of the operating mechanism. In addition, the closing coil is connected through a limit switch that is controlled by the position of the spring. In this way the closing circuit is only closed when the breaker is in the open position and the closing springs are fully charged.
Based on the above interlocking design, the following operations are not possible when in service:

- Closing operation when the breaker is already closed (i.e. a ”blind” stroke).
- Closing operation during an opening operation.

2.2 Multi-body dynamic system [2]

Mechanical part can be often modeled as a set of rigid bodies connected by joints so called multi-body system (MBS). The dynamics of MBS is described by equations of motion, mathematically expressed as system of nonlinear ordinary differential equations (ODE). The effective derivation of equation of motion for spatial mechanical system is still a challenging issue in scientific community. The practical problem of dynamics modeling can be solved using two basic approaches:

Manual approach should derive equations of motion using pen and paper. There are two main well known methods: the Lagrange equations of the second kind and the Newton approach. The appropriate CAS (Computer algebra software) such as Maple, MathCAD and Mathematica can be used for the symbolic manipulations and so for reduction of manual work. But still, the derivation of equations for more complex system is challenging.

Automatically derivation of equations -based on Lagrange or Newton methods mentioned above is algorithmized and implemented in so-called multibody dynamics formalism. The user specifies the geometry and topology (bodies, joints) of the system and algorithm prepare the mathematical model.

In MBS two kinds problem one can approach i.e. Kinematic and Dynamic problem. In kinematic simulation, all the degrees of freedom were controlled kinematically; that is, the motion of as many input elements as degrees of freedom is known. There are as many additional kinematic or driving constraint equations such as known angles and known distances, as degrees of freedom. Dynamic problem consists of determining the motion of a multi-body system that results from the application of the external forces and/or the kinematically controlled or driven degrees of freedom. In dynamic, it is necessary that the number of unknown dependent variables be greater than the total number of independent geometric and driving constraint equations. As a result, the motion of the multi-body system cannot be unequivocally defined by the geometric, driving constraint equations, by the known motion of points and vectors only. In order to determine the motion of the entire system, it is necessary to establish the dynamic equilibrium condition that leads to a system of second order differential equations generally called the equations of motion (EOM).

Several methods are available for formulization of EOM i.e Lagrange's equations, virtual power method, Newtonian method etc. It has second order differential equation which has to solve by various numerical methods. This are the basic methods are used by dynamic analysis software.

Adams is the most widely used multibody dynamics and motion analysis software. It helps engineers to study the dynamics of moving parts, how loads and forces are distributed throughout mechanical systems, and to improve and optimize the performance of their products.

2.3 Circuit breaker and drive

Fu-Chen Chen[5] has analyzed dynamic response of circuit breaker having very complicated mechanism that operate in 10 millisecond. The author has modeled circuit breaker in ADAMS to optimize, simulate and analyze a mechanism. He incorporated breaking time as an objective function non-linear equality function of mechanism motion, link stress and energy.

Performance of the circuit breaker depends on the spring operating mechanism. The spring, especially closing spring, stores the deformation energy due to the compression and then accelerates the big loads rapidly in the circuit breaker. To accurately carry out the kinematic and dynamic analysis of the circuit breaker, **Jeong-Hyun SOHN**[6] modeled the spring behavior in static and in dynamic condition. The effect of stiffness on the performance is derived.

Gil Young Ahn and Kwang Young Jeong[7] worked on optimization of spring parameter in Vacuum circuit breaker. The author has modeled, optimize spring parameter and also derived optimum speed for moving contact.

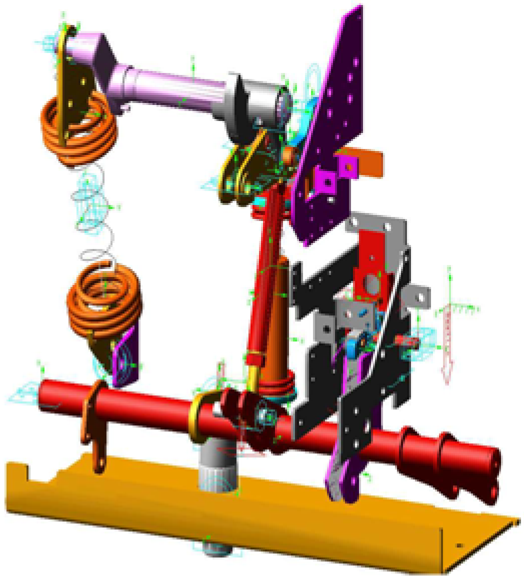

Figure 2.3: Medium voltage circuit breaker

Several research works have been carried out for evaluating dynamic characteristic of circuit breaker which is base for this current work. **C. Niu, J. Zhang and D. Chen**[8] investigated dynamics of low-voltage moulded-case circuit breaker operating mechanism using the multibody software package ADAMS. For that dynamics behavior has been investigated and results compared with experiments for improve the response time.

LIU Wei[9] worked on hydraulic operated circuit breaker drive. The author investigated factors to effect on existing breaker drive to develops new drive and studied feasibility of propose drive. **Tao Liu and Zhiying Ma**[10] worked on vacuum circuit breaker(VCB) drive to derived optimum time travel curve. The author has captured dynamic of drive and studied influence of location of port in damper during opening operation.

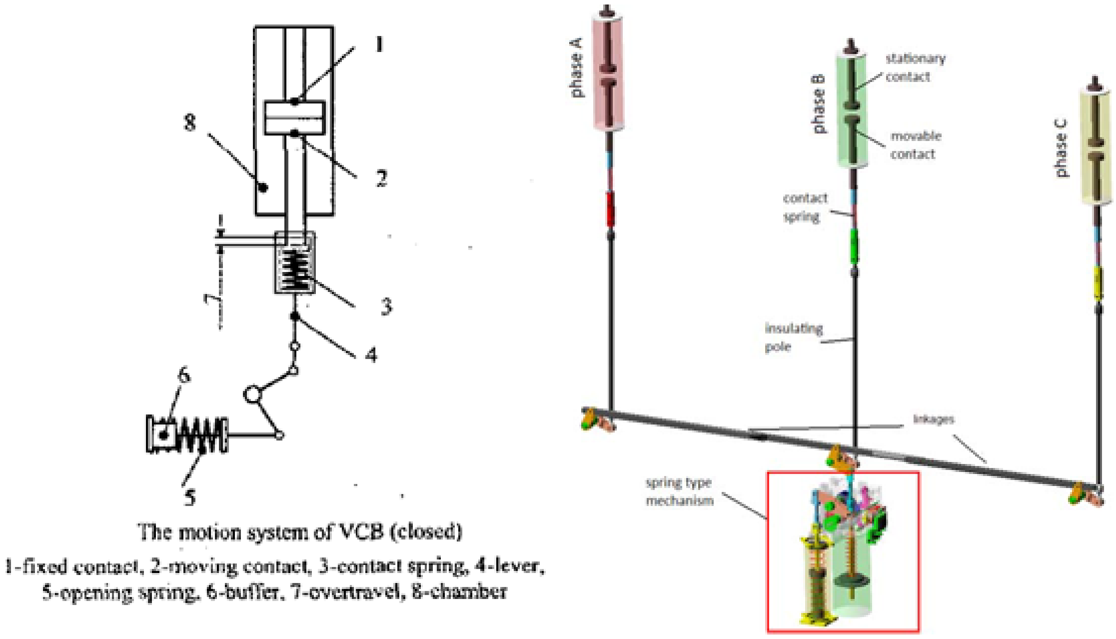

Figure 2.4: VCB schematic diagram and VCB model in ADAMS [4]

Similar work carried out by **Li Yu, Yingsan Geng, Zhiyuan Liu, Liqiong Sun and Jianjun Yao**[4] on VCB but in this literature includes parameter influence the moving part (time travel curve characteristic) i.e damper, cam profile and spring stiffness and preload are investigated during closing and opening operation.

2.4 Flexible analysis

In the past Finite Element Analysis (FEA) and Multibody System Simulation (MBS) were two isolated approaches in the field of mechanical system simulation. While multibody analysis codes focused on the nonlinear dynamics of entire systems of interconnected rigid bodies, FEA solvers were used to investigate the elastic/plastic behavior of single deformable components. In recent years different software products e.g. ADAMS/Flex have come into the market that utilize sub-structuring techniques to combine the benefits of both FEA and MBS.

The aim of the multibody simulation is to get results closer to reality, not only consisting of rigid bodies, but also representing their flexible behavior under the occurring loads. This was achieved by a modal representation of the flexibility of the bodies calculated by FEM analysis. This was not only an improvement for the MBS simulation, but also for the FEM simulation. These so called hybrid multibody systems made it possible, to determine loads on flexible components for FEM analysis to a very high accuracy.

Another benefit of the combination of FEM and MBS simulation is the possibility, to use FEM-based structural optimization using calculated loads of a MBS simulation and reimport the improved FEM model to investigate the influences of the changes to the component on the whole system and the arising loads for the component itself. It is of growing importance to consider these effects, especially for dynamic systems, where the components loads are influenced by its inertia.

Jingjun Zhang, Jitao Zhong, Ruizhen Gao and Lili[11] have carried out modal analysis of cable-stayed space truss by considering flexible body in ADAMS. They have considered the effect of flexible bodies to improve the simulation precision greatly and ANSYS can create the flexible body conveniently. Meanwhile, the analysis results of ADAMS can also provide complicated boundary conditions for ANSYS. Therefore, through the interface between ANSYS and ADAMS, the effect of flexible bodies can be taken into account easily and results of stress analysis base on the accurate dynamic analysis will be obtained. This literature helps to carried out flexible analysis in current work.

Chapter 3

Performance parameter of the drive

3.1 IEC 62271-100 High-voltage alternating-current circuit-breakers standard [3]

This International Standard is applicable to a.c. circuit-breakers designed for indoor or outdoor installation and for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1000V. It is only applicable to three-pole circuit-breakers for use in three-phase systems and single-pole circuit-breakers for use in single-phase systems. Two-pole circuit-breakers for use in single-phase systems and application at frequencies lower than 50 Hz are subject to agreement between manufacturer and user. This standard is also applicable to the operating devices of circuit-breakers and to their auxiliary equipment.

This standard covers basic technical terminology related to breaker, design criteria taken into consideration during designing stages, types of test carried out for reliable operation, provide guideline for selection of CB for best suited for service condition, as well as guideline operation and maintenance of breaker.

3.2 Terminology regarding Time travel curve of Circuit breaker

A useful section of IEC 62271-100 describes the circuit-breaker-related time definitions. The most frequently-used time definitions are define and explain in Figure[3.1] and [3.2].

Closing time is the interval of time between energizing the closing circuit, the circuit-breaker being in the open position, and the instant when the contacts touch in all poles.
Make time is the interval of time between energizing the closing circuit, the circuit-breaker being in the open position, and the instant when the current begins to flow in the first pole.
Pre-arcing time is the interval of time between the initiation of current flow in the first pole during a closing operation and the instant when the contacts touch in all poles for three-phase conditions and the instant when the contacts touch in the arcing pole for single-phase conditions.
Opening time is the interval of time between the instant of energizing the opening release, the circuit-breaker being in the closed position, and the instant when the arcing contacts have separated in all poles.
Break time is the interval of time between the beginning of the opening time of a mechanical switching device and the end of the arcing time.
pre-arcing time is the interval of time between the initiation of current flow in the first pole during a closing operation and the instant when the contacts touch in all poles for three-phase conditions and the instant when the contacts touch in the arcing pole for single-phase conditions.

Closing operation

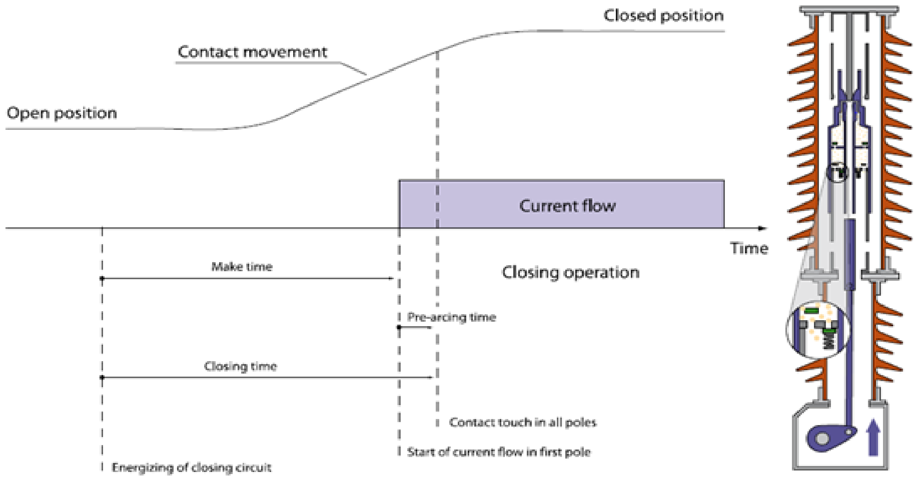

Figure 3.1: Closing operation time travel curve of Circuit breaker [1]

Opening operation

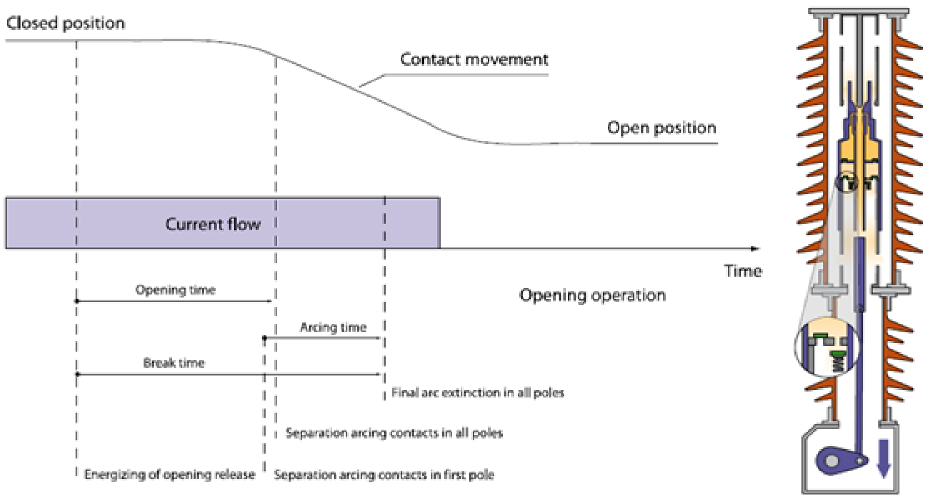

Figure 3.2: Opening operation time travel curve of Circuit breaker [1]

3.3 Mechanical Test [1]

In the beginning of the type tests, the mechanical travel characteristics of the circuit-breaker shall be established, for example, by recording no-load travel curves. These curves will serve as the reference mechanical travel characteristics. The purpose of these reference mechanical travel characteristics is to characterize the mechanical behavior of the circuit breaker.

