Høgskolen i Sørøst-Norge
Fakultet for Teknologiske fag
–
Mastergradsavhandling
Studieprogram: FMH606
Vår 2016

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Temperature rise in a load break switch

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Preface

Here, you give a brief introduction to your work. What it is (e.g., a Master's thesis in RAMS at USN as part of the study program xxx and...), when it was carried out (e.g., during the autumn semester of 2021). If the project has been carried out for a company, you should mention this and also describe the cooperation with the company. You may also describe how the idea to the project was brought up.

You should also specify the assumed background of the readers of this report (who are you writing for).

Porsgrunn, 03.06.2016

Peter Alexander Smestad

Kill the boy and let the man be born

Aemon Targaryen

Acknowledgment

I would like to thank the following people for their great help during my master thesis; Elin Fjeld, for helping and supporting me, while we fought deep down in the trenches. Thank you for visiting and helping out in the lab and correcting me when i erred from the path, and told me where i should place my focus and energy on. It meant a lot that you came and checked how I was doing. Wilhelm Gerard Jacob Rondeel, for taking the brute force of my questions in the field of heat transfer and electrical contacts. For always taking the time to help and guide me, even when I have come for guidance multiple times a day, and for helping me from home. Thanks for little talks, both personal and academically. Lastly challenging me to improve my understanding and thinking more scientifically. For I do pick up many of the words you say, even if i don't always show it. Cameron Lindberg, thank you for helping me with the set up of the equipment. For the time you took to help me with lab view, all that for a bottle of coca-cola. It was nice to have somebody to discuss with programming and in general about the switchgear. Lars Svindal, for being able to help me with the practical parts. A special thanks to Øyvind lab, Terje Bergrud for helping me with lab associated business, and encouraging words to succeeded.A thanks to my industrial supervisor; Magne Saxegård and Elham Attar, for welcoming me to ABB and taking the time to help with my thesis and experience a glimpse of what my future awaits in the industry.

This project was made possible due to the collaboration between ABB and HSN(formerly HiT): I would like to thank the people from both parties for giving students the opportunity to work on real and practical industrial engineering work. Especially, ABB for the opportunity to work on a project that will lead to a more green and environmental world.

P.A.S.

Summary and Conclusions

Given a switchgear and two different types of contacts and changeing the material of the crankcase to metal rather then using plastic. There are some limits the IEC has set, with the given changes try to improve the heat transfer from the conductive path to the surrounding air. A experimental design is presented, such that the experiment shall be reproducible. The sliding and braided contact are evaluated up against each other, to see which design is the best, by the best, which one can pass the IEC limits. the conclusion is that sliding is better then the braided connection. The sliding connection with the crankcase of aluminum is the closest one to pass the IEC limits, with the improvements done to the crankcase.

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Chapter 1

Introduction

Read Euler, read Euler. He is the master of us all

Pierre-Simon Laplace

A switchgear is a switching device used in power system protection. An analogy often used to explain in layman therms; what is a switchgear and what does it do. Like in your house, there is an manual switch that lets current into ones home, there are also fuses that short the system if there is too high a current coming in to your outlet. This same protection is also needed for high voltage. But, for high voltage it is not that simple to short the circuit. A more complicated design must be implemented, this is where the switchgear comes into place. Switchgear's are used in many fields and areas; industry, oilfields, wind farms et al. Most people have seen a small house box, this is known as a substation, nettstasjon. Figure 1.1, shows an example of a substation. The purpose of these substations, ensure a safe and reliable source of energy to the consumer. A station is comprised of one or several; distribution transformers, which job is to transform the high current into a current that the consumer can use. Dis-connector/ isolator switch, used to ensure that an electrical circuit is completely de-energized for service or maintenance. Switchgear, used to stop, lead and short load currents. It is the switchgear that is the focus of interest. Inside the switchgear, when a surge of current arises, the switchgear breaks the current, the result is an arc. In order to quench the arc, different ways have been developed, such as; oil immersed, distilled water, air pressure, vacuum switches and SF_6 Sulfur hexafluoride. The current desire is to replace the SF_6 with over-pressurized air.

Figure 1.1: A typical substation located around Norway - This a smaller one compared to where the switchgear that is being experimented on, it serves a illustrative purpose

There is a consensus among governments and organizations to limit the use of SF_6, since it is a potent green house gas. The switch to air will lead to a more green and environmental friendly products, paving the way for a future generations of air filled medium voltage switch gears. The issue with moving from SF_6 to air, is the heat generated inside and that SF_6 has a dielectric properties, acts as a dielectric and insulating material. This helps quench the arcing when a short has occur. If the arc is not quenched or removed sufficiently away, then the current will still flow from metal to metal via the arc. When an arc occurs, the temperature is increased, as well during nominal operation. The temperature must be under certain guidelines dictated by IEC. Which state that, temperature rise inside the open/close contacts must not exceed $65°C$ relative to $0°C$. For a braided configuration, the limit is raised by $10°C$. There are current talks, where the topic is to raise the limit by $10°C$, there are uncertainty surrounding a potential raise, for this thesis, the current guidelines will be followed. To achieve a temperature reduction, some possibilities have been proposed; combination of restricting heat generation on contacts and conductors, establish an effective heat transfer to the environment. There are many solution that are feasible, but the desire is to find an economical and simple technical manner, such that the temperature rise is limited. The proposed and a corner stone of this thesis, test and compare two different designs, sliding and braided contact, with plastic and aluminum crankcase.

1.1 Problem description

Using available equipment, establish and configure temperature measurement equipment. For both static and dynamic measurement collection. Map the temperature rise of the current LBS to that of the new design, which is a brained busbar and enclosed in an aluminum case tested against plastic casing. The same test is done with the rigid busbar design. The temperature mapping will be over the most critical parts; open/close, sliding, bolted contacts and busbars. Then measure the ambient temperature near the LBS along three spatial coordinates, x,y,z. Compare the two designs, analysis of the designs.

1.2 Motivation for task

HSN is engaged in a collaborative project together with NFR, ABB Skien, ABB Switzerland, SINTEF and NTNU. Where the goal is to prepare the scientific and technological basis for future generations of air filled medium voltage switchgear. Such that SF6 can be fazed out, leading to a more green and environmental friendly products.

1.3 Own contribution

In this thesis, the contribution ranges from academic and practical worth. Installment of acquired equipment, in this case; ABB and a initiative by Cameron Lindberg, to donate obsolete equipment, but still has value and application. The equipment, which is a data logging equip-

ment(Product name) for thermocouples, made by HP. There was no standard program to interface directly with the equipment, and therefor had to be programmed by the ground up in LabView. The functionality of program; collect the measured data, prepossessing of data, including alarms and other features, store the data for future post processing. In an academical sense, a explanation of my theoretical understanding in the fields of; heat transfer mechanisms, conduction in metallic conductors and the physics of electrical contacts.
In regards to the experimental goals; conduct power, resistance and temperature measurement for the given design changes. Where the changes are, Compare the design changes on the LBS.

Analysis of data, with the focus of effects of design changes, where and how does the heat move.
In my own volition and is added in the appendix. A manual is made in order to teach and guide future students on proper use of equipment, the thermal logging program and how to do modifications on the switchgear without error(s) and costly mistakes. The manual acts also as a documentation of how much practical work has been performed during the thesis. In the appendix, there are also added; information on the equipment used during the equipment, Hardware and software implementation.

1.4 Assumptions and Delimitations

For this project, certain assumptions and delimitations have been made.

Limitations The direction of radiation will not be taken into account.

Limitations Added mass and thermal paste is considered negligible with regards to crankcase size and emissivity

Chapter 2

Theoretical background

> Nothing in life is certain except death,
> taxes and the second law of
> thermodynamics.
>
> Seth Lloyd

In this chapter will contain and lay the theoretical foundation for this master thesis. The chapter outline will have flow as from electrical contacts, with what they are and how heat is generated, Then moving on to, how the heat is transfered from the body to environment. Then a brief explanation surrounding sensors, and finally

2.1 Heat transfer

The mechanisms of heat transfer with in a switchgear can be described by the following heat transfer mechanisms:

Conduction Conduction or diffusion The transfer of energy between objects that are in physical contact. Thermal conductivity is the property of a material to conduct heat and evaluated primarily in terms of Fourier's Law for heat conduction.

Convection The transfer of energy between an object and its environment, due to fluid motion. The average temperature, is a reference for evaluating properties related to convective heat transfer.

Radiation The transfer of energy by the emission of electromagnetic radiation.

Conduction is the most familiar heat transfer mechanism, in a basic sense; condition is transfer of energy from a high energy state to a lower energy state, given that the two regions are part of the same system. The equation for conductive heat transfer can be expressed by Fourier's law.

$$q_{cond} = -k\frac{\lambda S}{d}(T_i - T_j) \tag{2.1}$$

where λ is the thermal conductivity, S is the area of the heat exchange surface, T_j is the final temperature, T_i is the initial temperature, d is the distance between the two temperature points, λ is characteristics of the metal.

Radiation is electromagnetic energy emitted from a body that is above 0 K, this is valid for all types of states of matter, i.e. gas, solids, liquid and plasma. Photons are emitted from the body and out to the surrounding environment. Unlike the two methods of heat transfer, radiation is not dependent on a medium, such as a fluid or neighboring material, to transfer heat.[10] The radiative heat transfer is known as

$$q_{rad} = \epsilon\sigma A(T_s^4 - T_{sur}^4) \tag{2.2}$$

where σ is Stefan Boltzmann constant, A is the surface area that radiates the heat. T_s is the surface temperature and T_{sur} is the surrounding temperature. ϵ is the emissivity of the surface. The emissivity of a body, is the ratio between radiation emitted by the body to the blackbody radiation to that body at the same temperature. The perfect emitter has an emissivity of 1, which means that the emissivity ϵ, ranges between 0 and 1.[4] [10]

Convection is a combination heat transfer mode, since it encompasses energy transfer by bulk movement of macroscopic motion of fluids and random motion of fluid particles that collide with the surface of a conductive material. Inside the enclosure, there are no forced convection, on the other hand it is free convection. Since there are no forced velocities, such as a fan or other similar sources. The effects of free convection are much smaller then forced. Therefore, the heat transfer rate with free convection is reduced. The movement of particles is caused by a hot and cold region, due to the temperature and pressure difference, bouncy forces take in to effect, an generates convection currents. The governing equation for convection can be expressed as newtons colling law,

$$q_{conv} = hA(T_s - T_{sur}) \tag{2.3}$$

where h is the heat transfer coefficient, A is the surface area, T_s is the surface temperature and T_{sur} is the surrounding temperature.[9]

2.2 Resistance, joule heat

The Resistance is a measure how how good a material is of passing current through a conductive material. The initial resistance, R_i can be expressed by

$$R_i = \rho \frac{l}{A} \tag{2.4}$$

Where ρ is the electrical resistivity, l is the length and A is the cross sectional area. [3] The equation 2.4 , it does not take into account that resistances change with temperature. With in the scope of the thesis, only a linear model of temperature dependent resistor is used. Which is expressed as.

$$R(T) = R_i[1 + \alpha(T - T_0)] \tag{2.5}$$

Where $R(T)$ is the temperature depended resistance, α is the temperature coefficient of resistance, which for copper is $3.9 \cdot 10^{-3}$, T is the heated temperature and T_0 is the initial temperature.[11] When a current is passing a resistance, there will be generated heat, this heat is called Joule heating[3][2], which can be expressed as

$$P = IR^2 \tag{2.6}$$

2.3 The physics of electrical contacts

An electrical conductor leads current along the path in which the material shaped. When an electric conductor of material A, meets an electrical conductor of material B. A interface is formed between the two surfaces.

The definition stated in [11], is the one that will be used in this thesis.

- An electrical contact is defined as: the interface between the current -carrying members of electrical/electronic device that assure the continuity of electrical circuit and the unit containing the interface.

The surface of the metal plays an important role, when one joins two metals together one does not get a perfect contact between the two surfaces. Firstly, the current must break through an oxidate and other containment films e.g. grease from fingers. The metal is not smooth, it has a topology, like a mountain with tops and bottoms. This is the same for the surfaces. Only certain areas will have contact between the two surfaces.Now,when the current is starting to go through the oxide and film, the layer will be broken and small spots of conductivity will be the actual conductive area, called a-spots. In figure:2.1 one can the tops and bottoms, where there is contact between the two surfaces, that is where an a-spot is located.They are small cold welded conduction paths, it is only through these points areas that electrical current can flow. The theoretical calculation on how much the cross-sectional area can transfer between the electrical contacts is restricted to how many a-spots there are on the junction area.[11][8]

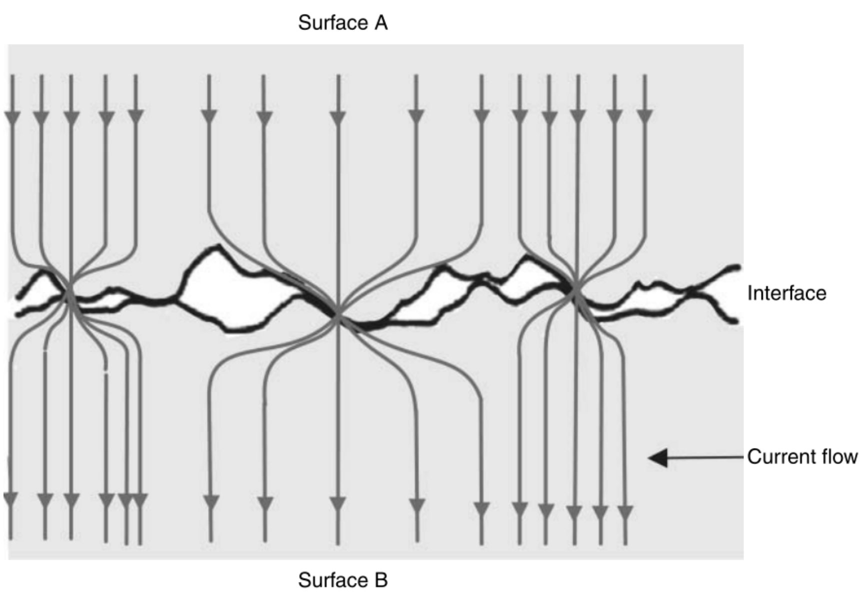


Figure 2.1: Illustrative figure of the interface between two surfaces, forming a-spots [11]

The most common **electrical conductive material** by far is Cu, copper. In resent times Al, aluminum has been used as the electrical conductivity material, this is due to cost and weight. Silver is often used to coat surfaces for various reasons. With the materials one can make different types of contacts, the most relevant are sliding, bolted, braided and open/close connection.

sliding The connection slides between two surfaces, once in position the two surfaces will conduct electricity.[2]

braided The braided connection, is a set of wires that are braided. The result is a flexible resistance.

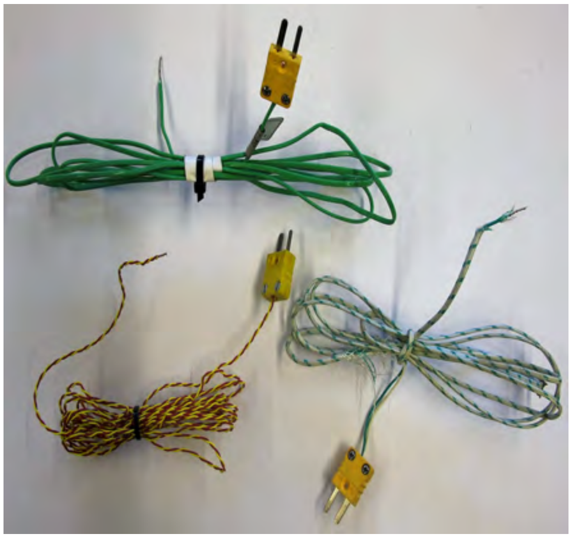
bolted The two surfaces are held together by using a bolt(s)[2]

2.4 Two wire method

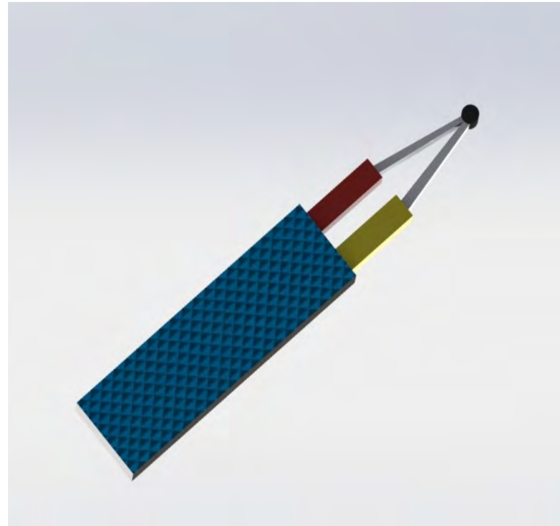
The two wire method is a method used to measure the power sent in to a system.

2.5 Thermocouples

A thermocouple is a temperature-sensing device. The thermocouple is comprised of two dissimilar metallic alloys, which form a junction at the tip. At the ends, the voltage is measured. This is the basic explanation on how thermocouples measure the temperature. Figure2.2, show how thermocouples look like.
In detail, two dissimilar alloys are joined in a junction, ether by forced braided or soldered together, often referred as the "measuring junction". If temperature is increased at the junction point, there will be generated a voltage difference between the two terminals, the cause of the voltage increase is known as the Seebeck effect. The Seebeck effect also works for a single metal wire, if a region is heated, the voltage difference between the two terminals is increased. The use of dissimilar alloys is to improve the accuracy and get the largest possible voltage.