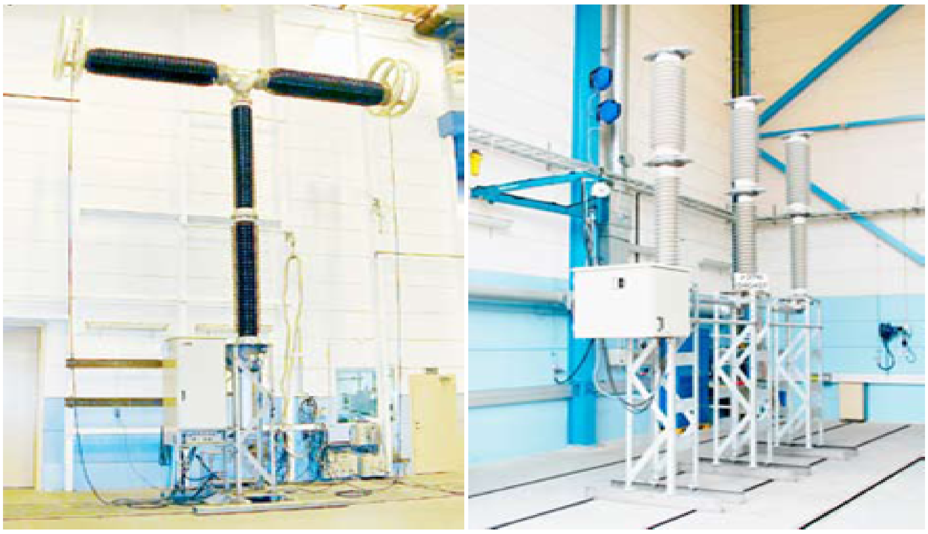

Figure 3.3: Test of circuit breakers at laboratory [1]

The following operating characteristics shall be recorded:

a. Closing time

b. Opening time

c. Travel speed of moving contact

d. Over Swing

e. Return swing

f. Damping time

g. Recharging time of the operating device

The circuit breaker shall be able to perform a specified set of operations, at rated minimum and maximum supply and control voltages. During the test the maintenance requirements specified by the manufacturer shall be taken into account. For the M1 class the operations at different voltages, according to Table 3.1 shall be performed for the M2 class this set of operations is repeated five times. The total number of CO operations is 2,000 for class M1 and 10,000 for class M2.

where

Operating sequence	Supply/control voltage and and operating pressure	Number of operating sequences Circuit breakers for auto-reclosing	Number of operating sequences Circuit breakers not for auto-reclosing
C - ta - O- ta	Minimum Rated Maximum	500 500 500	500 500 500
C - t - CO - ta - C -ta	Rated	250	-
CO - ta	Rated	-	250

Table 3.1: Number of operating sequences perform at laboratory

O = opening

C = closing

CO = a closing operation followed immediately (i.e., without any intentional time delay) by an opening operation.

ta = time between two operations which is necessary to restore the initial conditions and/or to prevent undue heating of parts of the circuit breaker (this time can be different according to the type of operation).

t = 0.3 s for circuit breakers intended for rapid auto-reclosing, if not otherwise specified.

3.4 Factors which act on drive during No-load test condition

Main function of drive is to provide adequate energy to operate breaker within define range of time as per the IEC standard. During operation of breaker various factors play major role on performance of breaker. During closing operation moving contact of breaker starts moving towards arcing rod at that time inertia of moving contact, friction between moving contact and wall, friction between various joints and friction force at the time when moving contact has just touch arcing rod.

When opening operation starts at that time first factor is friction forces between arcing rod and moving contact plus, between moving contact and wall, forces due to SF6 gas compression in puffer chamber as shown in Figure[3.4], thrust due to gas passing from the nozzle should considered.

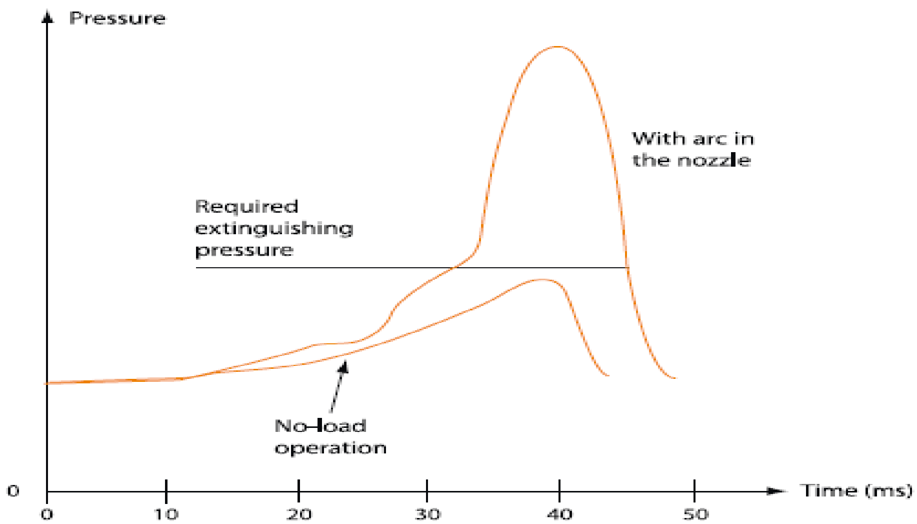

Figure 3.4: Puffer pressure in Circuit breaker during opening operation [1]

Total energy used to drive breaker is shown in Figure[3.5]. From the graph it is clearly come to remark on that how much energy drive must supply so that breaker can operate. These criteria can help to decide design of opening spring. In the below graph mainly gas compression energy and friction energy that drive have to overcome first and open circuit breaker within few millisecond. In the end of operation moving contact has very high velocity if energy is not absorbed then due to impact it will damage drive components and also moving contact of breaker. From the graph it is seen that end of operation high resisting force apply to avoid impact and smooth landing of lever take place.

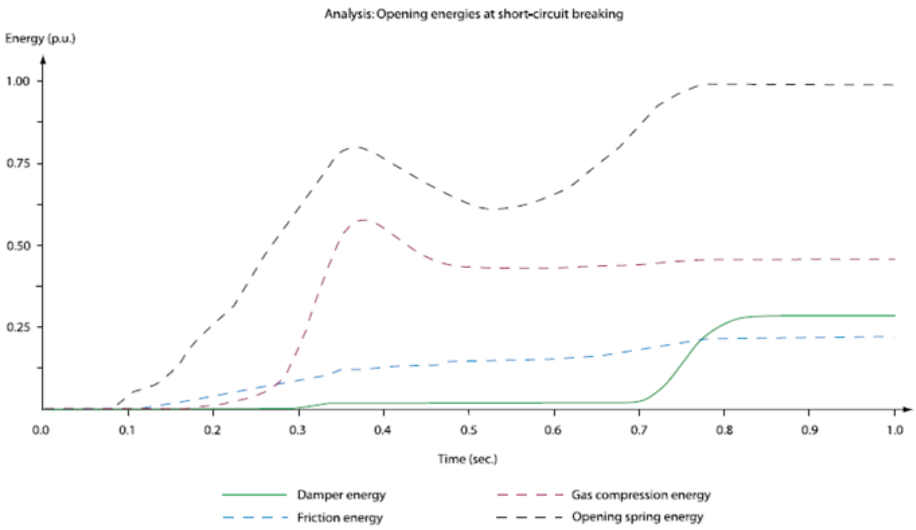

Figure 3.5: Utilization of operating energy at a breaking operation [1]

Same way in closing operation closing spring provides sufficient energy to charge tripping speed and also overcome friction, inertia force of moving contact. This is the design criteria to design closing spring. Here also in the end of operation damper should absorb adequate energy to avoid impact between retention lever and latch lever.

Chapter 4

Results and discussion

In this chapter inputs needed for the simulation, results from the simulation and its validation with experiment are describe.

4.1 Steps adopted for simulation

To carry out for kinematic and dynamic analysis steps needed are describe in Figure4.1

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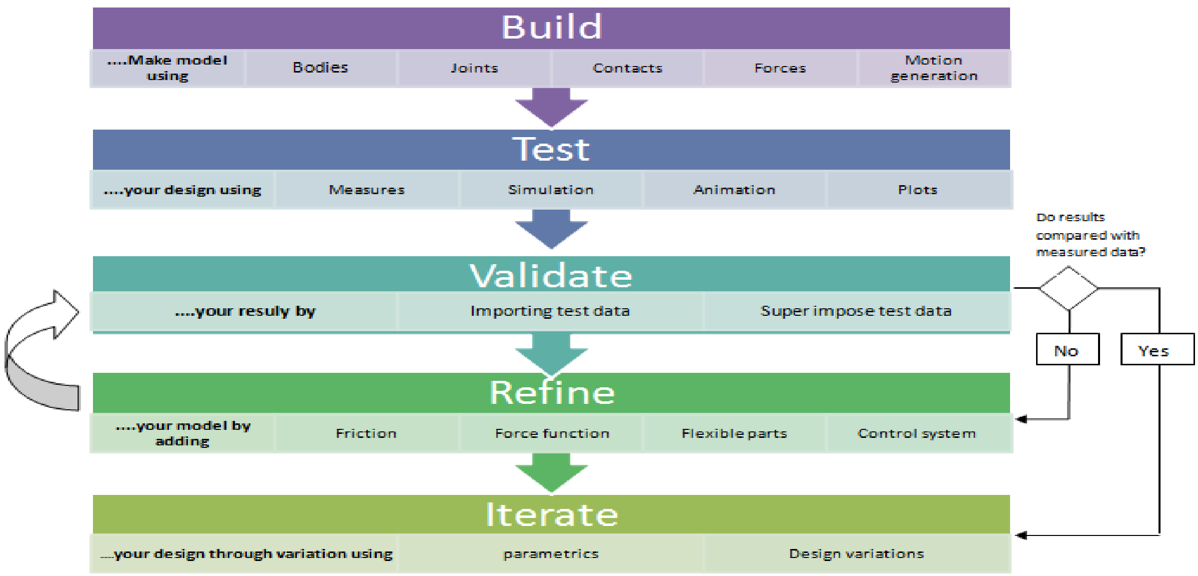

Figure 4.1: Simulation steps in ADAMS

[**1**] To carry out simulation import drive and breaker geometry in to MD ADAMS software. For that 3D model converted in to parasolid format in Pro-E CAD package and import it in MD ADAMS software show in 4.2.

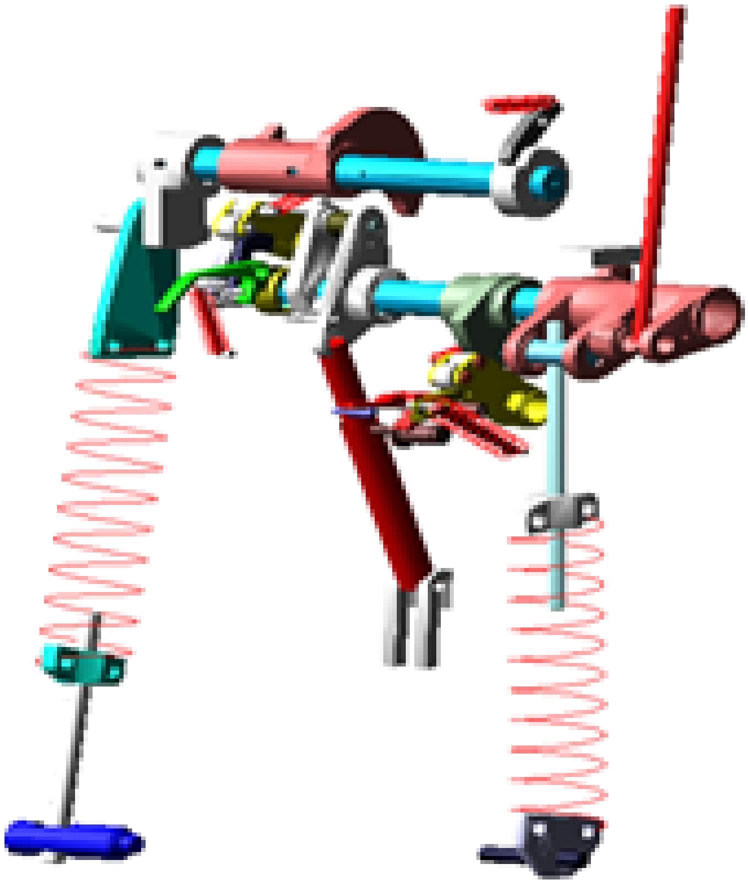

Figure 4.2: Spring operated drive imported in ADAMS

Mass and inertia property of component is extracted from Pro-E. These mention properties of individual component are listed in Table 4.1.