(a) Thermocouples used in experiments, real



(b) Thermocouples used in experiments, cad model

Figure 2.2: Depiction of thermocouples used in the experiments and a CAD model of a thermocouple for illustrative purposes

Since the concept of a thermocouple is simple, one may think it is easy and simple to use. This is not the case, one must aware of the inner working and limitations of thermocouples. For if used improperly, the measurement results may be misrepresented and give unrecognized measurement error.

2.6 Current path from current injector to LBS

In figure 2.3, show the LBS and where the different types of connections are located.

The current injector take the feed input and transforms to an desired current, in this case 630 amp at 5V. The current goes to the output terminals, where the analysis starts. Here the first electrical contact is encountered, which is two metallic plates hold together by an bolt, ergo bolted contact. The connection must be as secured, fastened and tightly as possible to ensure a good electrical connection. Then the current is passed to the wires, until they meet the next electrical contact The current enter the LBS from the bushings, it goes through the LBS, through the busbar, and down through a LBS, into the bushing and out of the LBS.

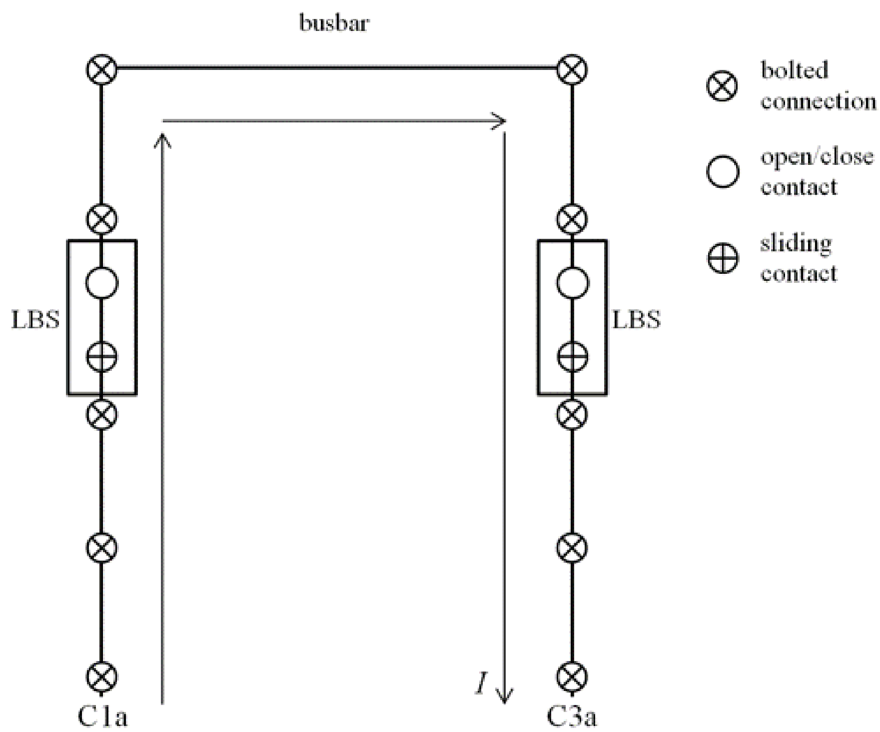


Figure 2.3: fhfh

2.6.1 Heat path analysis from Current injector to ABB Switchgear

As the electrons move through the components of the LBS conductive path, a joule heating occurs. As each part gets heated, the heat must be transfered out to the surroundings by radiation and convection, While the conductive spreads heat to neighboring components that are physically linked.

2.7 International Electro technical Commission - IEC

The International Electro technical Commission (IEC) is the world's leading organization for electrical standards. The IEC sets the standards for how electrical components can communicate with each other and the interface between the system(s). The IEC standard forms a universal language, which makes it easier for international companies to make compatible products. The IEC bla The points of interest are; for a sliding contact the temperature rise is $65°C$ relative to zero, for braided contact the limit is set to $75°C$.

Chapter 3

Experimental design

> A mind needs books as a sword needs a
> whetstone if it is to keep its edge.
>
> Tyrion Lannister

In this chapter the methodology and how the experiments are set up. Based on this chapter one shall be able to replicate the experiments.

3.1 Experimental setup

The experiments are done using a 12kV custom made prototype switchgear. Which has the main purpose for testing and verification. The unit at hand, consists of three modules, where C1 and C3 are connected, as shown in Figure 3.1 are connected to LBS in the three phases. The center module V2, is electrically disconnected. Once the switchgear is closed up, leaving the inside to be ambient air at 1 am pressure.

Figure 3.1: Switchgear with phase indicated

The input current is set to 630 Ampere, rated three phase current, at a frequency of 50 Hz, sinusoid signal. Which is delivered by in-house current injector. Figure B.2, shows the equipment used.

3.2 Load break switch

The load break switch as it is fully assembled.

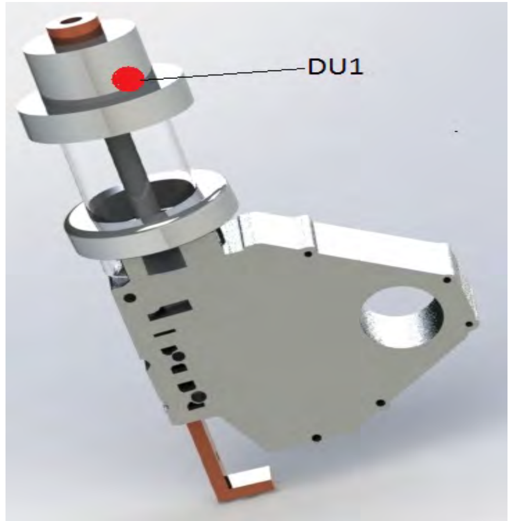
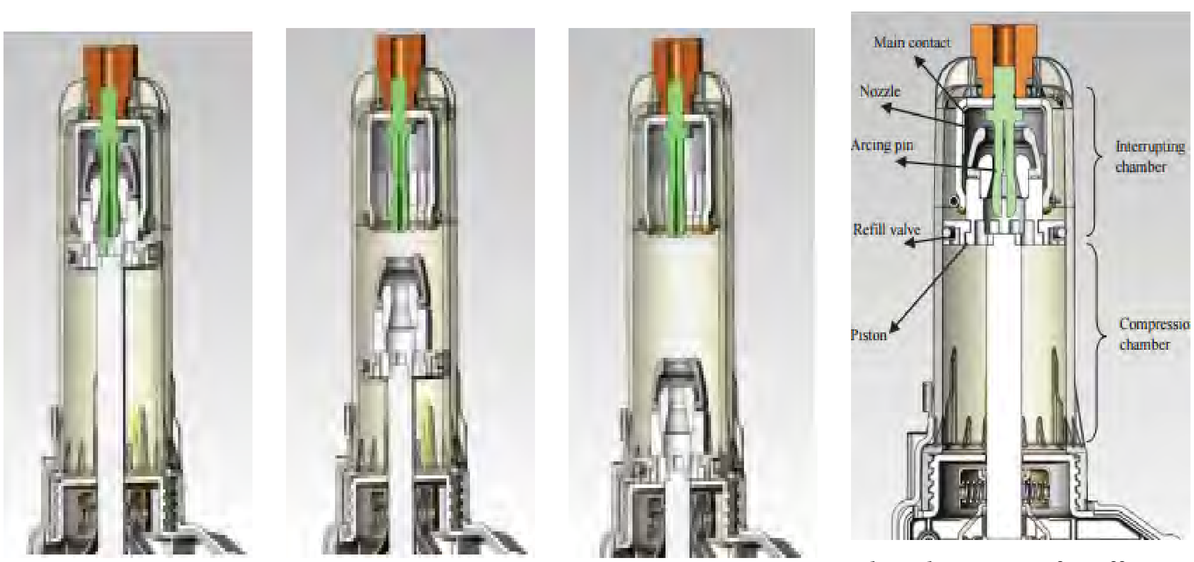


Figure 3.2: A complete LBS

A load break switch, has the task of breaking the the current path between two surfaces(arcing pin and nozzle, figure 3.3d), an mechanical system that breaks the contacts from each other when an arc is occurring. The LBS in question is based on puffer principal. Which is like piston, where compressed gas is used to build up pressure(figure 3.3a), once the piston breaks the electrical connection, figure 3.3c the pressure difference helps quench the arc, analogously like a candle being blown out.[6] [14]

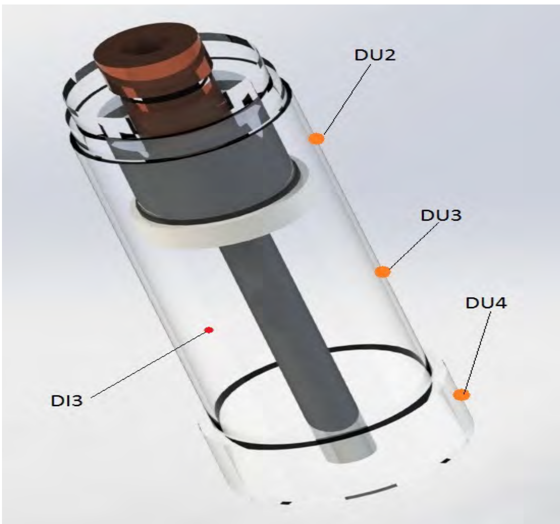


(a) Puffer sequence, A (b) Puffer sequence, B (c) Puffer sequence, C (d) Schematic of puffer interrupter

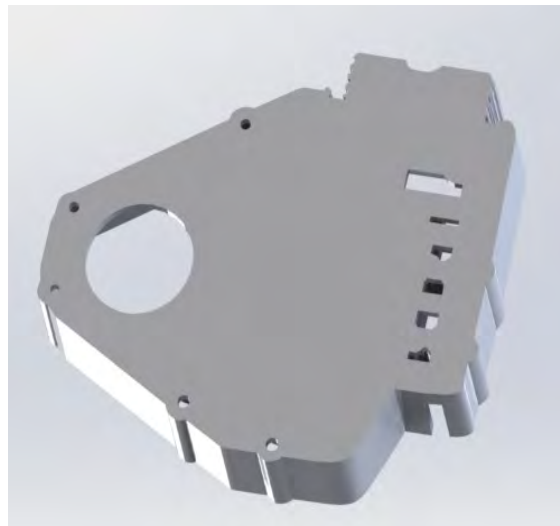
Figure 3.3: Puffer interrupter during operation and schematic of layout [6]

3.2.1 Parts forming a LBS

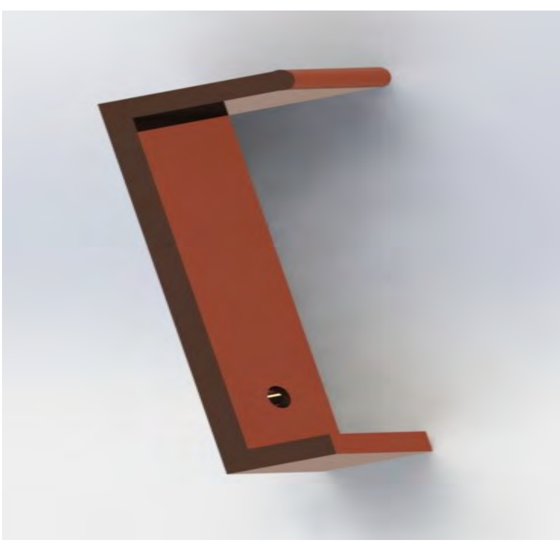
The LBS consists of a puffer switch encapsulated inside a pressure cylinder, 3.4a which leads to the sliding connection, which is the interface connection between the rod and the copper connection. The crankcase that holds the parts in place, such that a mechanical force can break the connection between the arc pin and nozzle, figure 3.3c



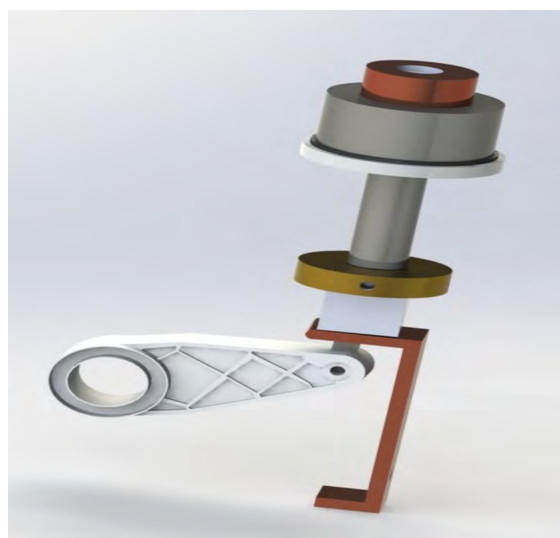
(a) Main connection with piston, encased in pressure cylinder



(b) Plastic crank case



(c) For sliding contact, copper connection



(d) A complete image over the stripped sliding contact

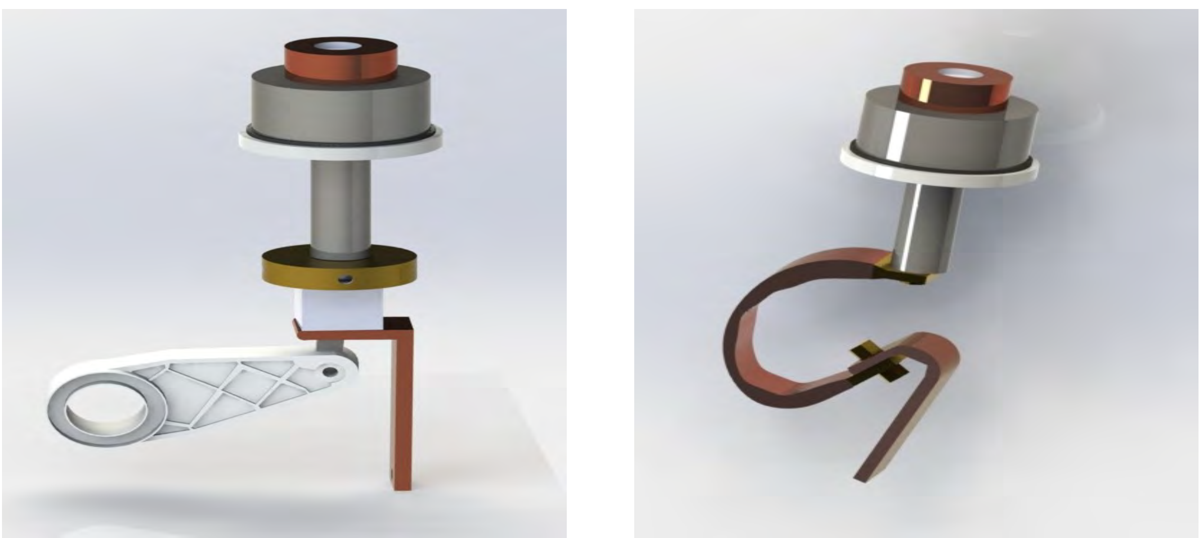
Figure 3.4: Illustrative overview of what parts form the LBS

3.3 Different designs for testing

The design changes are both a change in operation internally and a simple change of materials on the crankcase. The first design change is to replace the sliding contact with a braided contact, as shown in figure 3.5 and the other design change, replace and compare the effects of changing the material of the crankcase from plastic to aluminum.

3.3.1 Stripped sliding and braided

The LBS designs are tested in a stripped manner, i.e. all of the items that ensure nominal function are detached, such as pressure cylinder and crankcase. Forming only the essential functionality, which is to study the current path and evaluate the resistance of the different elements.



(a) Sliding contact stripped, 3d model

(b) Braided contact, 3d model

Figure 3.5: Caption for this figure with two images

For clarity, the configuration in figure3.5a is called sliding and in figure 3.5b configuration,

3.3.2 Crankcase - plastic vs aluminum

The LBS designs are tested in a stripped manner, i.e. all of the items that ensure nominal function are detached, such as pressure cylinder and crankcase. Forming only the essential functionality, which is to study the current path and evaluate the resistance of the different elements.

(a) Sliding contact stripped, 3d model

(b) Braided contact, 3d model

Figure 3.6: Caption for this figure with two images

3.3.3 Experimental path

Stripped contacts A stripped down LBS, where the crankcase and pressure cylinder is removed. This is to see how heat is generate without any components

Sliding plastic crankcase The standard configuration for the LBS with a plastic crankcase

Sliding aliminium crankcase The standard configuration for the LBS, but now the plastic crankcase is replaced by an Aluminum crankcase.

Sliding improved thermal connection The standard configuration for the LBS with Aluminum crankcase, but the thermal connection between the copper connection and crankcase is improved.

Sliding coated aliminium crankcase The standard configuration for the LBS with Aluminum crankcase, now the crankcase is coated, such that the emissivity has increased.

Braided plastic crankcase The new configuration, braided contact is tested with a plastic crankcase.

Braided aliminium crankcase Braided contact with with aluminum crankcase

Resistance measurement Resistance measurements are done pre and post a heat run.

Power measurement Power measurements are executed when the system is in steady state

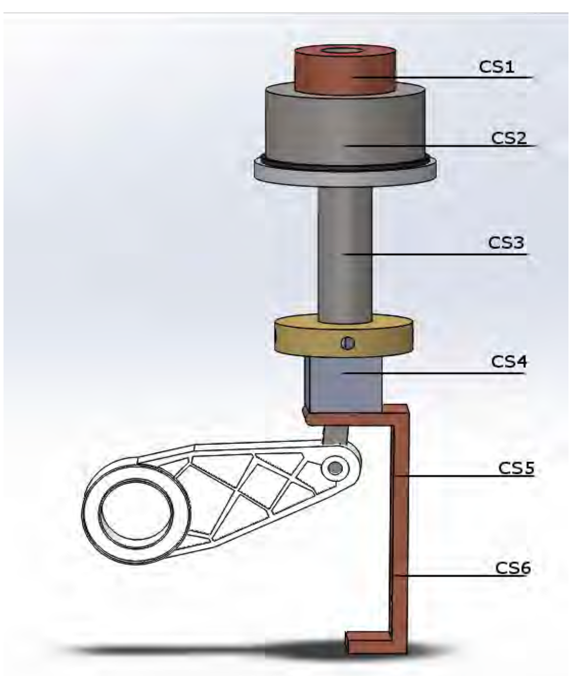
Emissivity Parallel with the experiments, using a thermal camera the emissivity of the components is conducted.

3.4 Sensor points on LBS

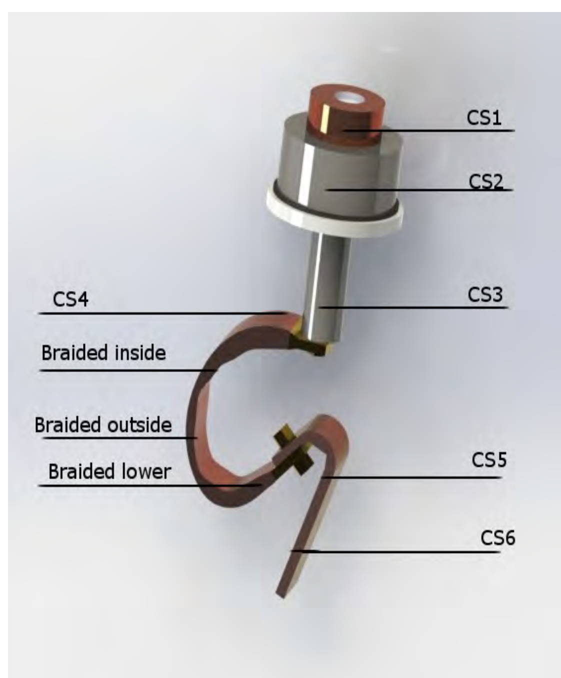
The sensor placement is critical for future calculation and measure what is of importance. The measurement points are placed in three main category's: on the connection path for sliding (3.7a) and braided (figure 3.7b), on the inside and the outside of the pressure cylinder and crankcase, and finally on the inside ambient(figure 3.9d), .

3.4.1 Sensors on Stripped Sliding and Braided contact

The thermocouples are placed on the current path, where they are designated the code name of CSx, control surface, where x is the number indicating downwards on the stripped sliding and braided contact. For the braided contact, there are three new points: B1,b2 and B3. The points are added such that CS naming is consistent between both designs.

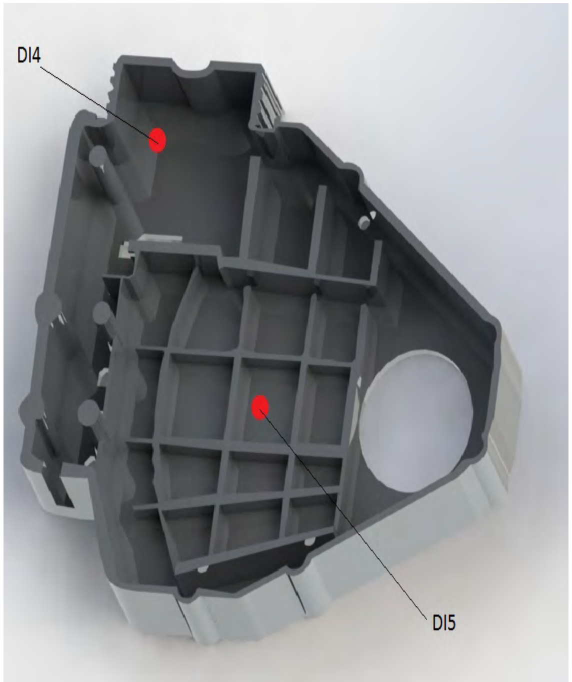


(a) Sensors placed on stripped sliding, CAD model

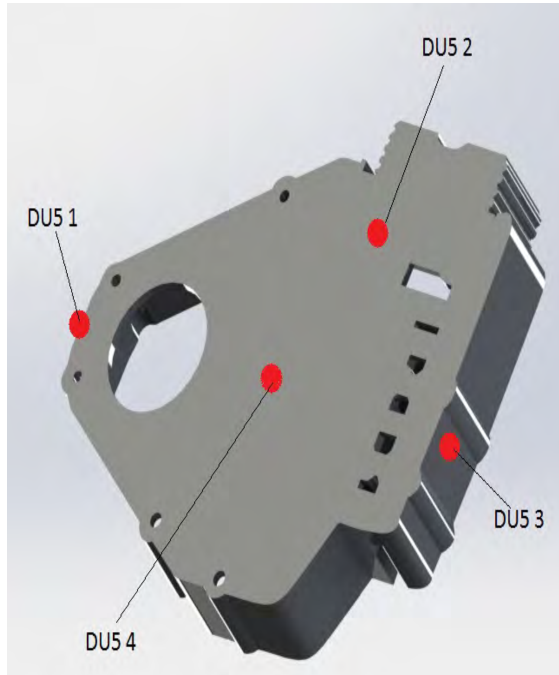


(b) Sensors placed on Braided, CAD model

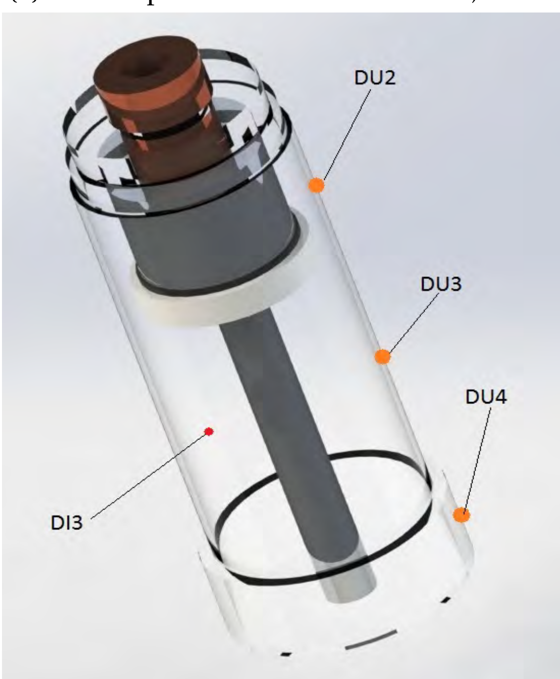
3.4.2 Sensor placement on individual LBS part



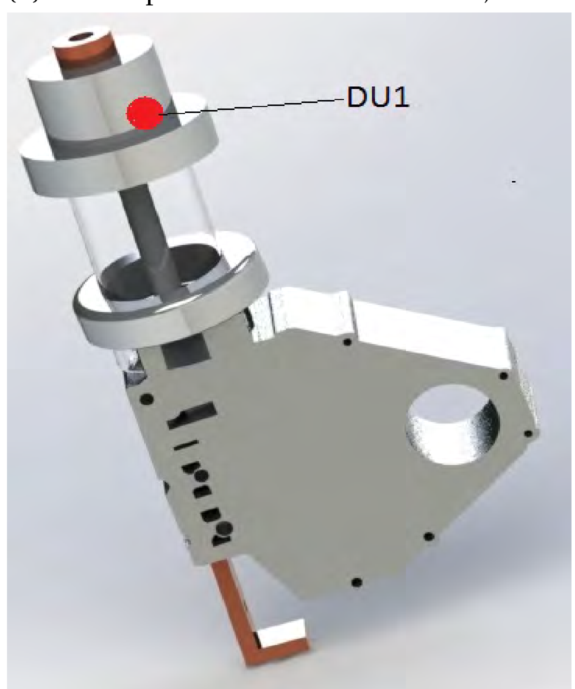
(a) Sensors placed on crankcase inside, CAD model



(b) Sensors placed on crankcase outside, CAD model



(c) Sensors placed on pressure cylinder and rod , CAD model

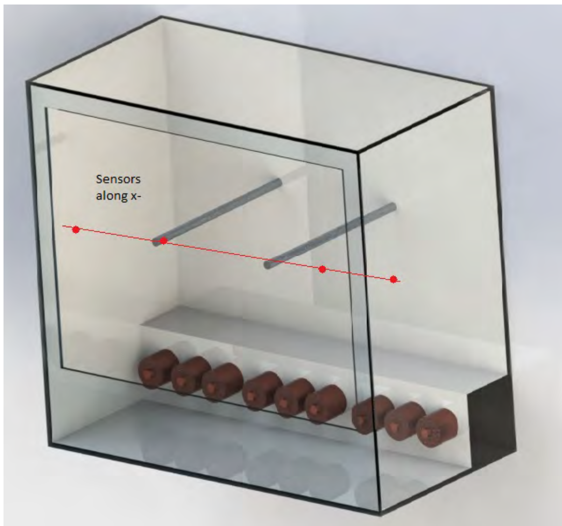


(d) Sensor placed on top field ring, with a complete LBS, CAD model

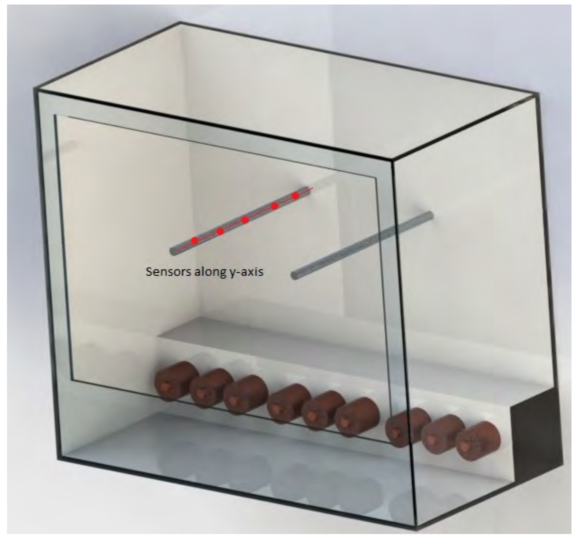
Figure 3.8: Sensors placed different parts forming the complete LBS

3.4.3 Sensor placement inside enclosure

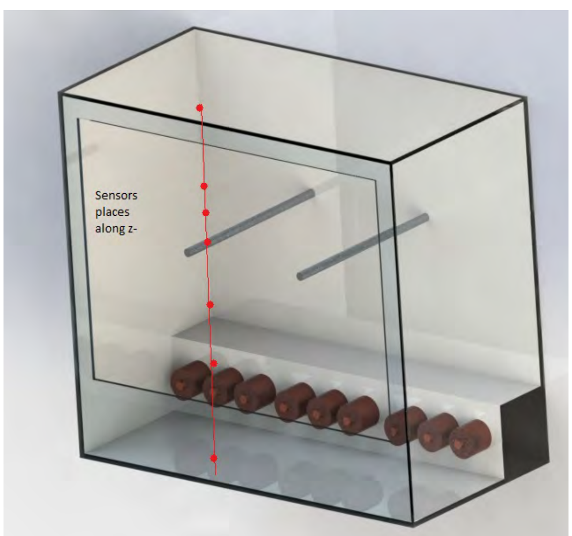
In order to provide a clear understand over where the sensors are placed inside the encapsulate. A CAD figure shows the sensors placed along axis, Figure 3.9a along x axis, Figure 3.9b along y axis, Figure 3.9c along z axis, and lastly Figure 3.9d shows the sensors name and placement scaled relative to real sensor placement.



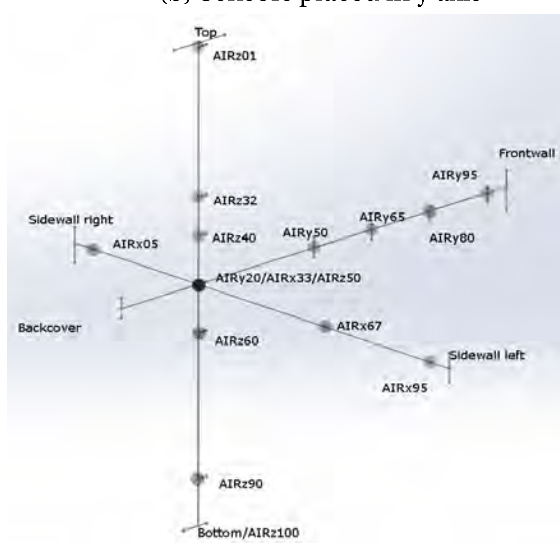
(a) Sensors placed in x axis



(b) Sensors placed in y axis



(c) Sensors placed in z axis



(d) 3d axis with labeling of sensor name and placement. The distances are scaled relative to real sensor placement

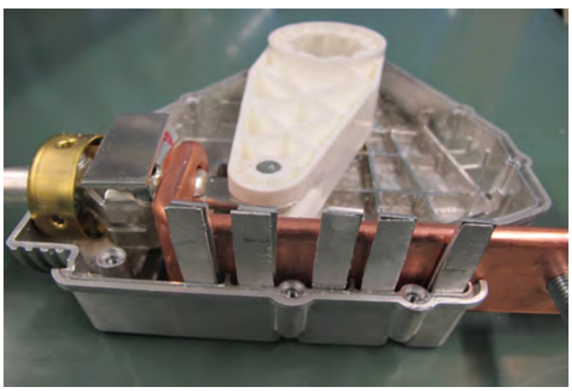
Figure 3.9: Sensor placement in 3 axis inside the enclosure, and a 3d axis with naming of sensors

3.5 Measures to improve the thermal heat transfer

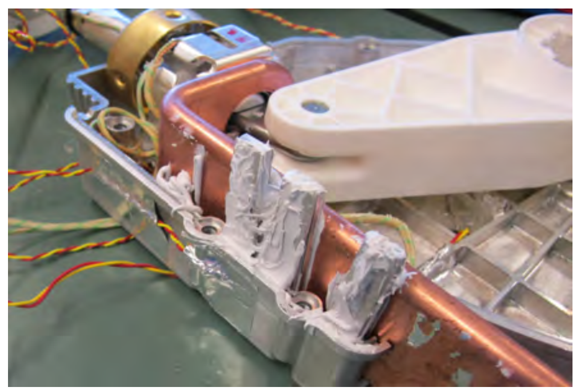
In order to improve the conductive transfer from the sliding contact. Based on eq:2.1, in order to increase the conductive heat transfer, two variables are chosen t manipulate to find the maximum conduct heat exchange between two surfaces, the distance between the contact point and increase the thermal conductivity by using thermal paste.

3.5.1 Improved thermal contact with copper connection and crankcase

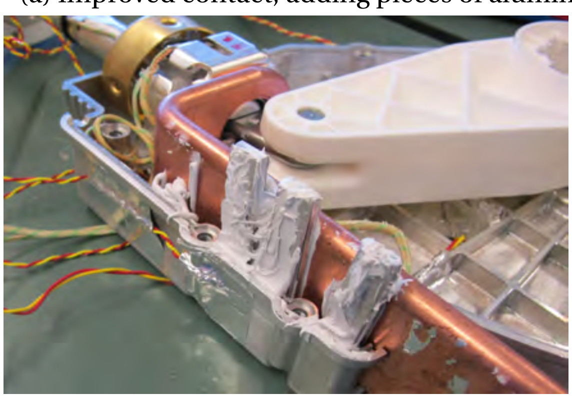
The physical connection between the sliding contact the aluminum crankcase are not designed for conducting heat from the electrical contact to a crankcase. The sliding contact has been modified such that the heat conduction is increased. This was achieved by adding strips of aluminum and thermal paste to create ideal conditions. The stripes are added due to the air gap between the electrical contact and crankcase see figure 3.10



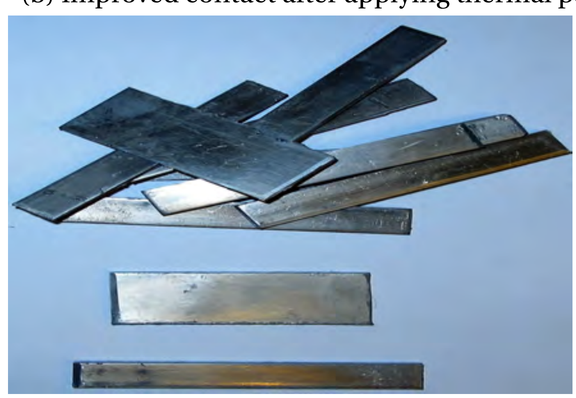
(a) Improved contact, adding pieces of aluminum



(b) Improved contact after applying thermal paste



(c) Thermal paste used



(d) Pieces of aluminum

Figure 3.10: Caption for this figure with two images

3.5.2 Coating

In order to increase the surface emissivity of metals, one option is coat the metal with black heat resistant material. There are other ways of increasing the surface emissivity of an metal, in this case the heat resistant spray has been selected due to cost and simplicity with applying the measure. There are two parts what are if interest to coat; crankcase and upper and lower field-rings. as shown in Figure 3.11

(a) Bare aluminum field rings

(b) Coated aluminum field rings

(c) Bare aluminum crankcase

(d) Coated aluminum crankcase

Figure 3.11: Illustration over the bare and coated field ring and crankcase

The reason for coating is to increase the ability of a metal to radiate more efficiently, given the formula 2.2, the emissivity will act as a ratio control over how much energy can be radiated. The closer to 1, the more the surface can radiate out to the environment.