Sr. no	Name of component	Mass per unit mass	Inertia Ixx per unit mass mm^2	Inertia Iyy per unit mass mm^2	Inertia Izz per unit mass mm^2
1	Motor shaft	0.866	7843.809	7839.868	130.411
2	Cam	0.611	1213.688	1121.505	596.220
3	Motor shaft lever	0.398	579.486	536.881	184.844
4	Stop lock disc	0.178	139.288	79.728	74.826
5	Motor shaft plate	0.334	881.431	707.229	182.569
6	Output shaft	1.000	12039.596	12033.563	151.361
7	Transmission lever	0.537	820.389	806.228	347.167
8	Cam roller	0.011	1.260	0.849	0.849
9	Retention lever	0.330	310.877	239.361	179.640
10	Output shaft lever	0.993	2661.145	1880.650	1351.024
11	Closing latch lever	0.178	239.567	223.978	36.305
12	Intermediate closing lever	0.024	8.235	7.929	1.196
13	Auxiliary closing lever	0.015	23.499	21.843	1.967
14	Closing upper roller	0.008	0.416	0.366	0.366
15	Closing lower roller	0.016	3.264	2.109	2.109
16	Tripping latch lever	0.178	259.141	243.505	38.811
17	Intermediate tripping lever	0.024	9.194	8.911	1.333
18	Auxiliary tripping lever	0.015	0.016	11.546	1.610
19	Tripping upper roller	0.008	0.416	0.366	0.366
20	Tripping lower roller	0.016	1.642	1.061	1.061
21	Circuit breaker moving contact	0.994	6128.851	6128.851	35.963
22	Bell crack lever	0.050	38.899	13.233	44.183
23	Tie rod	0.026	518.114	518.114	0.756

Table 4.1: Mass and inertia property of drive components

[**2**] After defining mass and inertia properties second step is to define joints of individual component. To capture real kinematic and dynamics of model proper joints selection play vital role as joints are the constraints which provide limitation on the part to move relative to other parts or ground in restricted direction. The various joints have been defined to individual parts are listed in Table 4.2.

Joints	Components joints between
Revolute joint	1) Motor shaft and ground 2) Motor shaft lever and spring plate 3) Output shaft and lever 4) Output lever and pin 5) Cam roller and cam 6) Closing latch lever and ground 7) Closing latch upper roller and closing latch lever 8) Closing lower roller and opening latch lever 9) Tripping latch lever and ground 10) Tripping latch upper roller and Tripping latch lever 11) Tripping Lower roller and Tripping latch lever 12) Common shaft of circuit breaker and ground 13) Bell crank lever and pull rod 14) Pull rod and moving contact
Fixed joint	1) Motor shaft and cam 2) Motor shaft and stop lock disc 3) Motor shaft and motor shaft plate 4) Output shaft and output shaft lever 5) Output shaft and transmission lever 6) Output shaft and retention lever 7) Various stops in closing and tripping latch and ground 8) Bell crank lever and common shaft of CB 9) Upper stop plate and ground 10) Lower stop plate and ground 11) Both springs support and ground
Spherical joint	1) Tie rod and output lever 2) Tie rod and common shaft lever
Translation joint	1) Moving contact of circuit breaker and ground

Table 4.2: Joints between different components of the drive

[**3**] Third step is to define contact forces between different parts. Following contact forces are defined between parts are listed in Table 4.3.

Contact force between
1) Cam and roller
2) Cam pawl and upper roller of closing latch lever
3) Closing latch lever and upper stop
4) Closing latch lever and lower stop
5) Closing lever and intermediate lever
6) Auxiliary lever and stop
7) Auxiliary lever and intermediate lever
8) Tripping latch lever and upper stop
9) Tripping latch lever and lower stop
10) Tripping lever and intermediate lever
11) Tripping Auxiliary lever and stop
12) Tripping Auxiliary lever and tripping intermediate lever
13) Retention lever and tripping upper roller
14) Output lever and upper stop plate
15) Output lever and lower stop plate

Table 4.3: Contact force between different parts of drive

[**4**] After defining contact force now define flexible connectors. Flexible connectors consists of spring and damper. The spring and damper characteristic are arrived either experimentally or by theoretical calculations. In this present simulation massless linear springs are considered. Spring force versus deflection characteristics during closing and opening operation are presented in Figure 4.3 and 4.4 respectively.

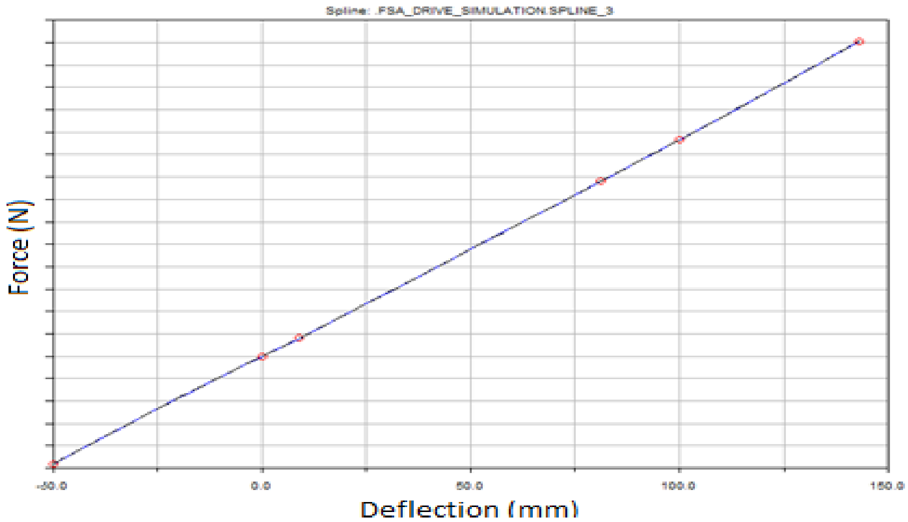

Figure 4.3: Closing spring characteristic force versus deflection curve

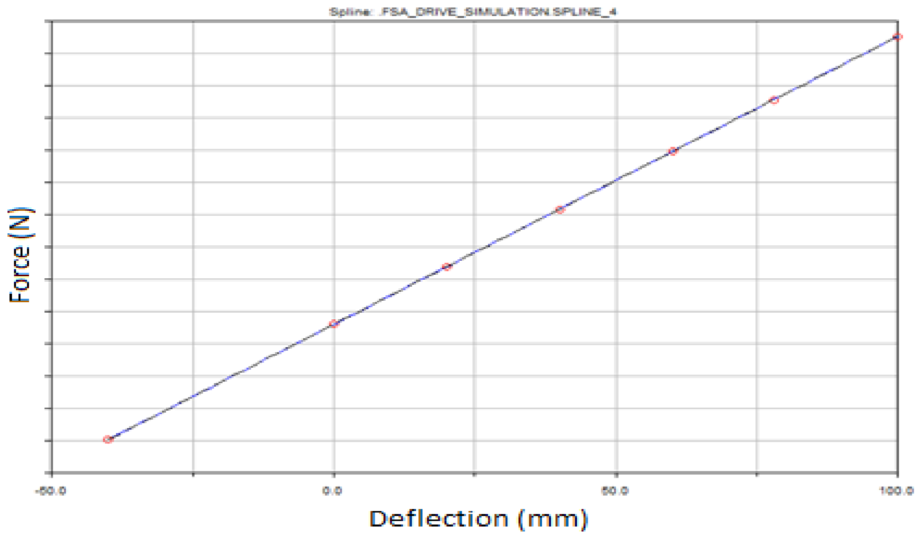

Figure 4.4: Opening spring characteristic force versus deflection curve

Closing latch lever spring stiffness is 4.48 N/mm, Closing auxiliary spring stiffness is 0.875 N/mm and tripping spring preloaded by 228 N load and has spring stiffness 11 N/mm.

Damper characteristic

Fb is a reactive force of the damper at the end of travel, which is often used to absorb high kinetic energy of the moving system in order to avert a great impact against some parts of the mechanism. Moreover, Fb can adjust the moving speed through modifying the size and position of orifice. Based on Bernoulli equation and liquid flow continuity law, buffer force can be described as follows:

$$Fb = \frac{(\rho V e^2 A e^3)}{(2Cd^2 \sum_{i=1}^{n} Ai^2)}$$

Where ρ is oil density;Ve is piston speed; Ae is piston area; Cd is flow coefficient; Ai is orifice area forward travel direction of piston, which changes with the position of movement. A schematic diagram of the damper is shown in 4.5.

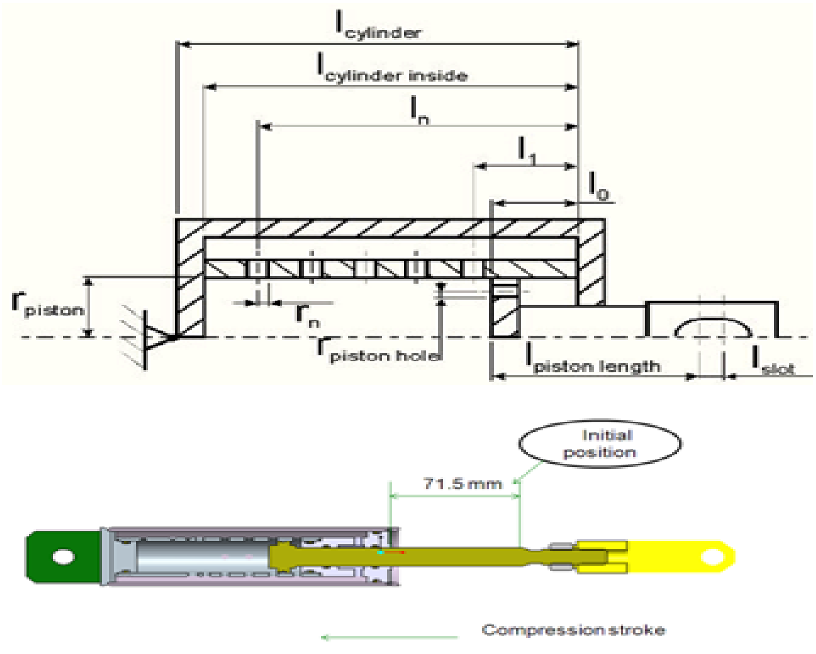

Figure 4.5: Damper schematic diagram

Damper parameter

Piston position	71.5 mm
Piston radius	12.5 mm
Piston length	182 mm
Cylinder length	148 mm
Cylinder inside length	136.5 mm
Oil density	1421 kg/m3
No of holes of 1 diameter	3
No of holes of 1.5 diameter	1
No of holes of 2 diameter	1
No of holes of 4 diameter	11

[**5**] Next step is to define friction between various joints and sliding components on other parts. Friction force can be derived from experiments.

Needle bearing = 0.005

Ball bearing = 0.0018

When breaker moving contact is in motion, friction acts on it at 3 different places.

a. At place friction acts between moving contact and wall as it starts motion.

b. Second when moving contact touch main current contact.

c. Third where moving contact comes in contact with arcing rod.

Friction force F0 = 260 N

Friction force F1 = 290 N

Friction force F2 = 200 N

Length l1 = 6 mm

Length l2 = 20 mm

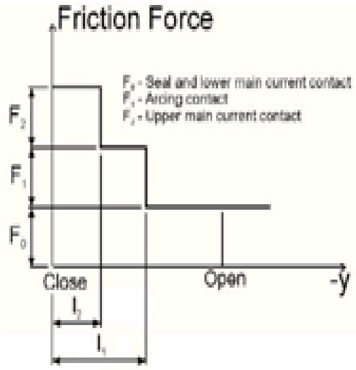

Figure 4.6: Friction force versus displacement diagram of moving contact

4.2 Simulation results

Circuit breaker performance depends on time travel curve. Drive should provide sufficient energy to open and close breaker within few milliseconds. In this current simulation work, dynamic characteristic of circuit breaker drive has been captured. For that all real data have been entered to capture actual behavior of drive. Drive's charging, closing and opening operation are captured in the simulation.Drive simulation model is shown in Figure4.7

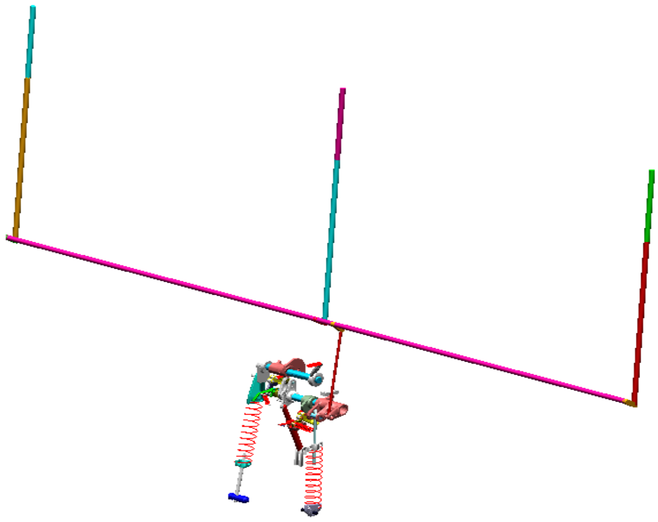

Figure 4.7: Spring operated drive model in Simulation

4.2.1 Closing operation time travel curve

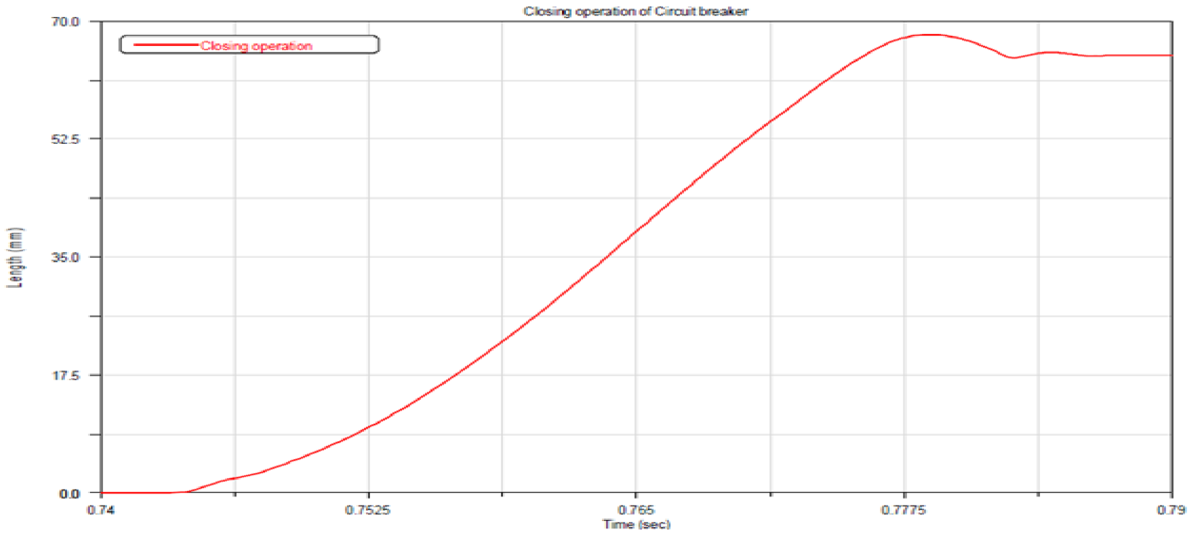

Figure 4.8: Closing operation simulated in ADAMS (displacement vs. time)

The total time taken by moving contact while extending from its bottom position to extreme position takes 35.5 millisecond is shown in Figure4.8.

4.2.2 Opening operation time travel curve

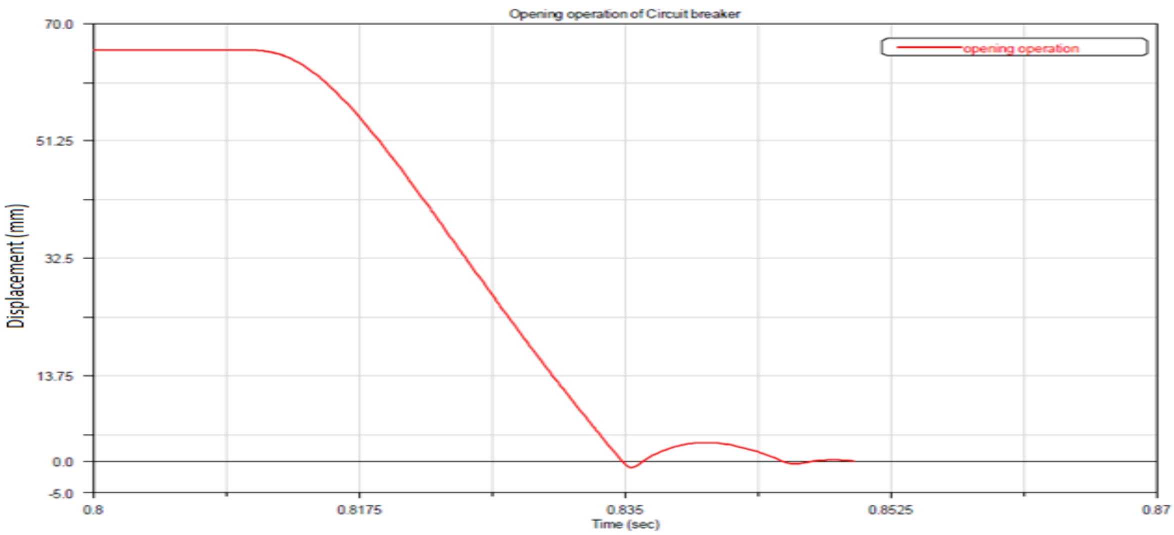

Figure 4.9: Opening operation simulated in ADAMS (displacement vs. time)

The total time taken by moving contact while extending from its extreme upper position to bottom position takes around 24.7 millisecond shown in Figure 4.9.

4.3 Comparison of Simulation and experiment results

Circuit breaker moving contact displacement versus time graphs are evaluated at ABB Mechanical testing lab. A rotary transducer is placed at circuit breaker common shaft where Spring operated drive tie rod is connected to breaker assembly through the linkages to measure displacement versus time graph known as time travel curve. Initially breaker is filled with SF6 gas at 7 bar. The experiment data for 72.5 kV circuit breaker are evaluated at test lab shown in appendix FigureA.1 and A.2 by following IEC 62271-100 standard test procedure which is to be compared with the simulation results.

4.3.1 Closing operation graph form experiment

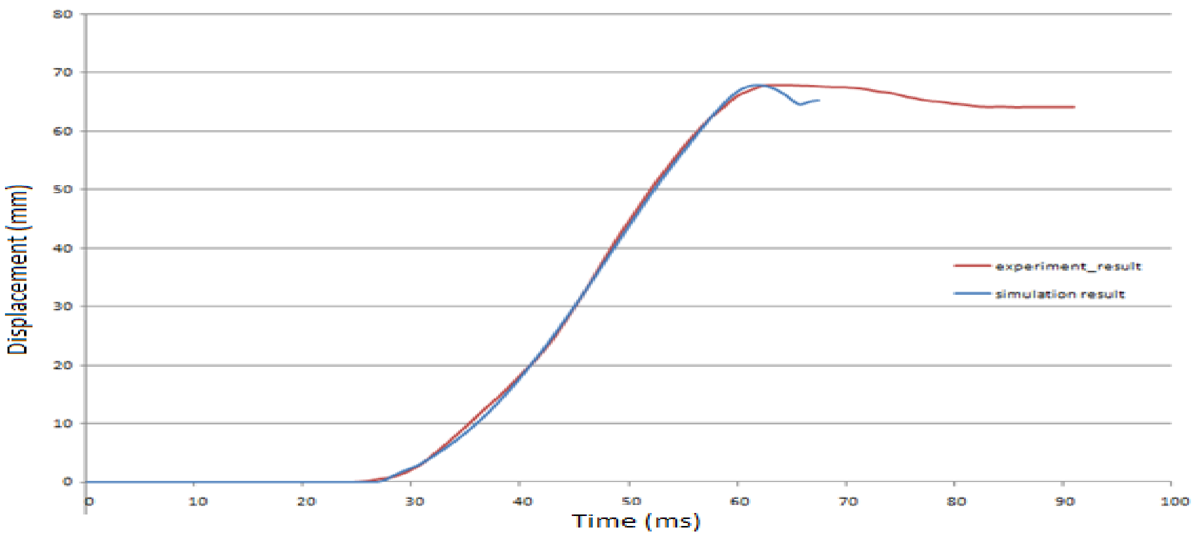

Figure 4.10: Comparison of experiment and simulation result (Closing operation)

Closing operation time travel curve is derived from experiment takes 39 ms shown in appendix Figure A.1. Experimental and simulation results have good agreement with each other, can be seen in Figure 4.10 except at the end due less damping force.

4.3.2 Opening operation graph form experiment

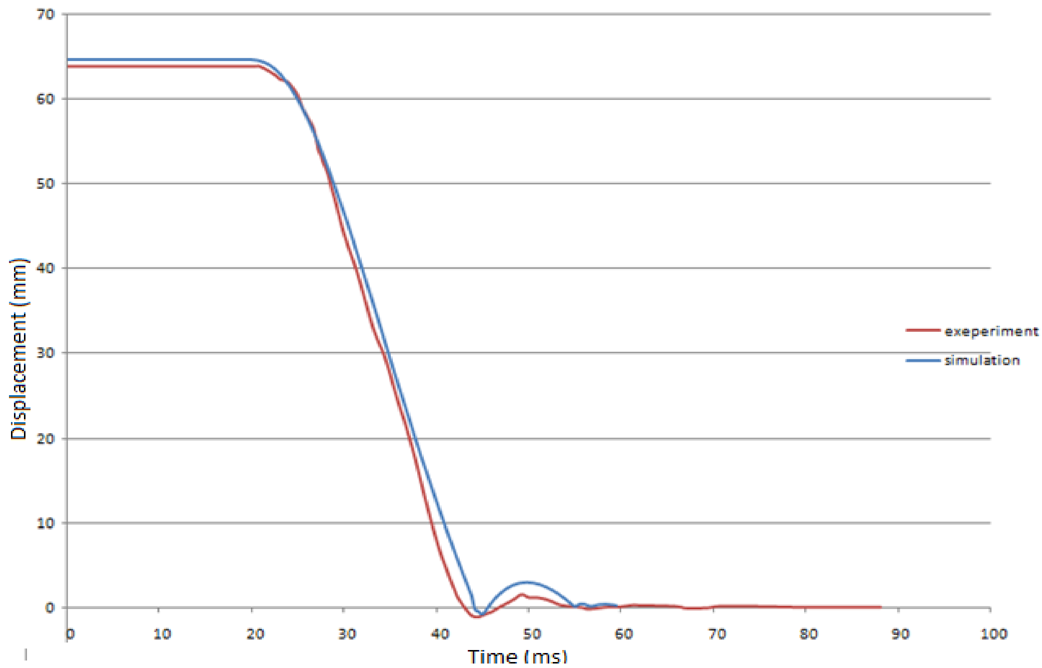

Figure 4.11: Comparison of Experiment and simulation result of opening graph

Opening operation time travel curve is derived from experiment takes 24.1 ms shown in appendix FigureA.2. Experimental and simulation results have good agreement with each other, can be seen in Figure 4.11. But when moving contact separated from arcing rod at 45 mm, it is close to experimental result. Further moving contact comes down in circuit breaker, SF6 gas compression takes place and some amount of gas escape from nozzle and back flow valve. From the above mention effect, only gas compression effect is consider where as nozzle and back flow valve effect are neglected. When moving contact reaches at 20 mm, damping effect starts significantly and at that instance deviation are in the results due to less damping force in simulation.

4.4 Drive performance by varying spring initial condition

Drive performance or moving contact characteristic can be influence by various parameter. 1) Opening and closing spring

2) Damper hole characteristic

3) Cam profile

4) Latch mechanism

From the above said parameter if one can change closing spring parameter then it influence closing operation only and if change damper hole position then in the end of the operation it effect the moving contact travel curve characteristic. To improve the response time of breaker during opening operation cam profile, latch mechanism and opening spring parameter should be change. Either one can change cam profile or increase response of latch to reduce opening time. In this present work to reduce response time, spring initial condition has been changed.