3.6 Resistance and resistance measurement

Thee switchgear and LBS, are not designed to be experimented upon, but in order to verify that that the design changes shall have the same resistance values, resistance measurements must be conducted. Inconsistent resistance measurements is a frequent problem, for both ABB and previous work done [15]. Resistance measurement is achieved by sending 100A DC into to the switch gear, and measure the voltage across two desired terminals. The reasons for using 100 A DC are as follows; IEC states that a minimum direct current of 50 A, since the resistance as so low, a higher current will increase the accuracy of the measurements, and a design choice of 100 A was made in order to simplify computations , such that operators can omit the use of calculators and “directly” measure the resistance. Since Ohm’s law, is given as

$$U = RI \tag{3.1}$$

By prearranging

$$R = U/I \tag{3.2}$$

with eq:3.2, the resistance can be found

3.6.1 Sliding

For the sliding connection, the resistance has been measured to be Using the relation eq: 3.2 The resistance can be calculated.

$$R = UI = 45 \cdot 100 = 45 \pm 0.225 \mu\Omega \tag{3.3}$$

3.6.2 Braided

The theoretical resistance can be calculated from using eq:3.4, since the material is braided, which is not the same as solid rigid metal. The mass is measured and the dimensions are known, the total resistance is calculated from mass and length.

$$m = \rho V = \rho \cdot A \cdot l \tag{3.4}$$

by rearrangement

$$A = \frac{m}{\rho l} = \frac{480}{8.96 \cdot 32} \frac{g}{cm \cdot g/cm^3} = 1.67cm^2 \tag{3.5}$$

Dimensions of braided contact

	Contact [mm]	Braid [mm]
length	320	2500
width	360	275
depth	80	120

Table 3.1: Braided connection dimensions, in millimeters

theoretical resistance for braided contact

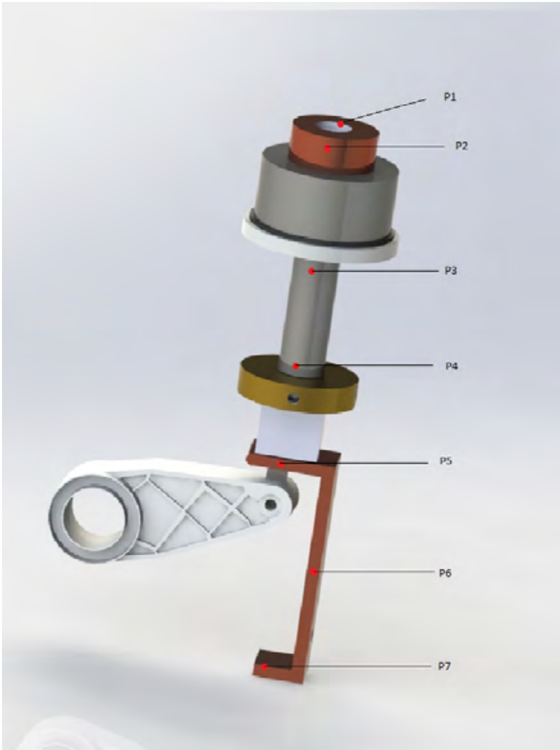
$$R = \frac{\rho l}{A} \tag{3.6}$$

where ρ is the resistivity of the material, for copper is $1.68 \cdot 10^{-8} [\Omega m]$, l is the length and A is the cross sectional area, found in eq: 3.6, which equates to a theoretical bulk resistance of

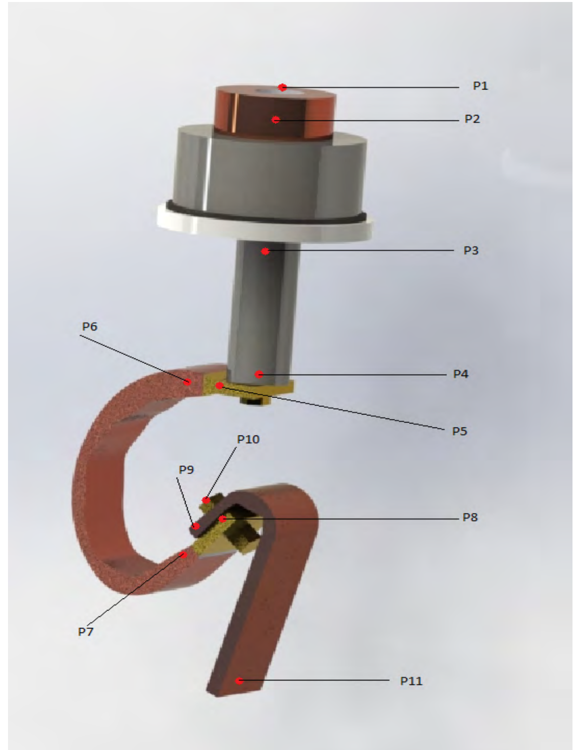
$$R = \frac{1.68 \cdot 10^{-8} \Omega m \cdot 0.35m}{1.66cm^2} = 25.3 \cdot 10^{-6} \Omega \tag{3.7}$$

3.7 Resistance points for sliding and braided contact

In order to measure the resistance, one has to measure the voltage drop over specified points. These points are define in figure:3.12a for the resistance points on sliding contact. Figure 3.12b, shows the resistance points on braided contact.



(a) Measurement points for sliding contact

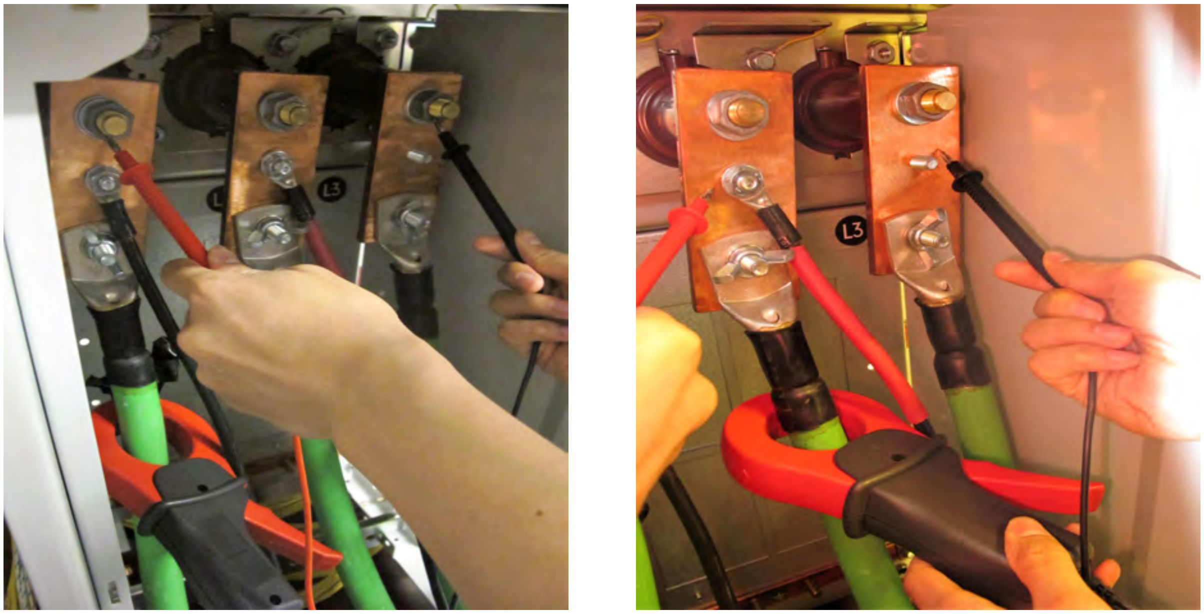


(b) Measurement points for braided contact

Figure 3.12: Measurement points for finding the resistance - Sliding and braided contact

3.8 Power measurement

In order to measure the power into the switchgear, a watt meter is used to measure how much watt is being sent into the system. One measures the L1-L3 as shown in figure:3.13a with the coil at L1. Then the same is done for L2-L3 with the coil at L2, figure:3.13a The sum of the two measurement is the total watt times a factor of 1000. This is due to the coil and Lenz law. [5]



(a) Photograph of how to measure the power, L1-L3 (b) Photograph of how to measure the power, L2-L3

Figure 3.13: How to find and perform a watt meter test

3.9 Surface area

The surface area of the LBS components is calculated by using Solidworks. The surface area is needed in future calculations.

Table 3.2: Calculated surface area for each part of the LBS. The calculations are computed in Solidworks, some design simplifications are made which reduce the accuracy.

Name	Surface area
Copper top	0.00547
"Tulip"	0.01400
Rod	0.00760
Sliding	0.01213
Copper connection S	0.0235
Copper connection B	0.0173
Crankcase, Plastic	0.08489
Crankcase, AL	0.08489
Crankcase, coated	0.08489
Plastic cylinder	0.04

3.10 shield

Previous attempts at describing the discrepancies between IEC model and work done by HSN and ABB. One idea has emerged, could the thermocouples be affected by the radiation? Could shielding the thermocouples result in more accurate measurement of the ambient temperature?

(a) Photograph of how to measure the power, L1-L3

(b) Photograph of how to measure the power, L2-L3

Figure 3.14: Measurement points for finding the resistance - Sliding and braided contact

The plan is to heat up the system, let the thermocouple be shielded while the current is on. Once steady state temperature has been reached, pull up the shield, and see if there are any temperature difference. In parallel, the same type of test is conducted, but the difference is the thermocouples are sealed inside a sheet of aluminum. hence the thermocouples are not affected by radiation.

Chapter 4

Results

> The greatest power on earth is the
> magnificent power we all of us possess...
> The power of the human brain!
>
> Charles Francis Xavier

In order to be clear and concise, some definitions will be stated. This is to be clear on the framework and wording on different areas and parts.

Warm The resistance value over the LBS after doing a heat run

Cold The resistance value over the LBS before doing a heat run

Ambient Room temperature

Surrounding The temperature inside the switchgear

Inside The temperature inside the LBS. I.e Inside the pressure cylinder and crankcase

Outside The temperature outside on the crankcase and pressure cylinder

4.1 Resistance and power measurements

Resistance measurements are performed on all the experiments. The measurements points are depicted in figure 3.12a for sliding contact and Figure:3.12b for braided contact. Figure:4.1 shows the resistance measurements performed over stripped sliding contact, and Figure:4.2 shows resistance measurements performed on the braided contact. In Figure:4.3, the post and preheat run measurement are presented. Lastly, Figure:4.4 show the power measurements into the switchgear at steady state.

4.1.1 Resistance for sliding an braided contact

Table 4.1: Resistance measurement for stripped sliding contact, Figure 3.12a shows where the measurement points are located on the LBS.

Description	Label	Resistance value [$\mu\Omega$]
Copper top	P1-P2	1.9
'Tulip'	P2-P3	6.9
Rod	P3-P4	3.5
Sliding contact	P4-P5	17
Upper part of copper connection	P5-P6	3.1
Lower part of copper connection	P6-P7	1.5
Top to end of sliding contact	P1-P5	31.6
Sliding copper connection	P5-P7	4
Sum of P1 to P7	P1-P7	35.4
Measured from P1 to P7	P1-P7	33.9

Table 4.2: Resistance measurement for stripped braided contact. Figure 3.12b shows where the measurement points are located on the LBS.

Description	Label	Resistance value [$\mu\Omega$]
Copper top	P1-P2	0.6
'Tulip'	P2-P3	4.8
Rod	P3-P4	5.4
Braided Contact	P4-P9	17
Copper connection	P9-P11	4.7
Braided connection	P5-P8	23.6
Braided copper connection	P1-P5	31.6
Sum of P1 to P7	P1-P7	35.4
Measured from P1 to P11	P1-P7	33.9

4.1.2 'Warm' and 'cold' resistance measurements

Table 4.3: Warm and cold resistance measurements for sliding and braided contact

	Sliding Cold [$\mu\Omega$]	Sliding Warm [$\mu\Omega$]	Ratio [$\frac{warm}{cold}$]
Stripped	62	48	0.77
Plastic	47	51.7	1.1
Aluminum	43	51.6	1.2
ITC	48	42.1	0.87
Coated	35	43.75	1.25
	Braided cold [$\mu\Omega$]	Braided warm [$\mu\Omega$]	Ratio [$\frac{warm}{cold}$]
striped	44	52.8	1.2
Plastic	42.2	51.9	1.23
Aluminum	45	53.5	1.18

4.1.3 Power measurement

The power measurements into the switchgear. The transformer take a voltage and converts it up to a desired out ampere, in this case 630 Ampere. Right before the current enters the switchgear, at steady state, using a watt meter. The power input is measured. Table:4.4, shows the measured power.

Table 4.4: Power input measurement for sliding and braided contact

	Sliding power [W]	Braided power [W]
Stripped	360	370
Plastic	390	390
Aluminum	380	380
ITC	390	
Coated	400	

4.2 Emissivity

In order to use the radiation heat transfer equation, eq:2.2 the emissivity must be known. The emissivity was found by using a thermal camera, as explained in B.3. The x method was used, as in accordance with ISO 18436-7:2014 standard, [1] The measured emissivity values for each component is presented in Table 4.5

Table 4.5: Measured emissivity of the components used

Part	Measured emissivity
Copper bus bar - Sliding	0.27
Copper bus bar - Braid	0.27
Braid wire	0.38
Rod	0.07
Sliding connection	0.07
"Tulip" connection	0.07
Pressure cylinder	0.75
Plastic crankcase	0.92
Aluminum crankcase	0.15
Field ring, bottom	0.14
Field ring, top	0.14
Coated Field ring, bottom	0.80
Coated Field ring, top	0.80
Coated Aluminum crankcase	0.80

4.3 Temperature correction

The ambient temperature is not constant, the room is influenced by many factors; opening/closing of door, amount of people is inside, temperature outside, how much sun light is emitted into the room and how much heat is generated by the switchgear. Many factors contribute to heat change inside the room. Therefore, a measure of correction must be implemented to compensate for the changes, all the temperatures will be scaled such that the ambient temperature will be 24˙C. The value of 24 is chosen due to being the closest common number to all values, as see in Table:4.6

Table 4.6: Measured ambient temperature during experiments

Name	Sliding°C	Braided°C	Corrective value Siding	Corrective value braided
Stripped ambient temperature	23.6	23.5	0.4	0.5
Plastic ambient temperature	23.96	24.47	0.04	-0.47
AL ambient temperature	24.21	24.91	-0.21	-0.91
ITC ambient temperature	23.99	-	0.01	-
Coated ambient temperature	25.36	-	1.36	-

4.3.1 Corrected temperature for surrounding temperature

When computing the Net Radiation Loss Rate, given by eq: 2.2 The surrounding temperature T_{surr} must be define, in the scope of this thesis, the T_{surr} will be the average of the wall temperatures. The measurements are based on previous work done on mapping the inside temperatures. [13] For convenience, the values are presented in table 4.7

Table 4.7: Temperature on the inside wall of a switchgear and temperature corrected values [13]

Name	Temperature in °C
Left side wall	39.8
Right side wall	41.40
Top wall	41,5
Back plate	34.9

To simplify the computations, the average value of the wall temperature is used. Which is computed to be 39.6$DegC$. The values in Table 4.6 and 4.7 must be corrected such that the wall temperature and ambient match. The correct values are presented in table: 4.8

Table 4.8: Corrected ambient temperature during experiments

Name	Corrected AVG Temp Sliding °C	Corrected AVG Temp Braided°C
Stripped	40	40
Plastic	39.64	39.13
AL	39.39	38.8
ITC	39.61	-
Coated	39	-

4.3.2 Ambient temperature

The ambient temperature is measured, the ambient temperature is used to calculate the relative values for

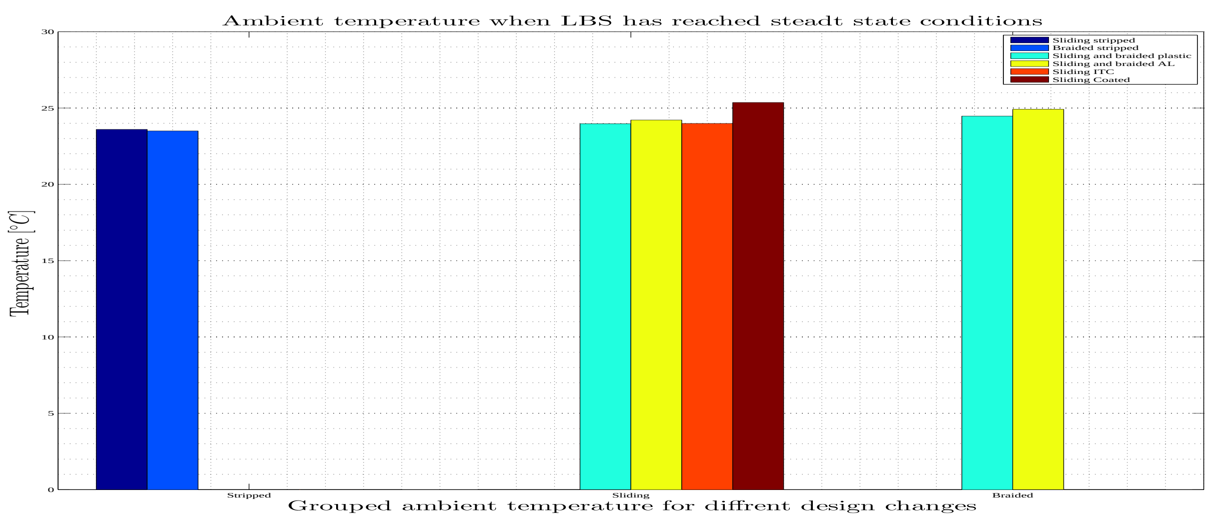
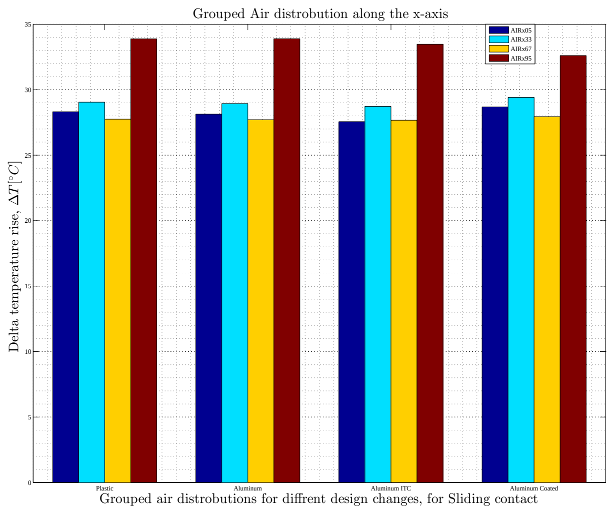