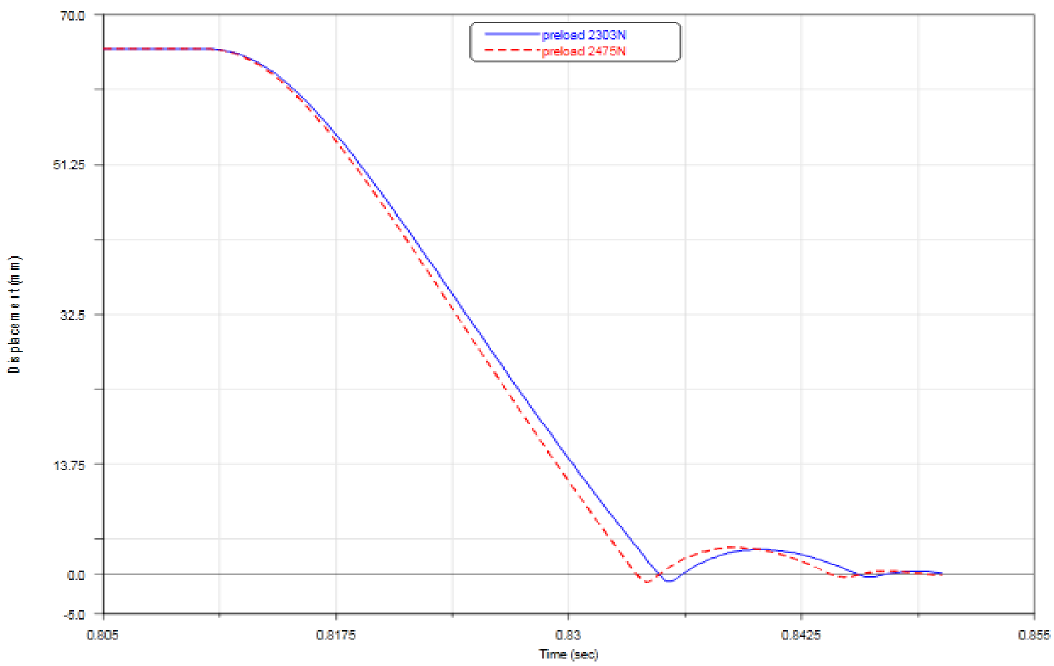

Figure 4.12: Drive response by varying opening spring initial condition

Opening spring is initially preloaded at 2303 N force. At this instance moving contact have velocity 3.26 m/s. Now according to standard moving contact velocity should have tolerance 3 to 3.5 m/s. Initial preload condition of opening spring is change to 2475 N force. Maximum velocity of moving contact at new preload condition obtain is 3.4 m/s which is within the tolerance limit. The improvement in response of moving contact is shown in Figure4.12. It is conclude that by varying preload condition opening operation spread time is reduced by 1.2 ms can but its counter part effect the closing operation time increase by 1 ms but velocity of moving contact during closing operation is within the limit.

Chapter 5

Stress analysis of drive components

5.1 Steps to carried out Flexible analysis

Following steps should carried out for flexible analysis in MD ADAMS To carry out

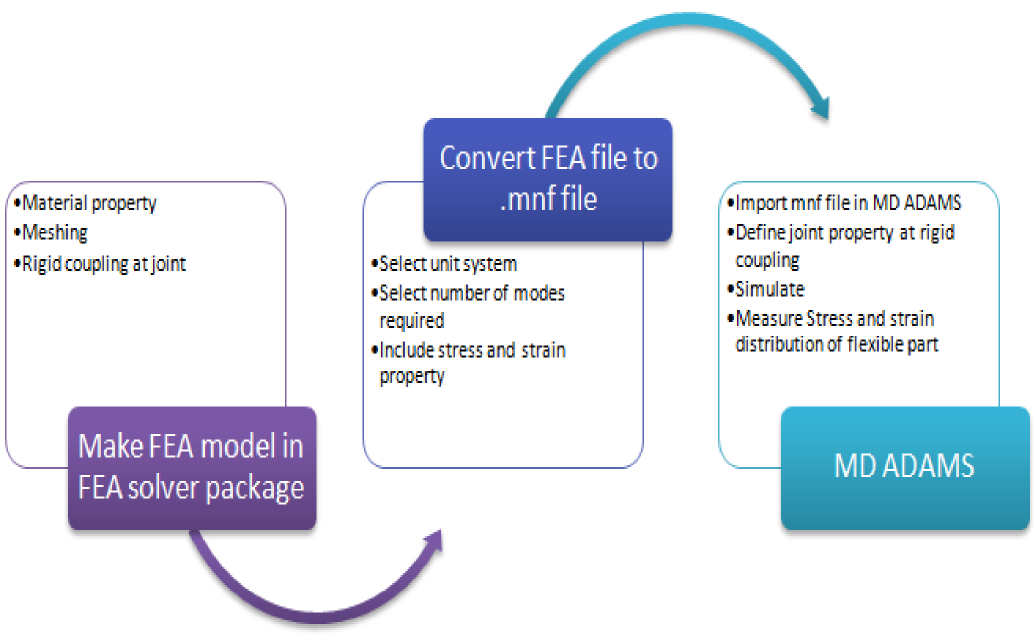

Figure 5.1: Step to carried out Flexible analysis in MD ADAMS

flexible analysis two methods are available. In first method, convert modal neutral file (mnf) from FEA package. Export mnf file in MD ADAMS, give proper boundary condition, simulate it and again transfer dynamic load to FEA package for FEA analysis. Second method is first convert mnf file in FEA package, import in MD ADAMS, give boundary condition, simulate it and extract stress and strain distribution in durability package in MD ADAMS.

In current work second method is used to carry out stress and strain distribution of individual components of the drive. To convert mnf file ANSYS FEA package is used. In these components are mesh with solid 45 element and tetra mesh is use to make finite element file. For rigid coupling mass21 element is used.

After meshing in ANSYS now go to ANSYS main menu → Solution → ADAMS Connection → Export to ADAMS option. New window will open for selection of more than two nodes on part where all degree of freedom want to transfer. Now select node, unit system, number of modes to extract, include stress and strain property and give ok command to create mnf file.

Now incorporate flexible component in ADAMS go to Flexible body option, go to replace rigid to flexible command and give ok. Give proper boundary condition, simulate and measure stress and strain distribution behavior of component versus time.

5.2 Material of Individual component

Material property of individual component are listed in Table 5.1

Component	Material	Young -modules(E) N/mm2	Density kg/mm3	poison ration
Retention lever	SG cast iron	1.73E+05	7.10E-06	0.28
Transmission lever	SG cast iron	1.73E+05	7.10E-06	0.28
Closing Cam	SG cast iron	1.73E+05	7.10E-06	0.28
Motor shaft lever	SG cast iron	1.73E+05	7.10E-06	0.28
Stop locking disc	SG cast iron	1.73E+05	7.10E-06	0.28
Closing latch lever	SG cast iron	1.73E+05	7.10E-06	0.28
Opening latch lever	SG cast iron	1.73E+05	7.10E-06	0.28
Output shaft lever	SG cast iron	1.73E+05	7.10E-06	0.28
Auxiliary closing lever	Aluminum Alloy	7.17E+04	2,74e-6	0.33
Auxiliary opening lever	Aluminum Alloy	7.17E+04	2,74e-6	0.33
Closing spring	Steel wire	2.01E+05	7.85E-06	0.3
Opening spring	Steel wire	2.01E+05	7.85E-06	0.3
All latch spring	Patented cold drawn wire	2.01E+05	7.85E-06	0.3
Roller	Steel	2.01E+05	7.85E-06	0.3
Motor shaft	Steel	2.01E+05	7.85E-06	0.3
Output Shaft	Steel	2.01E+05	7.85E-06	0.3

Table 5.1: Material property of drive components

5.3 Flexible analysis of Cam

To convert flexible part, meshing of the model in ANSYS is carried out as shown in Figure 5.2. To define joint in ADAMS, rigid coupling is required in mesh model. Mass 21 element is used for rigid coupling to transfer all joint load to part surface.

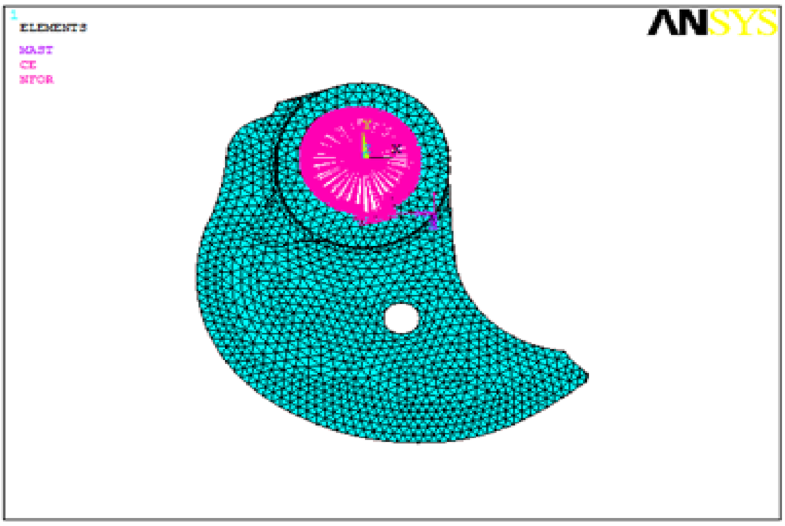

Figure 5.2: Mesh model of cam in ANSYS

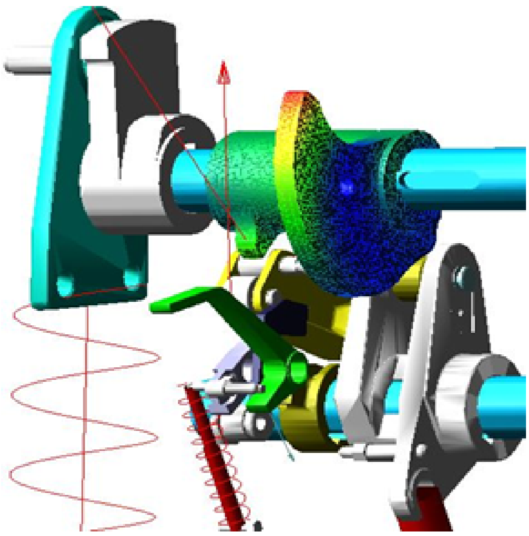

Figure 5.3: Cam flexible component in ADAMS

Now convert mesh model to modal neutral file and import in ADAMS environment. After importing mnf file shown in Figure 5.3, define joint at rigid coupling and simulate.

5.4 Stress and strain contour during operation

Stress and strain contour analysis have been carried out in simulation. In this stress and strain contour analysis for drive all three operation are combine i.e charging follow by closing and opening operation. The stress and strain contour analysis are carried out for individual components are as follows:

5.4.1 Cam

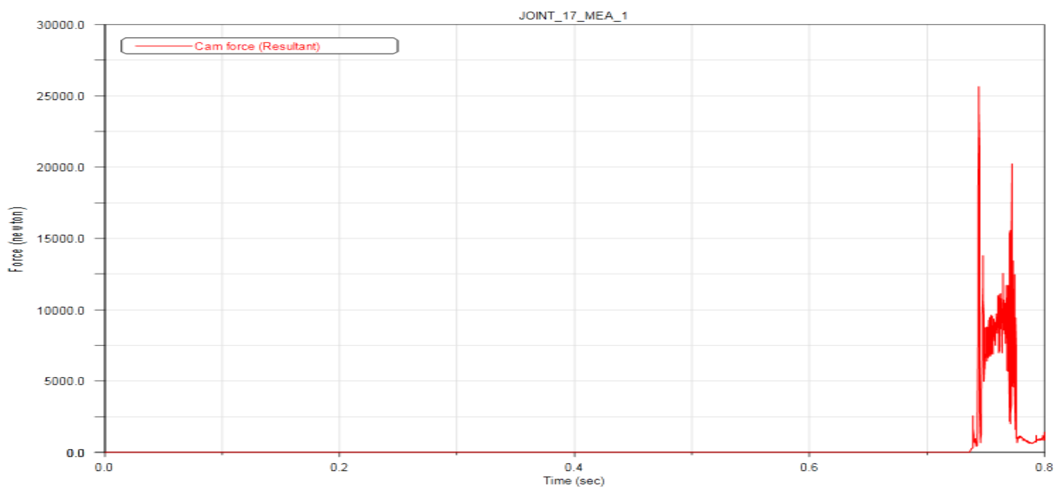

Figure 5.4: Cam Force versus time graph during operations

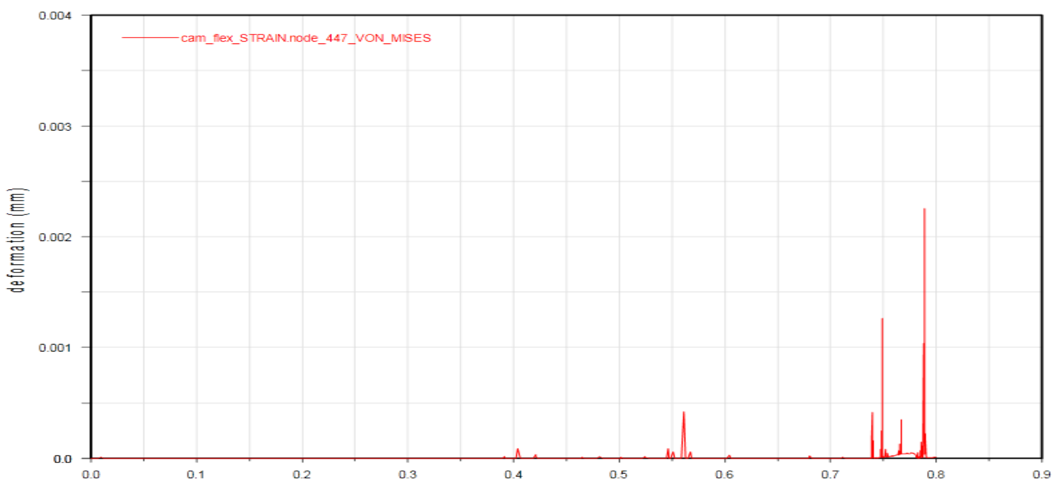

Figure 5.5: Cam deformation versus time graph during operation

5.4.2 Motor shaft

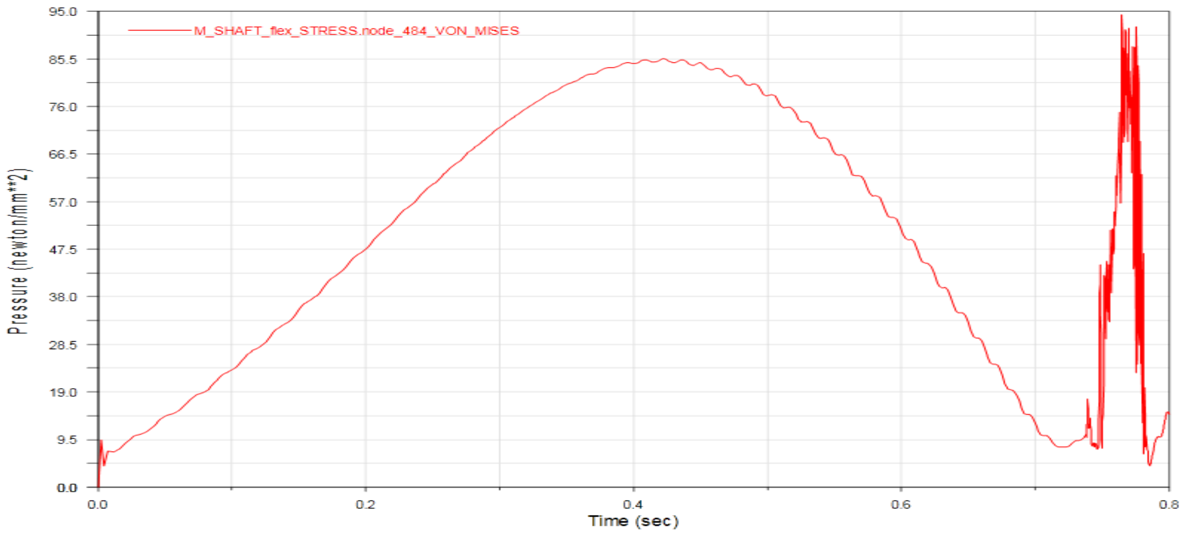

Figure 5.6: Motor shaft stress contour versus time graph during operation

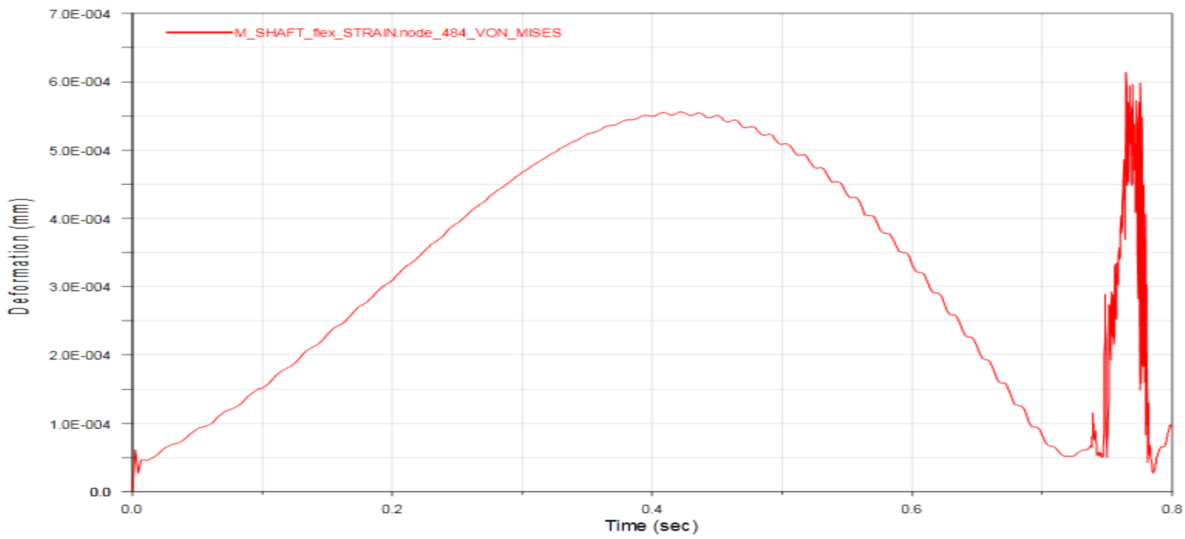

Figure 5.7: Motor shaft deformation versus time graph during operation

5.4.3 Cam roller

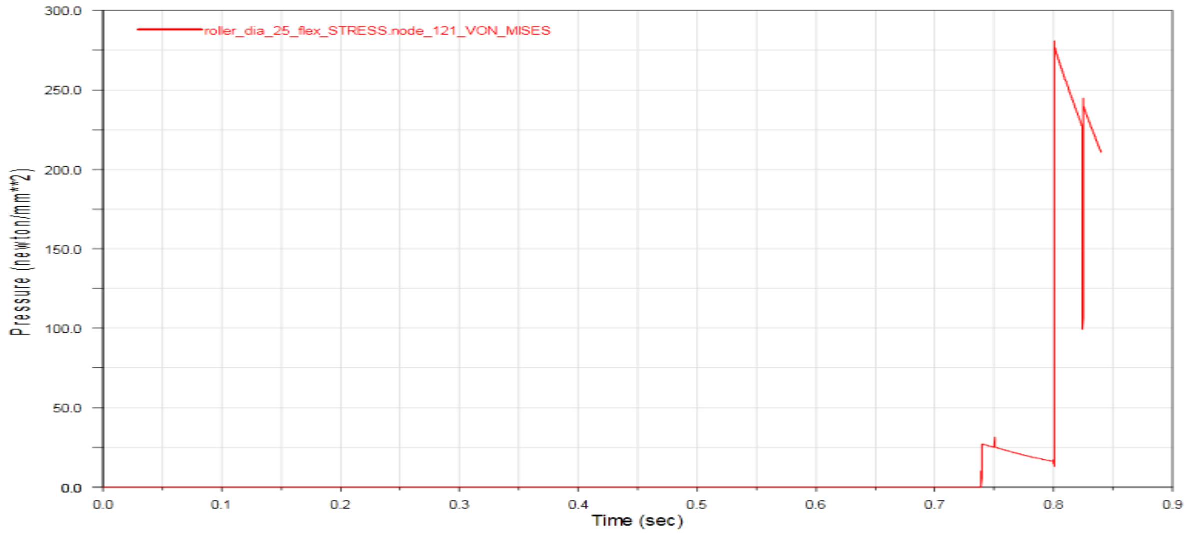

Figure 5.8: Cam roller stress contour versus time graph during operation

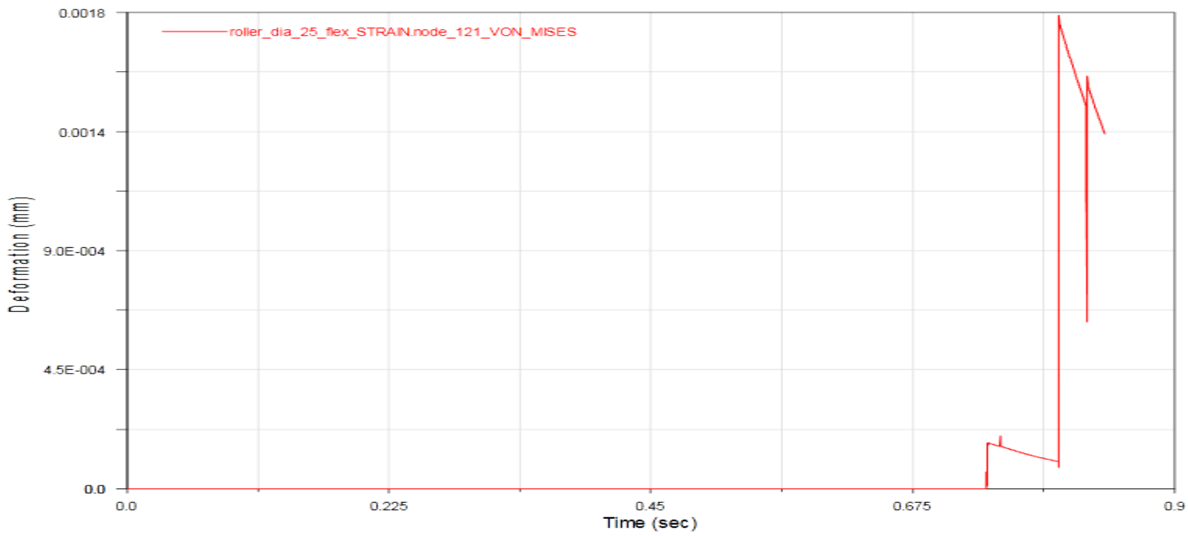

Figure 5.9: Cam roller deformation versus time graph during operation

5.4.4 Closing latch lever

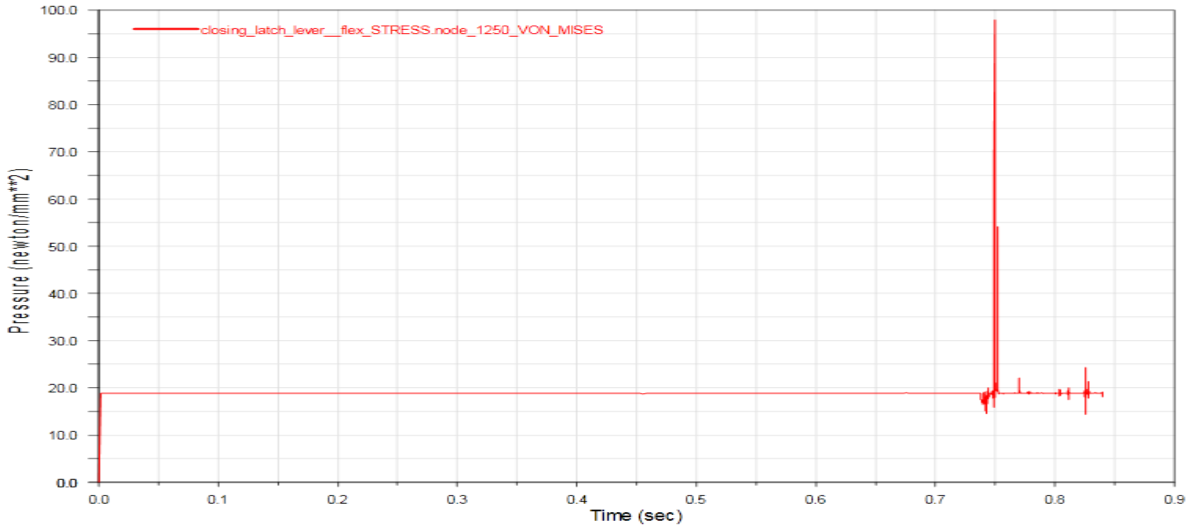

Figure 5.10: Closing latch stress contour versus time graph during operation

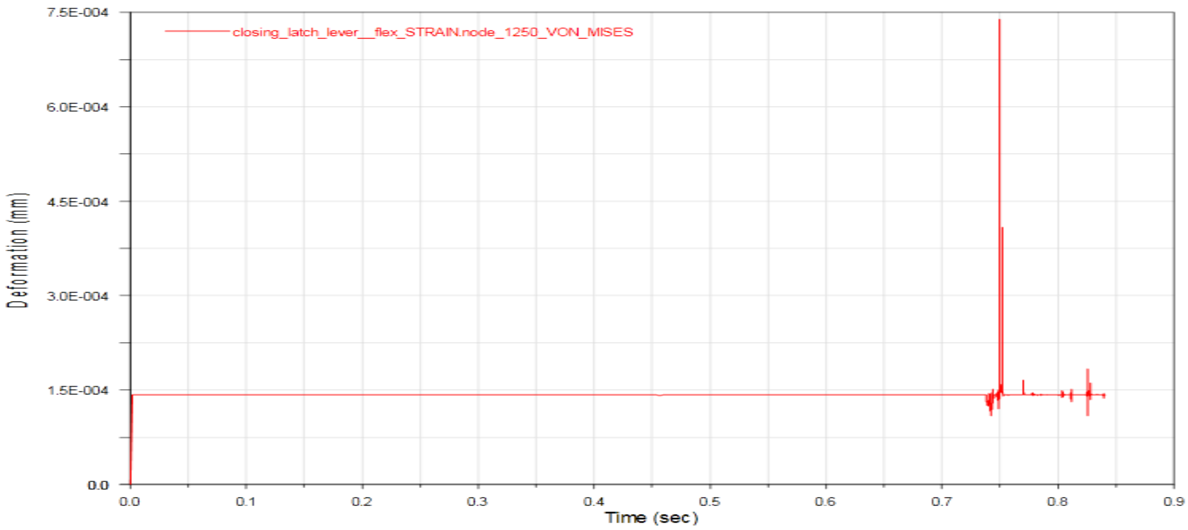

Figure 5.11: Closing latch deformation versus time graph during operation

5.4.5 Intermediate closing lever

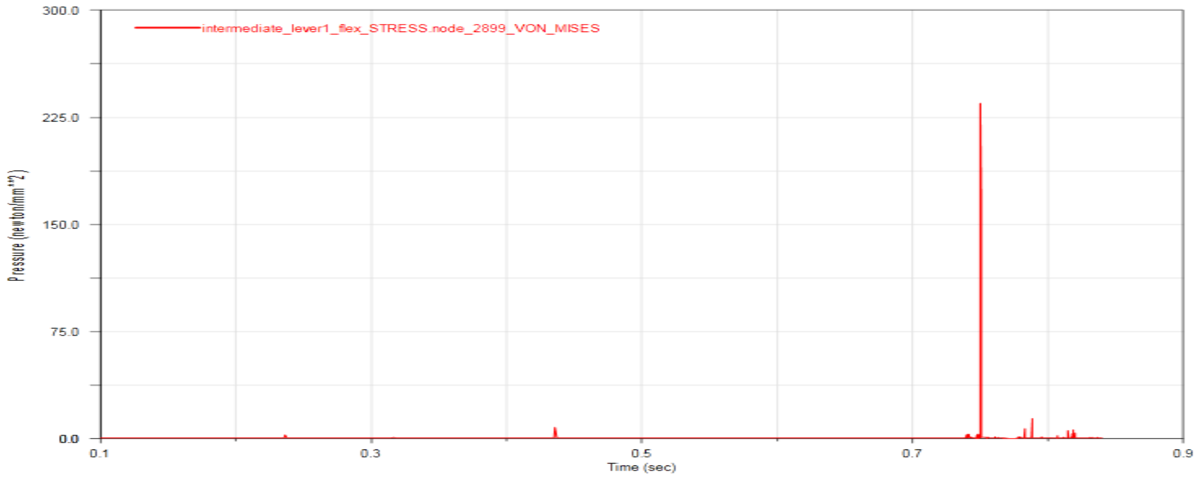

Figure 5.12: Intermediate closing lever stress contour versus time graph during operation

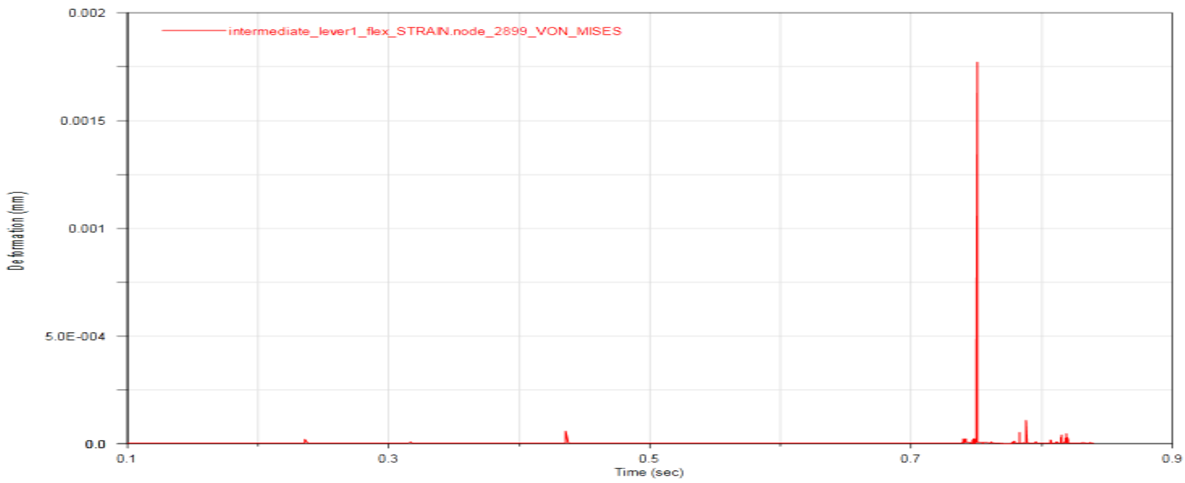

Figure 5.13: Intermediate closing lever deformation versus time graph during operation

5.4.6 Intermediate tripping lever

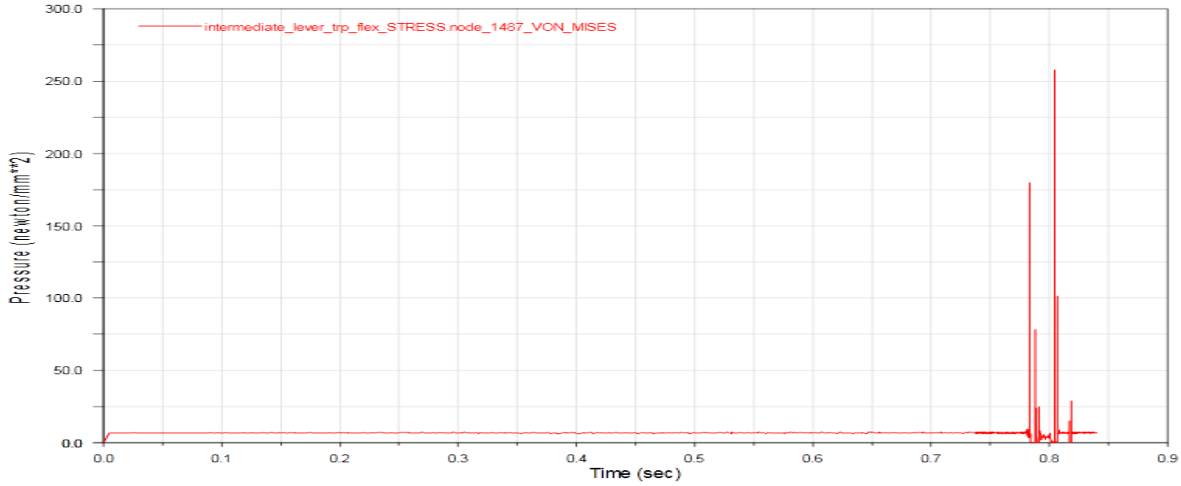

Figure 5.14: Intermediate tripping lever stress contour versus time graph

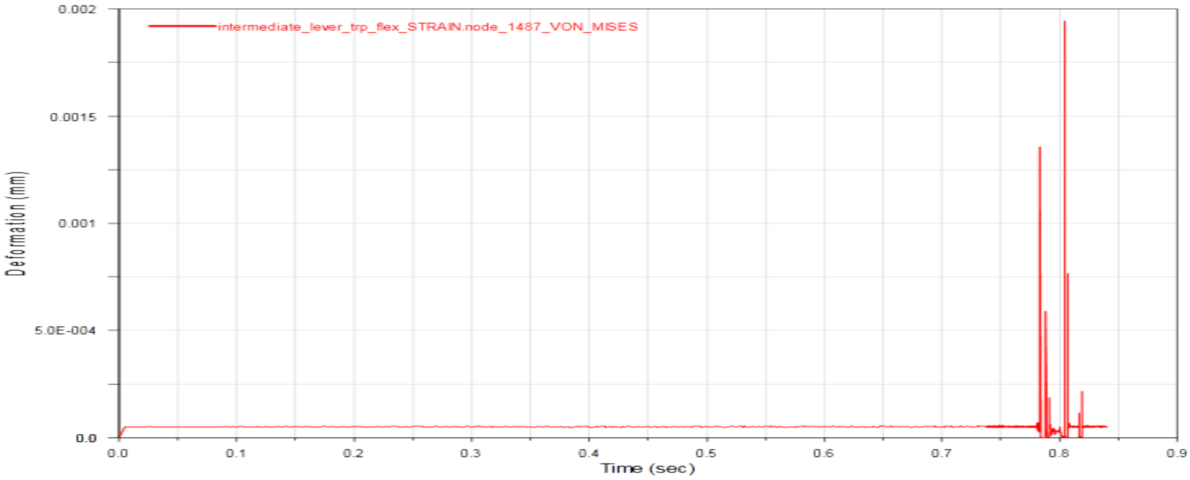

Figure 5.15: Intermediate tripping lever deformation versus time graph during operation

5.4.7 Transmission lever

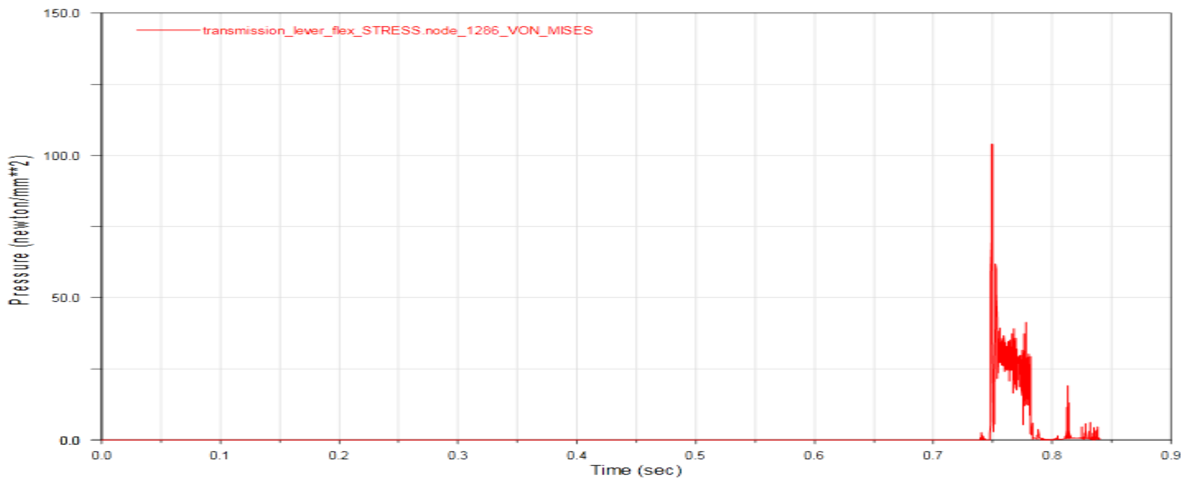

Figure 5.16: Transmission lever stress contour versus time graph during operation