Figure 4.1: Grouped ambient temperature for all experiments conducted

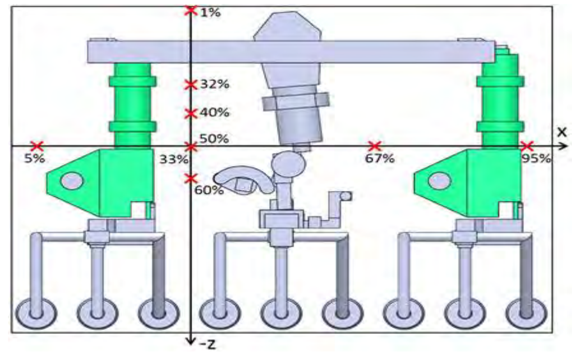
4.4 Grouped - Sliding vs Braided

In this section the results from each experiment is presented. All the measurements are grouped, this is to simplify the analysis by compare the measure values against each other. The layout: measurement is the left and sensor placement on the right. For a induvidual measuremtn result, see appendix

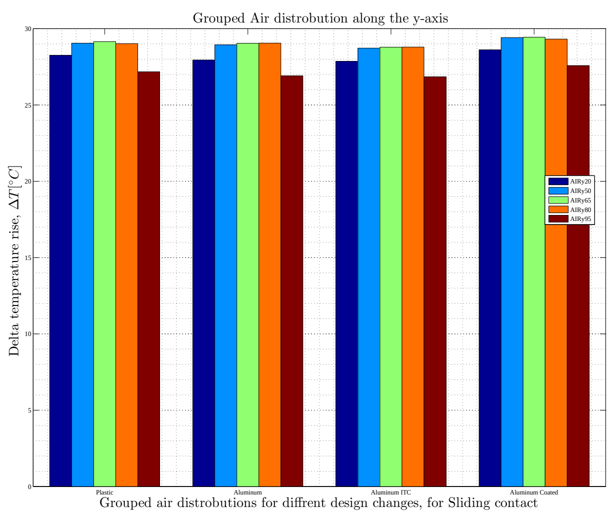
4.4.1 Grouped surrounding temperature - Sliding and Braided



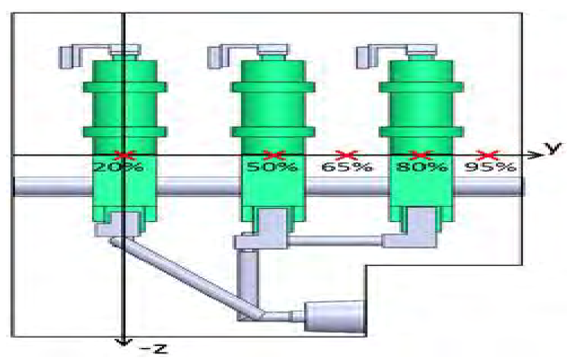
(a) Grouped surrounding temperatures along x-axis



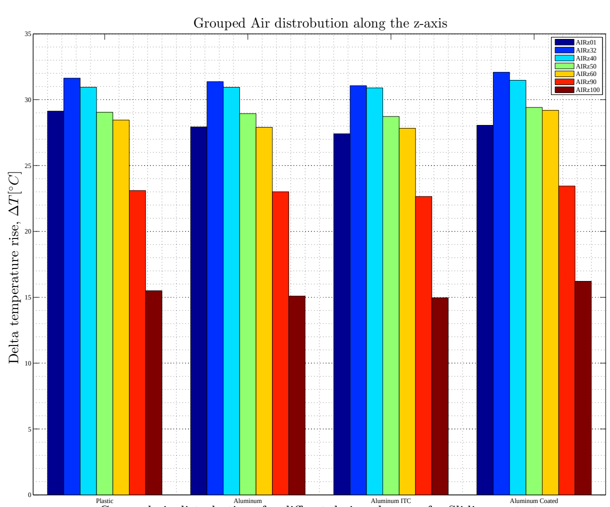
(b) Sensor placement for zx axis



(c) Grouped surrounding temperatures along y-axis

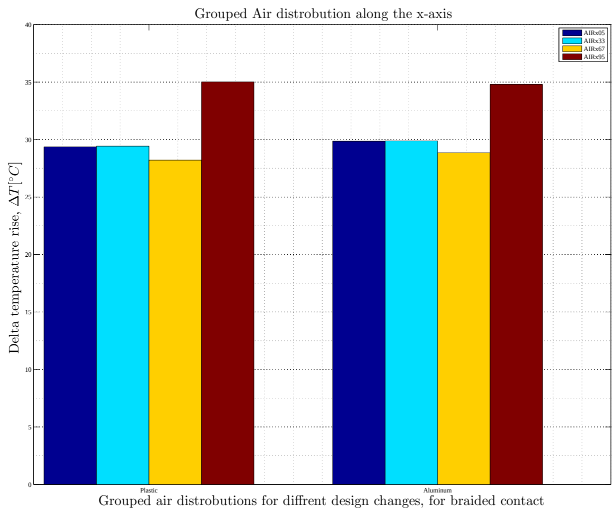


(d) Sensor placement for y axis

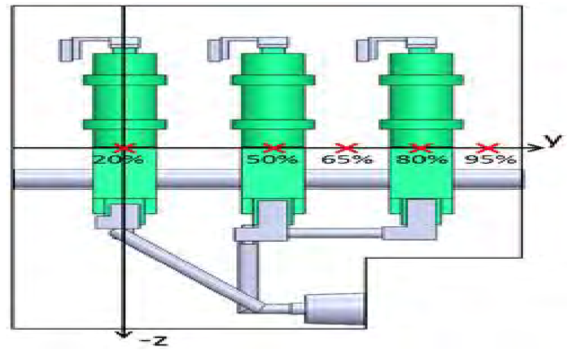


(e) Grouped surrounding temperatures along z-axis

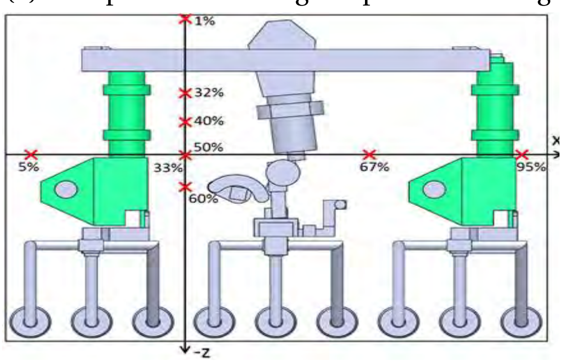
Figure 4.2: Grouped surrounding temperature along x,y,z axis for Sliding contact for different design changes



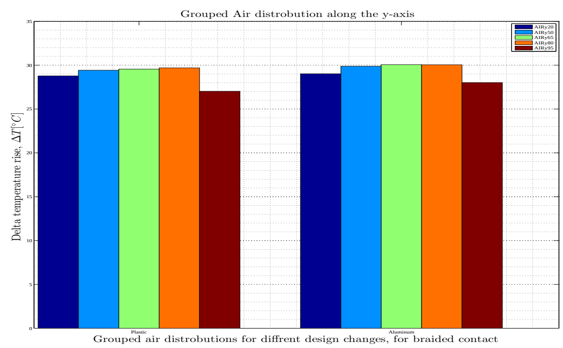
(a) Grouped surrounding temperatures along x-axis



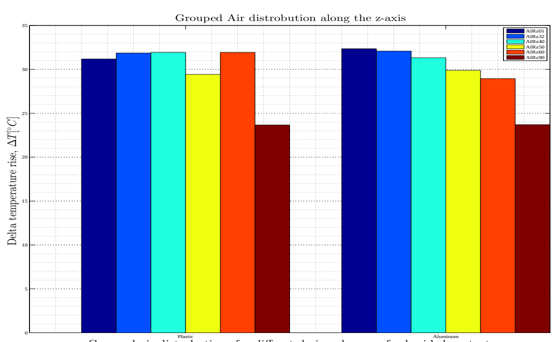
(b) Sensor placement along y-axis



(c) Sensor placement for zx axis



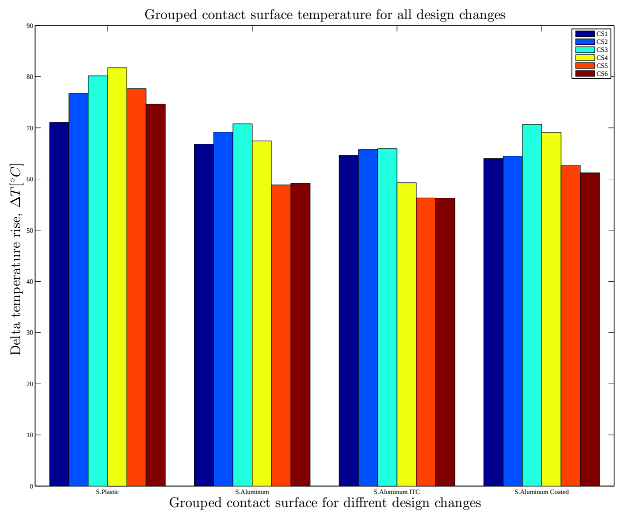
(d) Grouped surrounding temperatures along y-axis



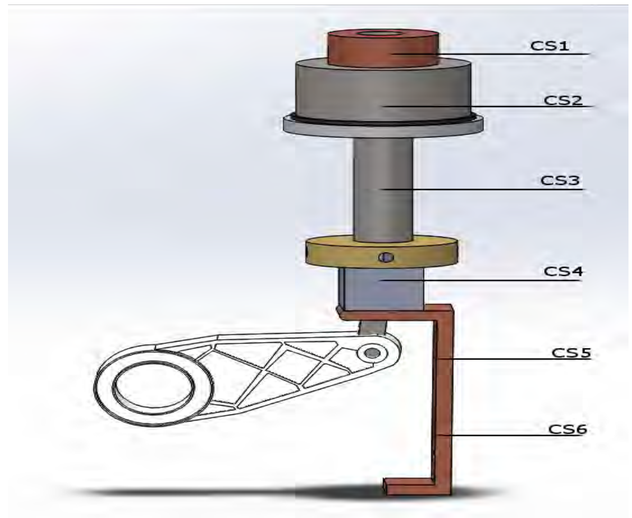
(e) Grouped surrounding temperatures along z-axis

Figure 4.3: Grouped surrounding temperature along x,y,z axis for braided contact for different design changes

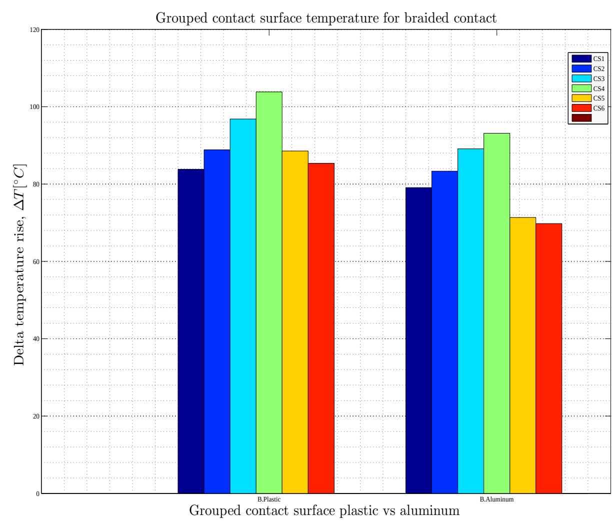
4.4.2 Grouped conductive surface temperature - Sliding and Braided



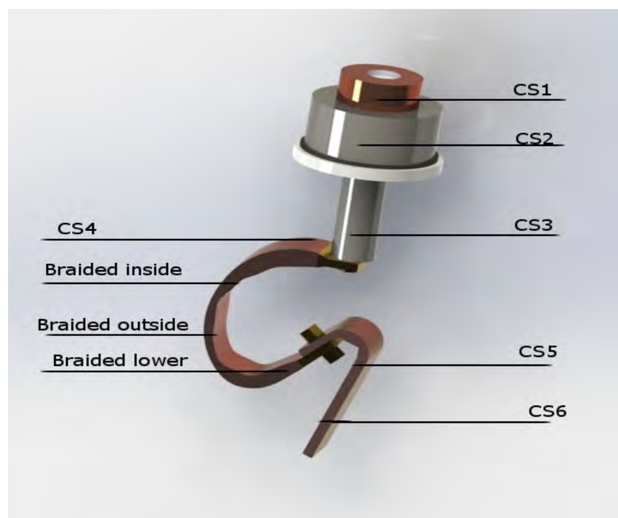
(a) Grouped conductive surface temperature sliding



(b) Sensor placement for Sliding



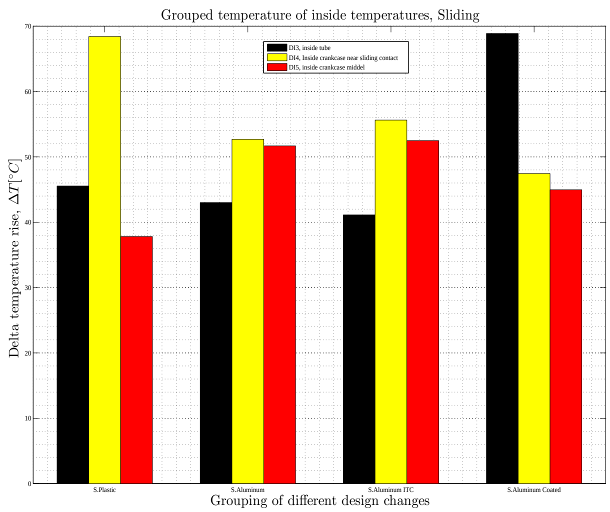
(c) Grouped conductive surface temperature for braided



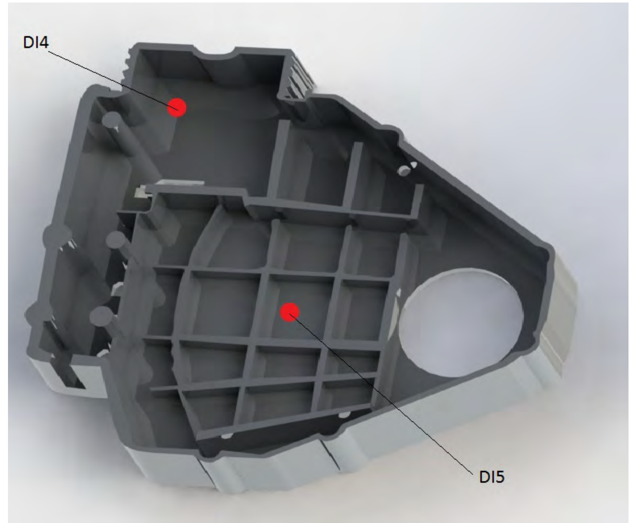
(d) Sensor placement for Braided

Figure 4.4: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

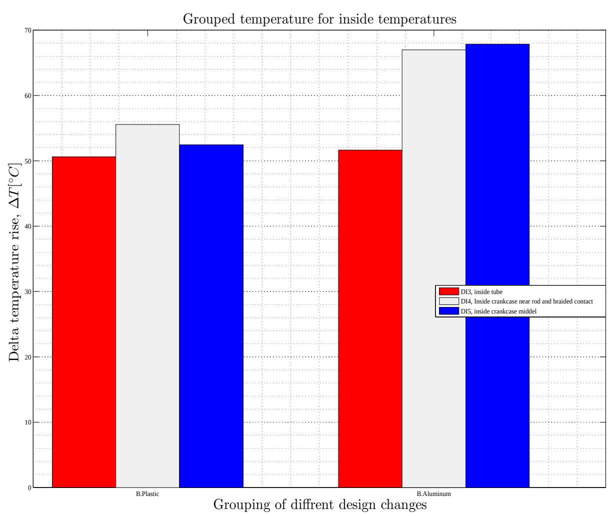
4.4.3 Inside grouped temperatures - Sliding and Braided