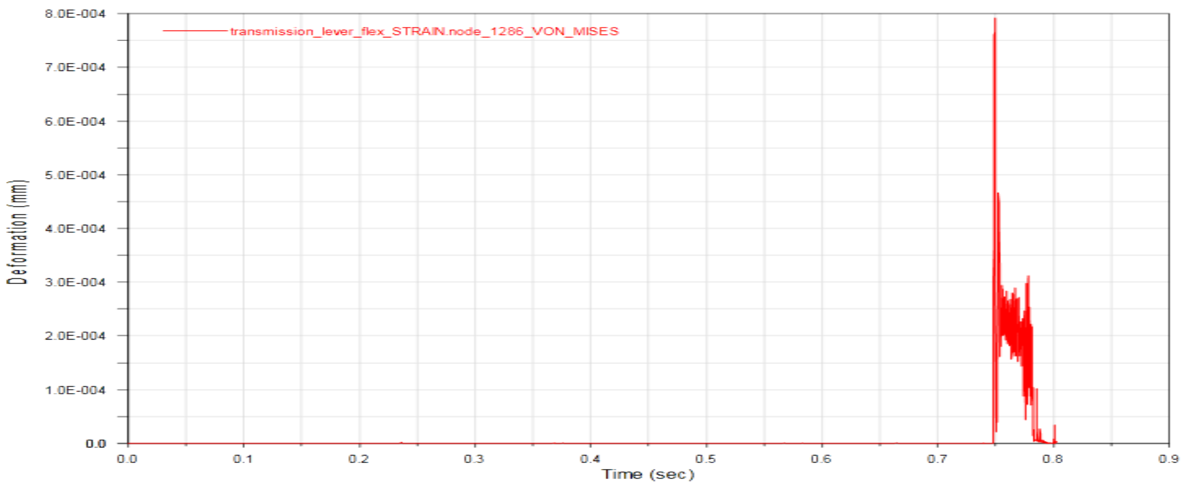

Figure 5.17: Transmission lever deformation versus time graph during operation

5.4.8 Output shaft

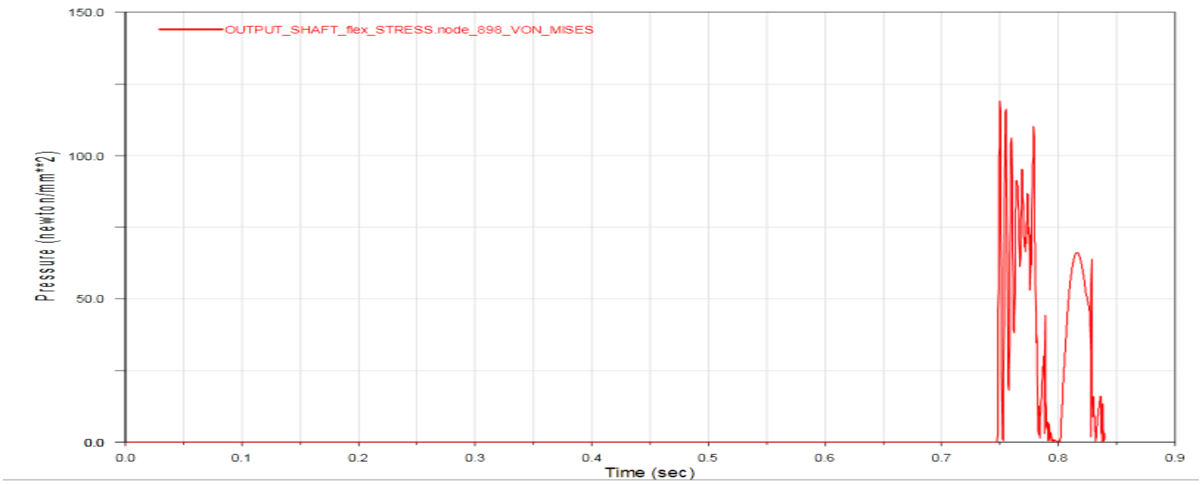

Figure 5.18: Output shaft stress contour versus time graph during operation

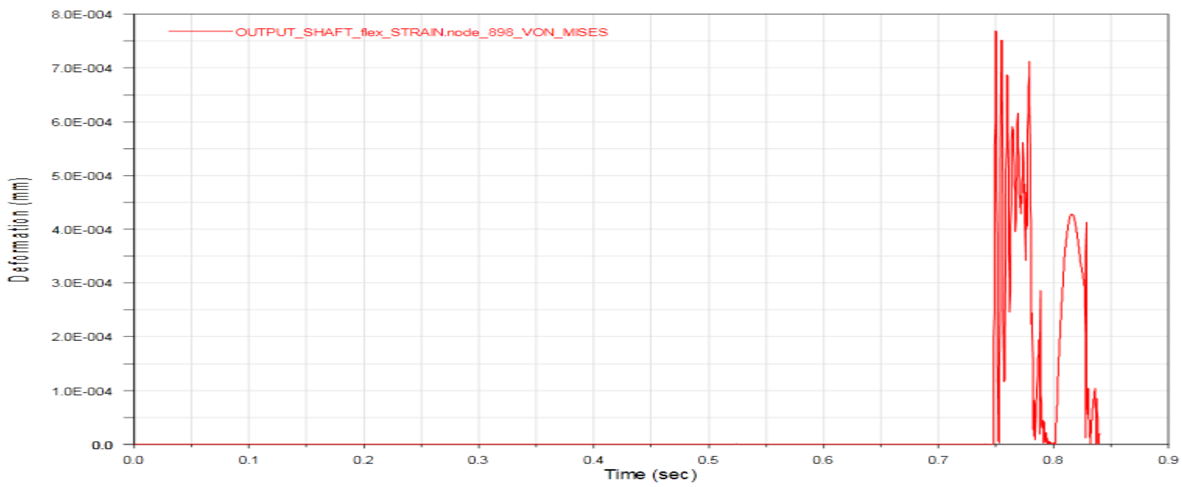

Figure 5.19: Output shaft deformation versus time graph during operation

5.4.9 Retention lever

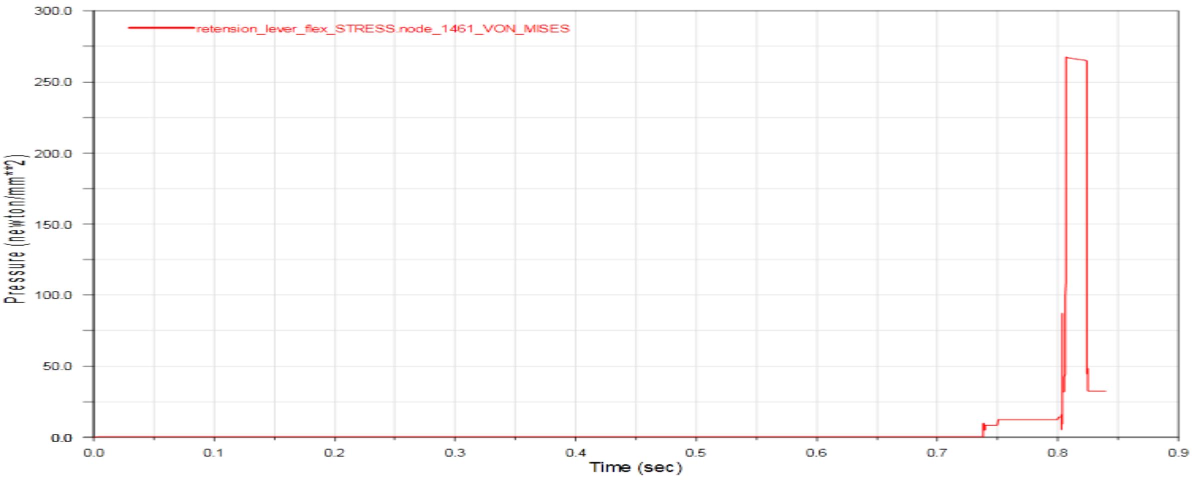

Figure 5.20: Retention lever stress contour versus time graph during operation

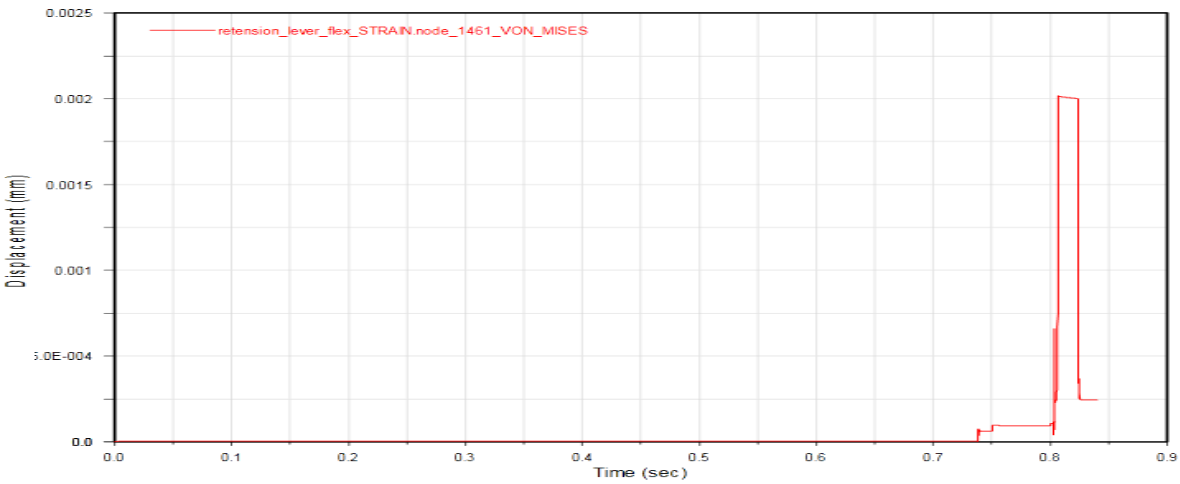

Figure 5.21: Retention lever deformation versus time graph during operation

5.5 Summery

Stress and strain versus time data evaluated for drive's individual components during operations by considering flexible body. From the above data it is concluded that all components are within the permissible limit. But few critical components i.e retention lever, cam and intermediate tripping lever experiences relatively higher stresses.

Chapter 6

Conclusion and future scope

6.1 Conclusion

Dynamic analysis of circuit breaker drive has been carried out using multibody dynamic simulation tool. The simulation results have good agreement with results obtained by experimentation. It has been attempted to investigate the dynamic loading condition by various drive components. It was observed that among various drive components, the retention lever, cam and intermediate tripping lever experience high mechanical stresses during opening and closing operation of circuit breaker. Finally it is conclude that, the opening time of circuit breaker can be effectively reduced by changing the pre-load condition of the opening spring of circuit breaker. This will result into a slight increase in closing time of CB, however maintains the operation velocity of moving contact of CB within applicable limit.

6.2 Future scope

- Damper modeling should be done at detail level.
- Optimization of drive performance will be done by changing closing and opening spring initial parameter or design and damper hole position.
- Fatigue analysis of drive can be carry out to evaluate drive reliability.

Appendix A

72.5 kV CB experiment results (Closing operation)

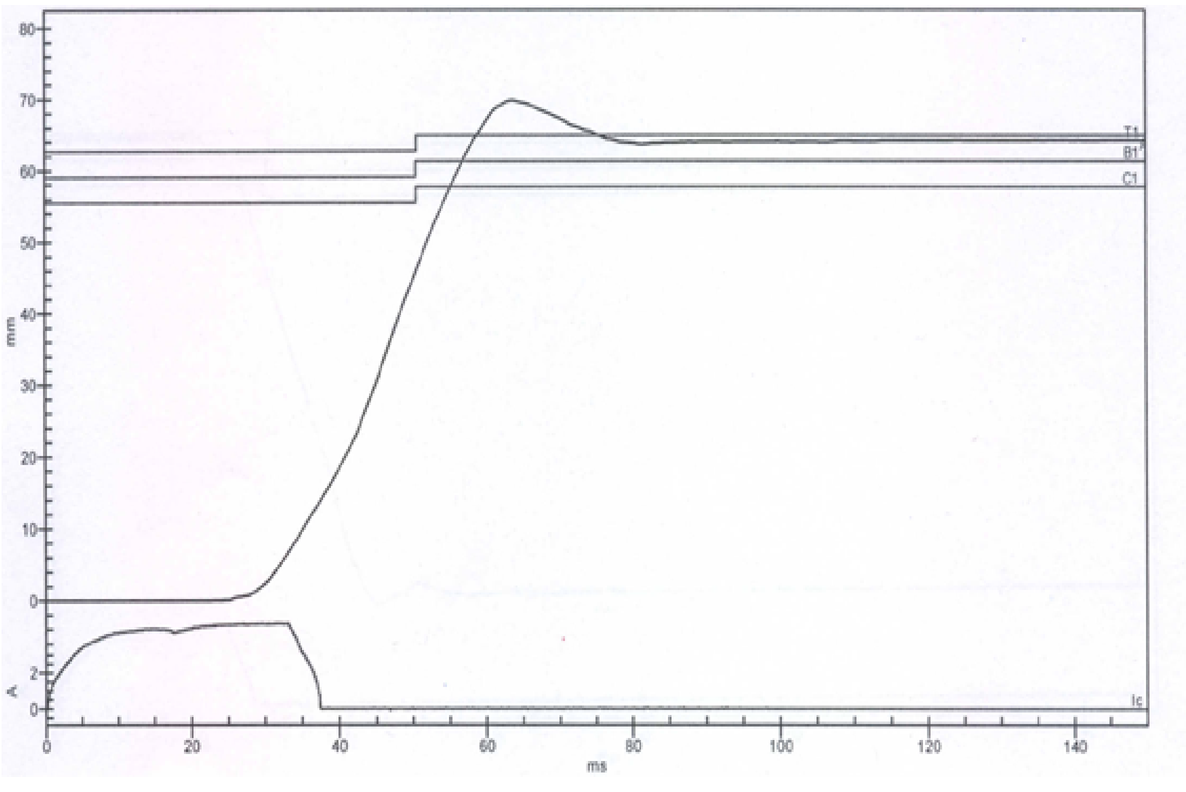

Figure A.1: Closing operation graph from experiment results

72.5 kV CB experiment results (Opening operation)

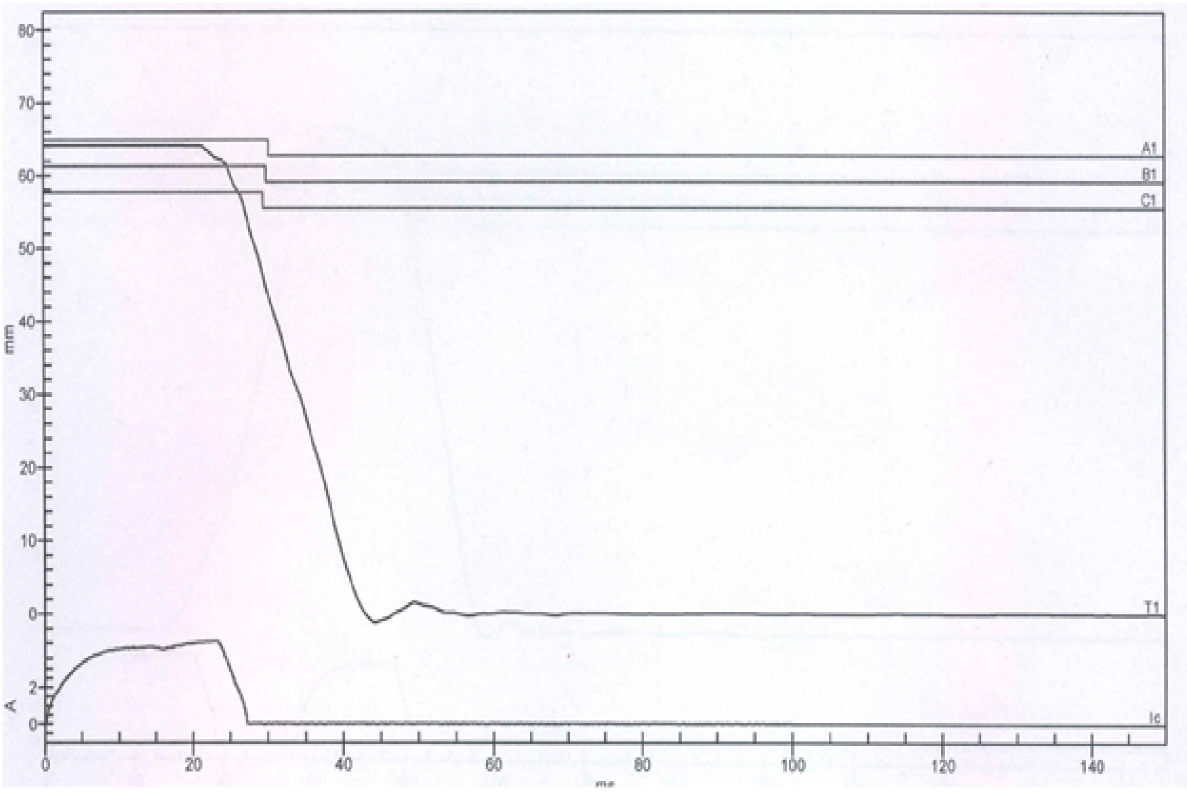

Figure A.2: Opening operation graph from experiment results

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