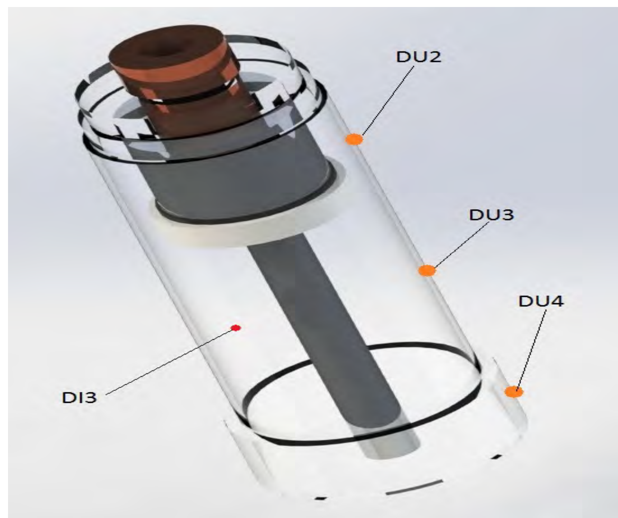
(a) Grouped inside temperatures for sliding contact



(b) Sensor placement on the inside of crankcase



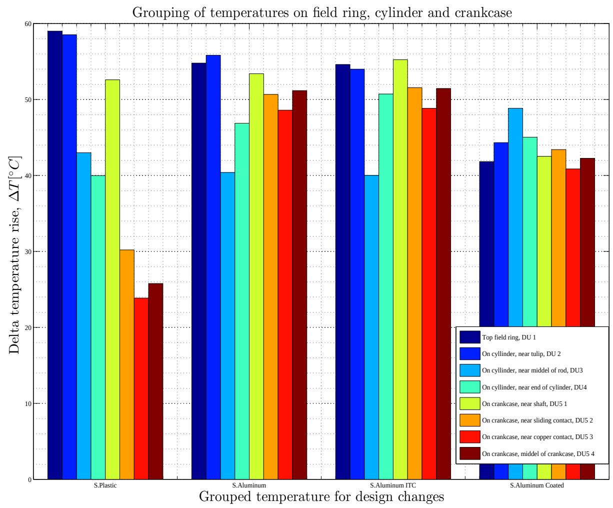
(c) Grouped inside temperatures for braided contact



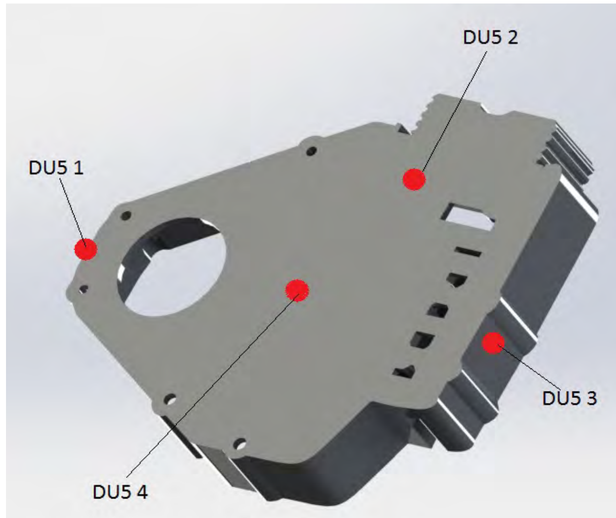
(d) Sensor placement inside pressure cylinder

Figure 4.5: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

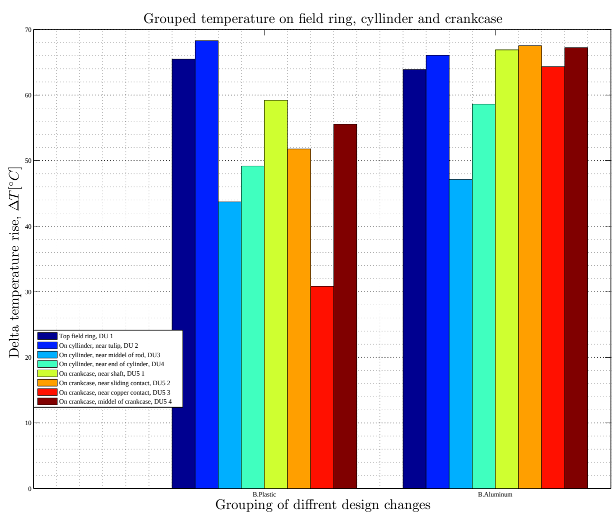
4.4.4 Outside grouped temperatures



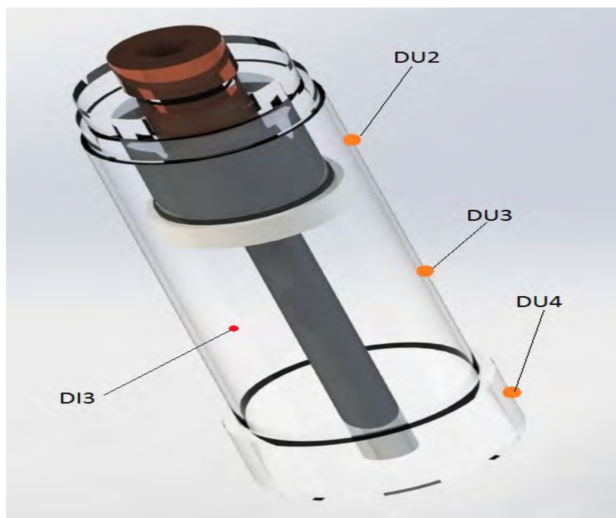
(a) Grouped outside temperatures for braided contact



(b) Sensor placement on the outside crankcase



(c) Grouped outside temperatures for braided contact

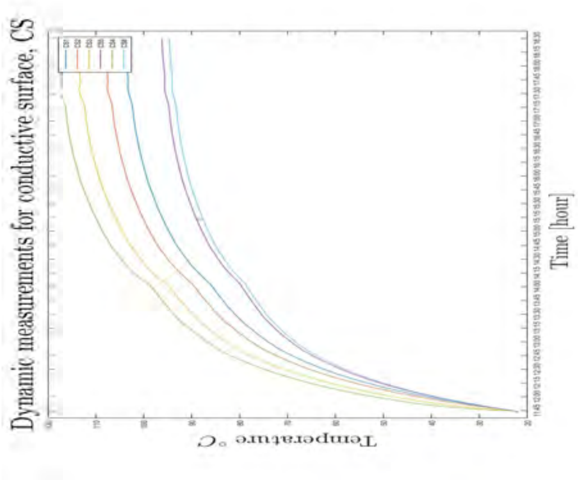


(d) Sensor placement on the outside of pressure cylinder

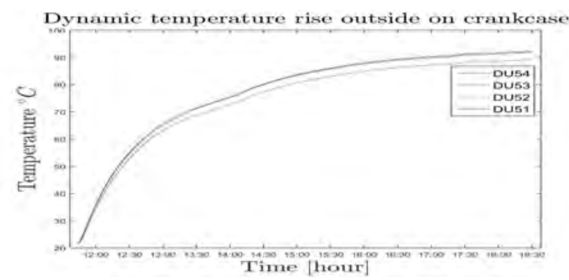
Figure 4.6: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

4.5 Dynamic rise of a heat run

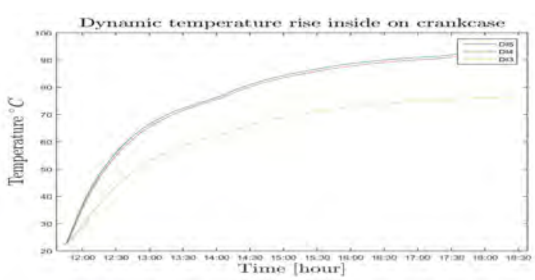
The results of the dynamic rise of a heat run, only one dynamic heat run is presented.



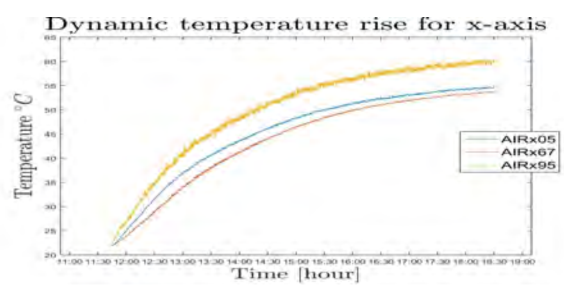
(a) Measurements points places on the current path



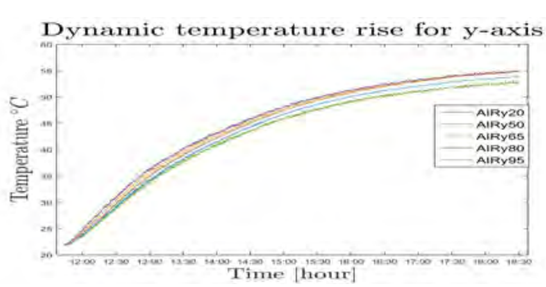
(b) Measurements points placed outside the pressure cylinder and crankcase



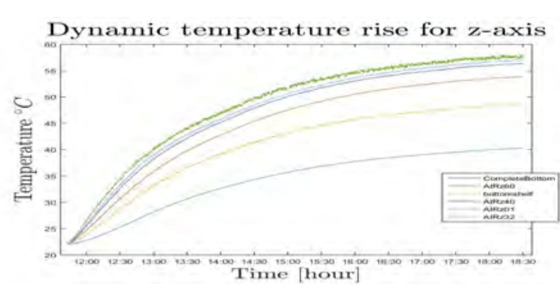
(c) Measurements points places inside the LBS



(d) Measurements points places on x-axis



(e) Measurements points places on y-axis



(f) Measurements points places on z-axis

Figure 4.7: Dynamic measurements of all measurement points on sliding contact with aluminum crankcase

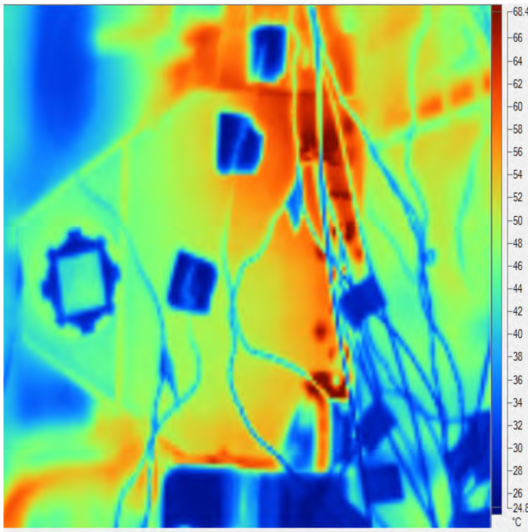
4.6 Infrared thermography of the LBS

With a thermal camera, one can take infrared(IR) images, where one can study the thermal distribution. There are two ways of measuring an item of focus, quantitative and qualitative.

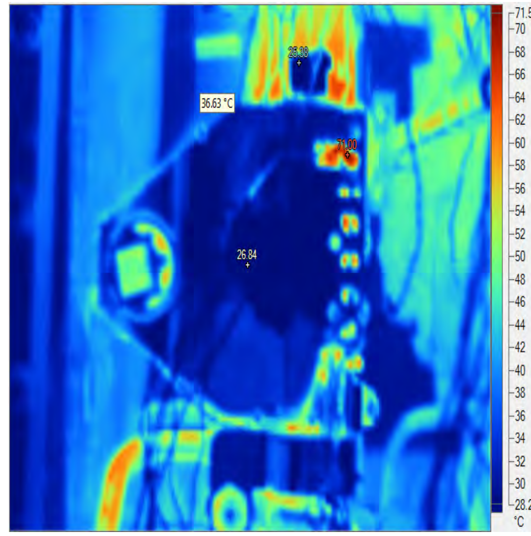
Quantitative IR inspection with known emissivity of all components, combined with a deep knowledge and understanding of radiation, such that the measurements are exact temperatures.

Qualitative IR inspection with a emissivity, $\epsilon = 1$, then evaluate the components relative to each other. I.e. measure the apparent temperature. Used when comparing similar equipment to similar loads.

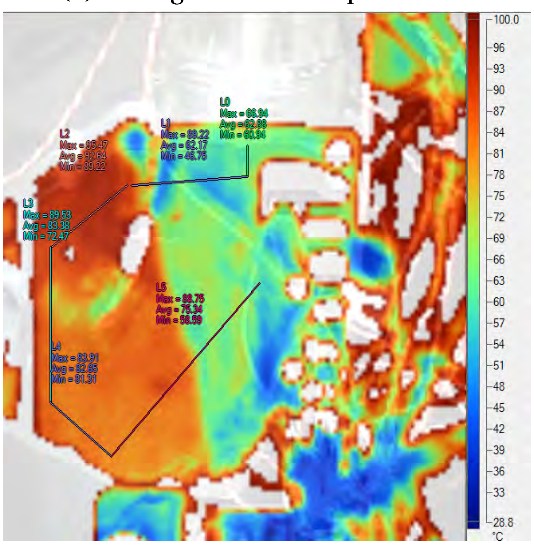
It must be noted, in low emissivity ranges, 0.01 to 0.10, a change will increase the temperature drastically. One must be aware of this fact.



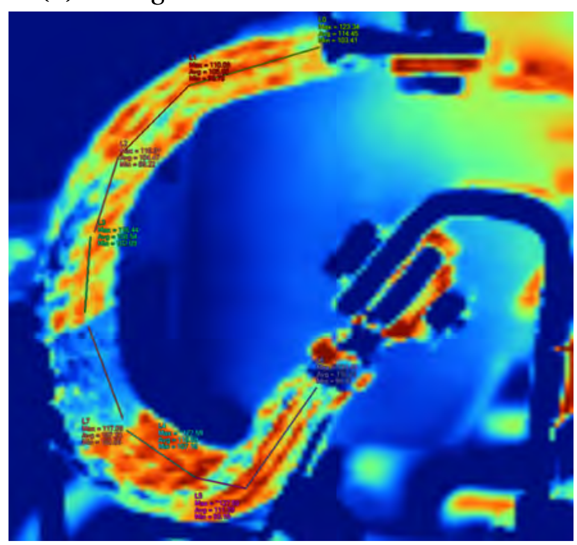
(a) Sliding contact with plastic crankcase, Qualitative



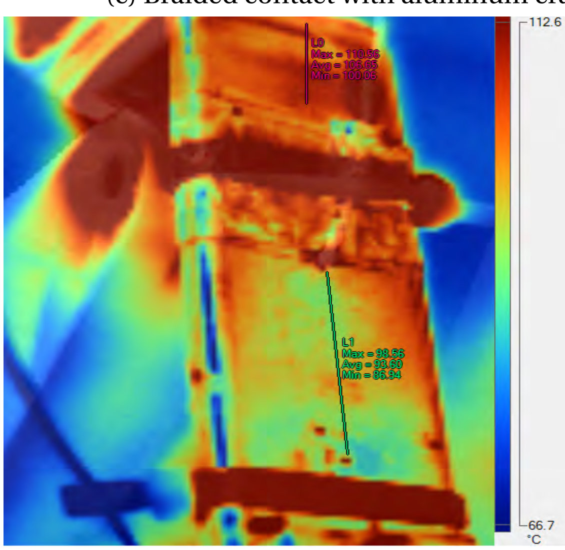
(b) Sliding contact with Aluminum crankcase, Qualitat



(c) Braided contact with aluminum crankcase



(d) Stripped braided connection, Quantitative



(e) Sliding copper connection, Quantitative

Figure 4.8: Quantitative thermal images of plastic and aluminum crankcase for sliding and braided contact. The images shows a comparison over how the temperature is distribution given a crankcase of plastic or aluminum, for sliding and braided.

Chapter 5

Discussion and Analysis

They say the best blaze burns the brightest, when the circumstances are at their worst.

Sophie - Howls moving castle

In this chapter the results will be discussed and analyzed. The chapter is structured such that there is a logical progress from measurement to results and analysis.

5.1 Resistance values

The resistance measurements are performed to ensure that the LBS has the specified resistance of $45\mu\Omega$. This task has proven to a challenge, this is a known problem for ABB and previous work, [15]. The staring point is to know the 'cold' resistances across the LBS. Table:4.1 shows the resulting resistances for the sliding contact. Based on the data, the sum of all the individual LBS components and the measured value across the measuring points P1-P7, as define in figure3.12a The difference between the two, Measured - Sum of individual parts = $35.4 - 33.9 = 1.5\mu\Omega$ The cause is inconsistent placement of measurement probes, the source is human error.**The sliding contact**, in Table:4.3 there is inconsistent resistance values, for both 'warm ' and 'cold'. The oxide film has not been broken through sufficiently, there are not sufficient a-spots and a heat run to ensure a good connection has not been done, due to time constraints. An other source of inconsistent resistance value is how much momentum to apply on the bolt. **The resistance**

of the braided contact is estimated to see what resistance value it has. From eq:3.7, the theoretical braided resistance is $25.3 \cdot 10^{-6}\Omega$. From table:4.2 the measured resistance is $23.6\mu\Omega$, the difference between the theoretical calculated and measured resistance, $25.3\mu\Omega] - 23.6\mu\Omega$ is $1.7\mu\Omega]$ The theoretical value is very close to measured value. The difference between the two is assumed be difficult in calculating braided material compared to rigid metal bar. The 'cold' resistance measurements don't give much information. A more interesting and more significant value is to see at the **'warm' resistance** values, as given in table:4.3. The resistance of a resistor is temperature dependent, as stated by eq:2.5. In the table 4.3, one can see strange values. The stripped sliding contact has decreased while the others have increased. The most probable causes; human error, installation error and conductive errors. The measurement in in the earliest stage of the the experiment part. At this point the engineers were not a familiar with the procedure of changeing the LBS. By wiggleing the LBS, the resistance varies a bit. The oxidation film covering the copper to aluminum interface, which the current must break through, will form more a-spots. Thus getting closer to the 'true' resistance value.

5.1.1 Sliding vs braided

From Table 4.2 and 4.1, by comparing the resistance values of "warm" resistance for sliding and braided. In table 4.3, one can see the inconsistent resistance values for the sliding contact, while the braided contact has more consistent resistance. The relation to joule heating is $P = RI^2$, a higher resistance will generate more heat. Considering only the max and the min warm resistance, eq:5.1 and 5.2. There is a 4.53 W difference between max and min. Since the resistance is temperature dependent, which means that when the AC is turned off, the backplate will be removed and switch to 100 Ampere DC. The critical time is from DC running and backplate is removed, which is the critical time to conduct a voltage reading, to find the resistance. The surrounding hot air is released, the LBS goes to a new thermal equilibrium. The result is a cooler LBS and less accurate 'warm' resistance measurement.

$$P = RI^2 = 630^2 \cdot 42.1 \cdot 10^{-6} = 16.7 \tag{5.1}$$

$$P = RI^2 = 630^2 \cdot 53.3 \cdot 10^{-6} = 21.36437 \tag{5.2}$$

There might be other effects that contribute to a higher temperature than simply just an higher resistance value. The total length of the LBS has increased by 75%, which could also be a contributer to an increased total temperature. In addition, the cross sectional area has been increased, but to the nature of braided material are not as dense as a solid block of metal. The effective cross section is determined by weight, which has a smaller value than the rest of the current path. [7]

5.2 Energy balance

Energy balance forms a fundamental physical law, energy can neither be created nor destroyed, the energy must be conserved. In the enclosed space, the energy balance is assumed to be formulated in the form

$$\dot{E_g} - \dot{E_{out}} = \dot{E_{ST}} \tag{5.3}$$

Where each of the terms can be expressed as

$$\begin{aligned} \dot{E_g} &= I^2R \\ \dot{E_{out}} &= hA\Delta T_{bareCrankcase-ambient} + \epsilon\sigma A[T^4_{crankcase} - T^4_{sidewall}] \\ \dot{E_{ST}} &= mC_p\frac{dT_b}{dt} \end{aligned} \tag{5.4}$$

Where the $\dot{E_g}$ is heat generation, which is expressed by Joule heating equation. $\dot{E_{ST}}$ is thermal energy storage and lastly, $\dot{E_{out}}$ is the heat transfer for the control volume, which is the LBS. The heat transfer mechanisms are limited to convection and radiation. By inserting the values from eq:5.4 into eq:5.3, the dynamic form equates to

$$mC_p\frac{dT_b}{dt} = I^2R - hA\Delta T_j - \epsilon\sigma A[T^4_p - T^4_k] \tag{5.5}$$

the eq:5.5 is derived in dynamical form. This is done to show the completeness and how it leads to the steady state equation. In steady state, the $\dot{E_{ST}}$ becomes zero. The system is in equilibrium, therefore the stored energy is at maximum, as such the energy generated is equal to energy out, as shown in eq:5.6 in layman therms: a joule in is a joule.

$$\dot{E_g} = \dot{E_{out}} \tag{5.6}$$

$$\cancel{mC_p \frac{dT_b}{dt}} = I^2 R - hA\Delta T_j - \epsilon\sigma A[T_p^4 - T_k^4] \tag{5.7}$$

$$I^2 R = hA\Delta T_j + \epsilon\sigma A[T_p^4 - T_k^4] \tag{5.8}$$

5.3 Estimating the heat transfer coefficient, h

The heat transfer coefficient is most commonly estimated experimentally, since the value is dependent on the size and geometry. The method which will be used to estimate h, is to asume there is a relation between two measurements i.e. sliding contact with aluminum crankcase and coated aluminum crankcase. Assuming there exists an relationship between the two measurements, as well as a factor which scales the two measurements to be equal to each other. The basis for assumption of relationship is given by

$$q_{cranckcasetotal} = q_{conv} + q_{rad} \tag{5.9}$$

A symbol change is performed,in order to not use any greek or latin letters to denote heat transfer mechanisms. Where now $\aleph_{subscript}$ is denoting the heat transfer mechanisms.

$$\begin{aligned} \aleph_{bare} &= q_{conv} + q_{rad} \\ \aleph_{coated} &= q_{conv} + q_{rad} \end{aligned} \tag{5.10}$$

Inserting for q_{rad} and q_{conv} in eq:5.10,

$$\begin{aligned} \aleph_{bare} &= \epsilon_{cb}\sigma A[T_{cc}^4 - T_{wall}^4] + h_c A[T_{wall} - T_{amb}] \\ \aleph_{coated} &= \epsilon_{cc}\sigma A[T_{cc}^4 - T_{wall}^4] + h_c A[T_{wall} - T_{amb}] \end{aligned} \tag{5.11}$$

In order to equate $\aleph_{coated}$ and $\aleph_{bare}$, a scaling factor between the two must be found. Eq:x, shows the equating with scaling equation.

$$\aleph_{coated} = \wp\aleph_{bare} \tag{5.12}$$

The scaling factor $\wp$ can be found by finding the resistance factor. Based on table - hot and cold resistance, using the 'warm' resistance measurements for sliding with bare and coated aluminum crankcase, the factor based on resistance can be found

$$\wp_R = \frac{R_{coated}}{R_{bare}} = \frac{50.2}{42} = 1.2 \tag{5.13}$$

In order to verify and explore an different route, the factor is also calculated as a factor between current path CS5 and CS6 3.7a and 3.8b. The average of these measurements are used to compute a factor $\wp_T$, which is based temperature measurements.

$$\begin{aligned} \wp_{bare} &= \tfrac{83.23}{75.2} = 1.1 \\ \wp_{coated} &= \tfrac{87.33}{67.62} = 1.3 \\ \wp_T &= \tfrac{1.1+1.3}{2} = 1.2 \\ \wp &= \wp_R = \wp_T = 1.2 \end{aligned} \tag{5.14}$$

Now equality can be achieved. Inserting $\wp = 1.2$ into eq:5.12

$$\aleph_{coated} = 1.2\aleph_{bare} \tag{5.15}$$

$$\epsilon_{cb}\sigma A[T_{cc}^4 - T_{wall}^4] + h_c A[T_{wall} - T_{amb}] = 1.2\{\epsilon_{cc}\sigma A[T_{cc}^4 - T_{wall}^4] + h_c A[T_{wall} - T_{amb}]\} \tag{5.16}$$

In order to reduce complexity, h_{coated} and h_{bare} are set to be equal. The surface area is prevalent in all the therms, therefore it can be removed. By rearranging and solving the heat transfer coefficient h, can be expressed as

$$h = \frac{1.2\epsilon_b\sigma[T_{b,c}^4 - T_{wall,b}^4] - \epsilon_c\sigma A[T_{c,c}^4 - T_{c,w}^4]}{[T_{wall,c} - T_{amb,c}] - 1.2[T_{wall,b} - T_{amb,b}]} \tag{5.17}$$

	rad	conv	total
W_{bare}	3.74	5,7	9,44
W_{coated}	15,07	2,89	17,96

In order to solve the system of equations, some assumptions are made. There is done in order to reduce the number of the unknowns. As eq:5.11 stands, there unknowns are: $\aleph_{bare}$, $\aleph_{coated}$, h_{bare}, h_{coated} and the ratio $\wp$between the two measurements. Also, the reason for finding the ratio between the two experiments, is the inconsistent resistance and power influx, the need for scaling exists. If the resistance and power input are equal, there would be no need for a ratio between the two.

The h is calculated to av value of 2.90, this a typical value for a free convection heat transfer coefficient.

5.3.1 Validity of the assumptions

In order to test if the assumptions are valid, a simple play with increase of h, how affected is the heat transfer coefficient. The change is linear and small, therefor the assumption is that h is robust.

5.3.2 Using the heat transfer coefficient

The emissivity decides how efficient a surface can emit energy by radiation. When a surface has a low emissivity, the dominating heat transfer mechanisms are convection and conduction. The opposite is true when one has a emissivity at unity, then the dominating heat transfer is radiation. It is easy and often done, which is to assume when you increase the emissivity, the convection will be the same. Coating a surface or any process to increase the emissivity will lead to a higher heat transfer. This is not the case, there exists an interaction between the two modes. Increasing radiation and convection will lead to reduction of the convection, and opposite. But the total energy transfer will be the same. Table :?? shows this ratio between radiation and convection.

5.4 Analysis and discussion of grouped measurement data

5.4.1 Analysis and discussion on surrounding temperatures

In appendix **??**, the measurement results of each individual experiments are presented. For easier comparative view, the measurements are grouped together. Starting with **Sliding**, in figure 4.2a, the *x-axis* temperatures are plotted. There are measurements are very consistent along the x-axis. There are small variations, they are considered negligible. The reason for the spike in AIRx95, is related to the geometry of the LBS and the side walls. In figure 4.2c, the *y-axis* temperatures are plotted.There are measurements are very consistent along the x-axis. But, for the case with the coated aluminum, temperature is slightly higher overall when compared the other values. The only reasonable explanations is due to radiation is dominating the heat transfer. In figure 4.2c, the *z-axis* temperatures are plotted.There are measurements that are very consistent along the z-axis. The overall temperature has increased a bit along the z-axis. The most interesting, is for the case with the coated aluminum, where the bottom and bottom shelf have increased by 1 deg C, from the other measurements. It means that there must be more radiation and/or convection which is transferring more heat to the bottom. It is difficult to say which heat transfer mechanism is the dominating and how much it can contribute. Since there are other LBS inside and the experiments are only focusing on one. For the **braided contact** along the *x-axis* figure:4.3a, the values are consistent, no noticeable change. For the *z-axis* figure:4.3e, the temperature at the top has increased. The most striking change is at AIRz60, which made a 4 deg C temperature drop. The difference can only be caused by radiation. The plastic has a emissivity of 0.92 and the aluminum has emissivity of 0.15, Which is peculiar. Since earlier measurements indicated that radiation did not effect the thermocouples. The puzzling part, is the only measurement affected, with out any further testing, the measurement is assumed as a fluke.

5.4.2 Analysis and discussion on conductive surface temperatures

With the standard LBS with plastic crankcase, the effect of changing crankcase material from plastic to aluminum, is to achieve higher heat transfer from the conductive surface. This is due to aluminum being a metal, is superior to plastic in conducting heat. Based on Figure:4.4a, there is a clear trend in the data, that by changing the crankcase material to aluminum, and further attempts on improving the heat transfer has yielded a temperature reduction. Table5.1 illustrates the difference between plastic and the design changes done to the aluminum crankcase. The effect just of change from plastic to Aluminum is the largest effect, and further improvements have diminishing returns. When comparing the aluminum crankcase to the improvements done, they are comparable to each other on CS1, CS2 and CS6. But CS3, CS4 and CS5 are very different. The with AL ITC, the there is a better conductive connection between the sliding/rod and copper connection interface to the crankcase. The temperature shall not increase, due to thermodynamic laws. The only explanation for this is; to do a comparison of the temperatures the resistance and power input must be the same. This is not the case here, based on the temperatures found in 5.1, and the tables for power and resistance 4.4 and 4.3. **Sliding**, Plastic vs aluminum, these values are comparable in both power and resistance. But aluminum vs (ITC and coated), the resistance and power inputs are different, and hard to compare. If the measurements are scaled in order compensate for resistance and power differences, assuming linear relationship. This will not be done, if the resistance measurements, as previously stated in the discussion on resistances. If there is a to long a gap between the opening and switching to DC, and then performing a "resistance measurement" voltage drop over the LBS. Then any scaling of measurements will decrease the accuracy of the measurements. Even if the indication of that the values need scaling. By considering economics and cost of actually implementing improved thermal connection might be expensive. For the improved thermal contact, this is the maximal value that can be achieved by improving the connection. This was achieved by thermal paste and adding metal to increase the surface area to which heat could conduct through. An issue with the paste is; how will it perform under extended time periods? The most obvious way to improve the conductive heat transfer is by ensuring that the crankcase is as tightly as possible to the copper connection, and the area between the two surface should be at a maximum.

Table 5.1: Comparative view over temperature reduction for conductive surface(CS) of LBS with sliding contact. The first part shows how much temperature reduction has been achieved by switching to aluminum, then against the design changes. Then the same is done, by now against aluminum vs design changes.

$\Delta T[°C]$	CS1	CS2	CS3	CS4	CS5	CS6
Sliding plastic	71.07911	76.74316	80.16306	81.73436	77.65036	74.65137
	Delta value					
Plastic vs Al	-4.25489	-7.56737	-9.37302	-14.28514	-18.79196	-15.46484
Plastic vs AL ITC	-6.44141	-11.00878	-14.23532	-22.45799	-21.33786	-18.37891
Plastic vs coated AL	-7.06934	-12.25487	-9.49313	-12.624	-14.92965	-13.42773
$\Delta T[°C]$	Delta value					
Aluminum	66.68	69.17	70.79	67.44	58.85	59.18
AL vs AL ITC	-2.18	-3.44	-4.86	-8.17	-2.54	-2.91
AL vs AL coated	-2.81	-4.68	-0.12	1.66	3.86	-2.03

Table 5.2: Comparative view over temperature reduction for conductive surface(CS) of LBS with braided contact. The table shows how much temperature reduction has been achieved by switching to aluminum with a braided contact

$\Delta T[°C]$	CS1	CS2	CS3	CS4	CS5	CS6
Sliding plastic	83.8	88.86	96.81	103.81	88.55	85.34
	Delta value					
Plastic vs Al	-4.7	-9.77	-17.72	-24.72	-9.46	-6.25

For the **braided contact**, due to time constrains only three tests were conducted for braided contact; stripped, plastic and aluminum. Based on table 4.4c, the effect is clear. The aluminum crankcase reduces the temperature along the conductive path. Table:5.2 shows how much the aluminum can reduce compared to plastic. Based on 4.4 and 4.3, the values are comparable to each other to a high degree, no scaling will be needed.

5.4.3 Analysis and discussion outside and inside of the LBS temperatures

The design changes will not only affect the surrounding temperature, but also the inside and outside of the entire LBS. **On the outside of sliding LBS** when comparing the different design changes the outside is affected. The based on table:5.3, the outside of the crankcase has increased, except for the the coated crankcase, where the temperature has decreased.

With out scaling the temperatures for resistance and power, it is difficult to compare the coating vs improved thermal contact(ITC). But, when comparing to plastic vs aluminum. The results are clear, and the power and resistance are comparable. The aluminum crankcase has a much higher temperature, as seen with the grouped outside temperatures, **??**. Based on the same figure, one can see that the plastic crankcase has not a uniform temperature distribution, the heat is situated near the conductive path. With, the aluminum crankcase the temperature is uniform.

Table 5.3: Comparative view over temperature reduction for outside of LBS with sliding contact. The first part shows how much temperature reduction has been achieved by switching to aluminum, then against the design changes. Then the same is done, by now against aluminum vs design changes. Figure 3.8b and 3.8d, shows the sensor placement.

$\Delta T[°C]$	DU5 1	DU5 2	DU5 3	DU5 4
Sliding plastic	23,9	30.2	53,6	25.77
	Delta value			
Plastic vs Al	25	20,72	1	25,65
Plastic vs AL ITC	25	21,35	2,7	25,7
Plastic vs coated AL	18	14,6	-8,7	17,88
$\Delta T[°C]$	Delta value			
Aluminum	48,85	50.9	53,64	51.4
AL vs AL ITC	0,2	0,65	1,6	0,06
AL vs AL coated	-6,8	-6,2	9,72	-7,75

On the outside of braided LBS table:5.4, comparing plastic vs aluminum with braided contact. With the braided contact, it is always the best conductive contact to the crankcase. This is due to the nature of the braided contact, is lies as a sandwich between the two crankcase half's. Based on figure4.5c, the temperature is close to uniform.

Table 5.4: Comparative view over temperature reduction for inside of LBS with braided contact. The table shows how much temperature reduction has been achieved by switching to aluminum with a braided contact

$\Delta T[°C]$	DU5 1	DU5 2	DU5 3	DU5 4
Sliding plastic	30,77	51,78	59,2	55,56
	Delta value			
Plastic vs Al	36,11	15,75	5,13	11,67

Comparing the **inside temperature of sliding LBS**, based on figure 4.5a the most striking is the two spikes: Plastic with DI4(inside of crankcase near sliding contact/copper connection interface) and with the coated the temperature spike is inside the pressure cylinder. While for the plain aluminum and ITC aluminum, they are similar. the only connection between the two, is there high emissivity.

Table 5.5: Comparative view over temperature reduction for inside of LBS with sliding contact. The first part shows how much temperature reduction has been achieved by switching to aluminum, then against the design changes. Then the same is done, by now against aluminum vs design changes.

$\Delta T[°C]$	DI3	DI4 2	DI5
Sliding plastic	45,56	68,41	37,8
	Delta value		
Plastic vs Al	-2.53	-15,72	13,87
Plastic vs AL ITC	-4,4	-12,8	14,67
Plastic vs coated AL	23,34	-21	7,15
$\Delta T[°C]$	Delta value		
Aluminum	43	52,7	51,67
AL vs AL ITC	-1,85	2,93	0,8
AL vs AL coated	25,87	-5,24	-6,72

Comparing the **inside temperature of braided LBS**, figure:4.5c The temperatures in the DI3, inside the cylinder. They are similar, while inside the crankcase the temperature has increased. This is expected, that the outside crankcase temperature has increased compared to plastic as see on figure:5.4. From table:5.6, the temperature has decrease. The value is assumed as invalid, the temperature should increase. The resistance and power input inaccuracy's explains the small variation negative value.

Table 5.6: Comparative view over temperature reduction for inside of LBS with braided contact. The table shows how much temperature reduction has been achieved by switching to aluminum with a braided contact

$\Delta T[°C]$	DI3	DI4 2	DI5
Sliding plastic	50,59	55,55	52,44
	Delta value		
Plastic vs Al	-1,04	11,41	15,41

5.4.4 Analysis and discussion pressure cylinder

The pressure cylinder is not subjected to any design change, but is still affected by the design changes. Based on figure:**??**, the field ring with plastic crankcase has a high temperature, and for each design change the temperature is decreasing. From table:5.7

when compressing with aluminum crankcase with coated and ITC, there is a large drop in temperature with coated crankcase, for the field ring. This must due to the copper top CS1, having a lower temperature and that the field ring is now coated, there by emitting more heat. Du4, has increased in temperature. This is expected, since the aluminum crankcase will conduct more heat to the pressure cylinder. With out correcting for resistance and power input, it is difficult to accurately analyze the results. Assuming, that the trend is as seen in table:**??** for DU3 and DU4. The crankcase is conducting heat to the cylinder, but since the cylinder is a poor heat conductor, the heat will not travel far, only near the crankcase.

Table 5.7: Comparative view over temperature reduction for cylinder of LBS with sliding contact. The first part shows how much temperature reduction has been achieved by switching to aluminum, then against the design changes. Then the same is done, by now against aluminum vs design changes.

$\Delta T [°C]$	DU 1	DU 2	DU 3	DU 4
Sliding plastic	59	58.53	43	40
	Delta value			
Plastic vs Al	-4.2	-2.7	-2.6	6D.88
Plastic vs AL ITC	-4.38	-4.53	-2.98	10.74
Plastic vs coated AL	-17.17	-14.21	5.85	5
$\Delta T [°C]$	Delta value			
Aluminum	53.4	50.67	48.6	51.17
AL vs AL ITC	-0.18	-1.84	-0.38	3.858
AL vs AL coated	-12.96	-11.5	8.44	-1.83

For the pressure cylinder with braided contact, the DU2, DU3 and DU4 are very similar, but with some higher and lower values. Except, for DU4 the temperature has raised.

Table 5.8: Comparative view over temperature reduction for cylinder of LBS with braided contact. The table shows how much temperature reduction has been achieved by switching to aluminum with a braided contact

$\Delta T [°C]$	DU 1	DU 2	DU 3	DU 4
Sliding plastic	65,48	68,3	43,7	49,17
	Delta value			
Plastic vs Al	-1,58	-2,23	3,42	9,45

5.4.5 Discuss the CS Sliding vs braided

The sliding and braided contact have different design. They both work, as intended. The benefit of a braided contact; the temperature rise can be 75°C compared to sliding contacts which has a limit of 65°C. for simplicity, lets assume that the resistance values are the same for all designs. With a just changing the plastic to aluminum, in order to pass the temperature must be reduced by 4.2 deg C at CS2(open close contact) and 2.44 deg C at CS4(Sliding contact). With the improved thermal contact, CS4 has passed, while CS2 needs 0.73 deg C reduction in order to pass. With the coated crankcase, CS2 passes, while CS4 did not pass. For braided contact, there is no possibility of passing. The temperature over CS2 is 18 deg C and for CS4 it is the same. If the new preposition of increasing the temperature by 10 deg for both sliding and bolted contact, then braided contact will still not pass, but for the sliding contact, now all the design changes will pass the new IEC limit.

5.4.6 Plastic vs aluminum crankcase

There is large difference between plastic and aluminum crankcase, the plastic crankcase is a poor heat conductor, while aluminum is a excellent heat conductor. In order to achieve a conductive and an efficient way of transferring heat from the conductive path, then aluminum is the choice.

5.5 Dynamic data of temperature measurements

The temperature rise on the LBS and the inside atmosphere is measured. The resulting temperature rise plots is shown in figure 4.7. The plots are separated in six: control surface temperature, the inside temperature, along the three axises, temperatures on the pressure cylinder and crankcase.

5.6 Shield test

The results was, no noticeable change in temperature. There were no formal or rigor was carried out, the test was conducted in order to wither or not the idea is worth pursuing. The most probable reason for why the radiation did not affect the thermocouples, is due to low radiation.

5.7 Thermal images

By using a thermal camera, the surface temperatures can be mapped and displayed. By analysis of IR images, one can discover the areas that are heated more then the rest, is the heat distributed evenly. In future design changes, these hot areas might be increased in size, in order to dissipate more heat. As well, give an indicator on where to focus design changes in a CFD/FEM analysis. Firstly, **the sliding contact with a plastic crankcase**, as shown in figure 4.8a The heat is not being transfered efficiently, near the sliding/copper connection, there is a large heat spot compared to near the crankshaft. It is evident that the plastic is not suited for transferring heat from the hot zones. With the change to aluminum, as shown in figure 4.8b, the heat distribution is uniform. Note that the figures 4.8a a and b, are qualitative.

The Braided contact with aluminum crankcase with a quantitative method is shown in figure:4.8c the interesting part here is, that there is a distinct two zones. One hotter then the other. This is not possible, since heat conduction is continuous in its movement. A jump like this can't happen, this is a indication that the image is incorrectly taken. This is due to the geometry of the crankcase, it is not a straight plate. The angle at which the picture is take will influence the temperature measurements. Thus, figure:4.8c serves only as a illustrative figure. Figure:4.8d shows a qualitative image over how the temperature is distributed. The braid has a smooth heat distribution. Figure: 4.8e shows a qualitative image over the sliding copper connection. The closer one is to the sliding/copper connection interface, the hotter the temperature is. This is important to note when one is to place thermocouples. The assumption is that, if there will be an design change on the copper connection. Know where the hottest regions are located, and how the temperature is along the copper connection.

Chapter 6

Conclusion

> If you wish to understand the universe,
> think of energy, frequency and vibration
>
> Nikola Tesla

An effective measure of logging the measurements have been achieved. For both dynamical and static measurements. The design changes are can almost pass the IEC limits, by changeing the crankcase material with improved thermal connection. If the new limit is passed, then one can keep using the sliding contact and only change the material of the crankcase. The braided contact is generating more heat, and can not pass the IEC limits, even if the the limit is raised by 10 deg C.

Chapter 7

Future work

> Its more important to master the card
> you're holding than to complain about
> your opponents were dealt
>
> Grimsley Pokemon trainer

7.1 Future work

Anodization Since coating the different components is not desired; an economical cost,uncertainty of out gassing and unforeseen effects of coating. The option of anodization of the Aluminum parts, the process will increase the emissivity and result in a higher heat transfer from the LBS to the inside environment.

Model Make a CFD/FEM model of the LBS to make an design tool

Model Use neural networks to make an experimental data model of LBS

7.2 Electrical and measurement

Meaurement The copper connection after current has passed AL connection. Measure the points and see how much if any temperature difference by changing from plastic to Al crankcase.

Electrical Evaluate if there is a creep voltage from copper connection to al crankcase to crank shaft. If there is a current passing, evaluate a change to an non conductive crankshaft.

Electrical Mount a voltage measurement points on copper top to copper bottom, such that the measurement equipment can log DC voltages with out opening the switchgear. When DC measurements are to be conducted, the AC must be turned off and switched to DC, once the measurements are complete, change back to AC. Do the change as often as needed. Tis is to do resistance measurements more methodically and to find if there is a way of ensuring more stable resistance measurements.

7.3 Design change recommendations

Material Make the material choices have an high emissivity

Material Make the part interfacing between the rod and the mechanical action out of metal. The added metal will contribute to a lower temperature.

Material Make the interface between the mechanical rod and crankcase "round thing" out of metal. By doing this modification the crankcase will have more metal to conduct heat away from the Contact surface to

Chapter 8

Refrences

All that we are is the result of what we have thought. The mind is everything. What we think, we become

Siddhartha Gautama Buddha

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Appendix A

Additional Information

Are humans really so deprived of stimulus that they must insist on touching everything?

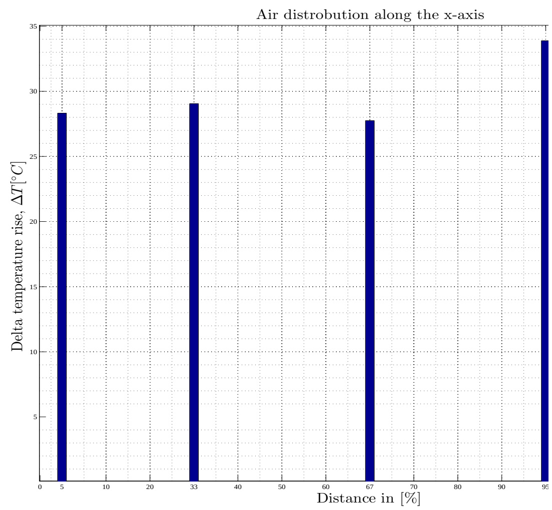
Unknown

This is an example of an Appendix. You can write an Appendix in the same way as a chapter, with sections, subsections, and so on.

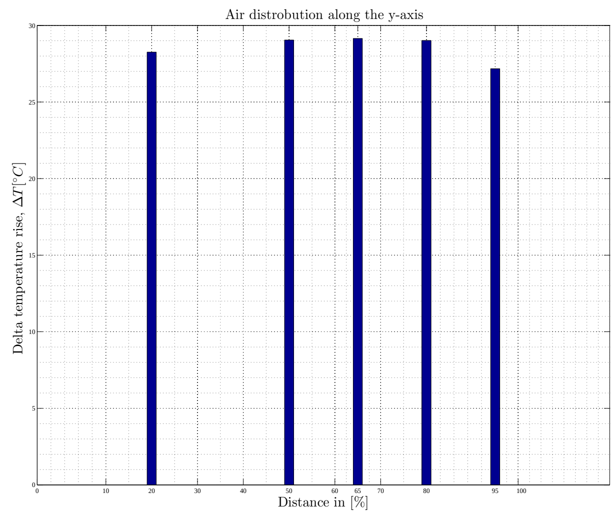
A.1 Temperature measurement results for sliding and braided contact

This section will present the results from each experiment. The layout is on two pages, where the first page presents the surrounding air for the experiment. The bar plots(figure a,b,c) are scaled relative to height and width, such that they represent the temperature at the measurement point. The forth(figure d) graphically presents all the temperatures in '3d' picture. Lastly on the first page, is a figure illustrating the sensor placement for the surrounding measurement points. One the second page, one will find the temperature along the current path(figure a), labeled CS. The next image (figure b) show where the sensors are placed. The two last figures(c,d) show the temperature on the outside of the crankcase and pressure cylinder, and the temperature inside the crankcase and pressure cylinder. The layout of the results is the same for both sliding and braided contact.

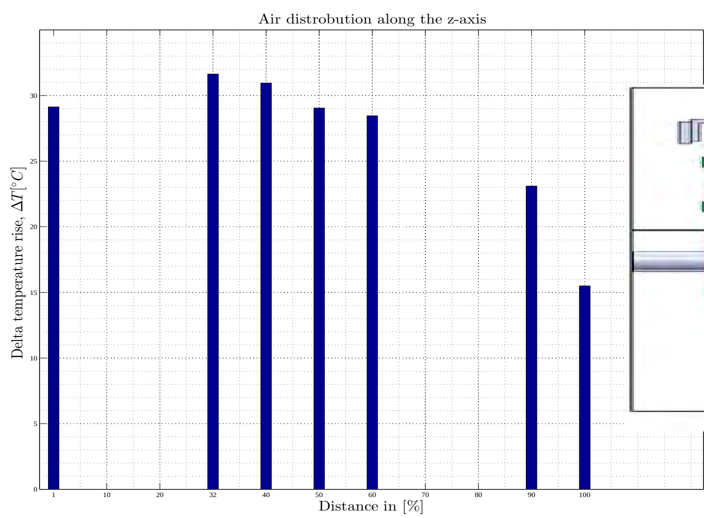
A.1.1 Thermal distribution surrounding temperature - Stripped Sliding



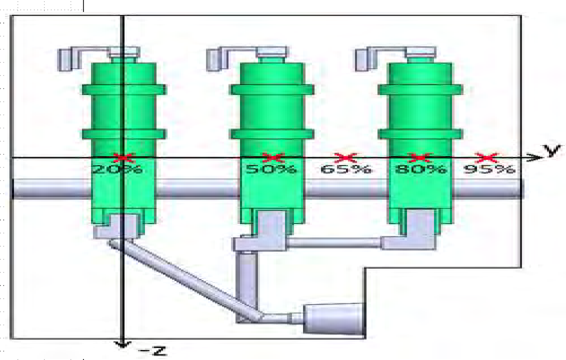
(a) Surrounding temperature along x-axis



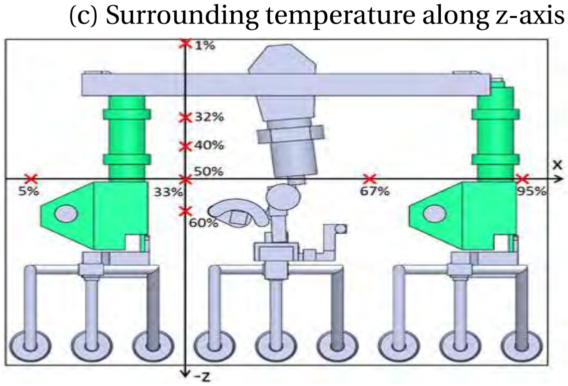
(b) Surrounding temperature along y-axis



(c) Surrounding temperature along z-axis



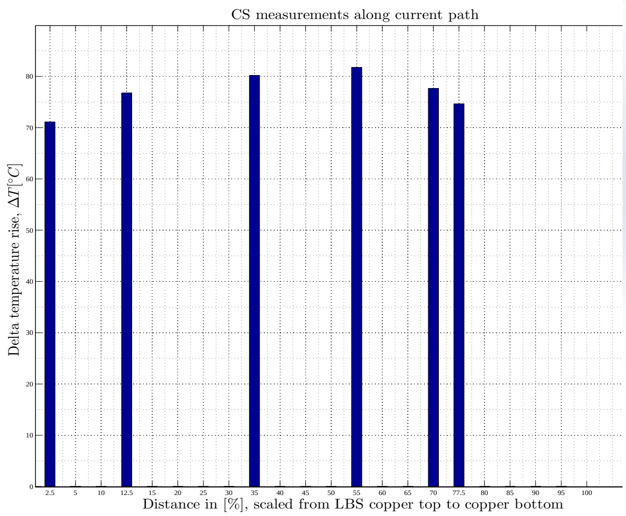
(d) text



(e) text

Figure A.1: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

A.1.2 CS and inside and outside distribution - Stripped Sliding



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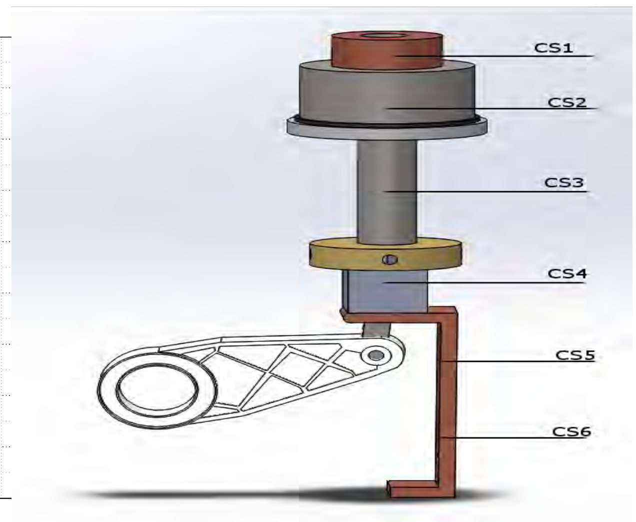

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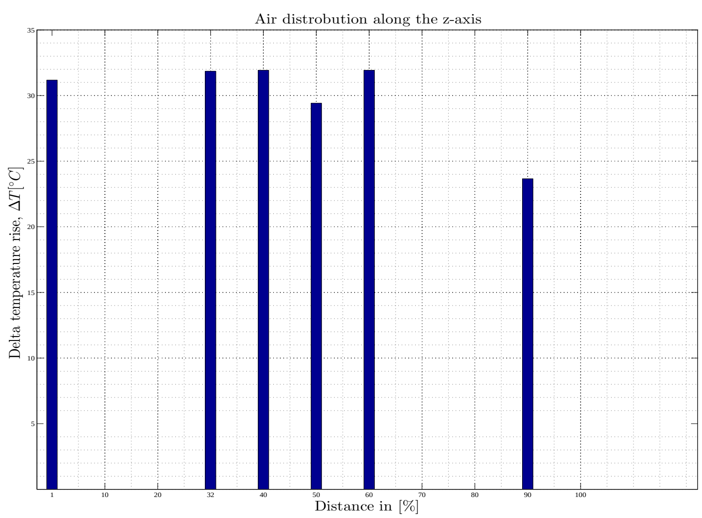
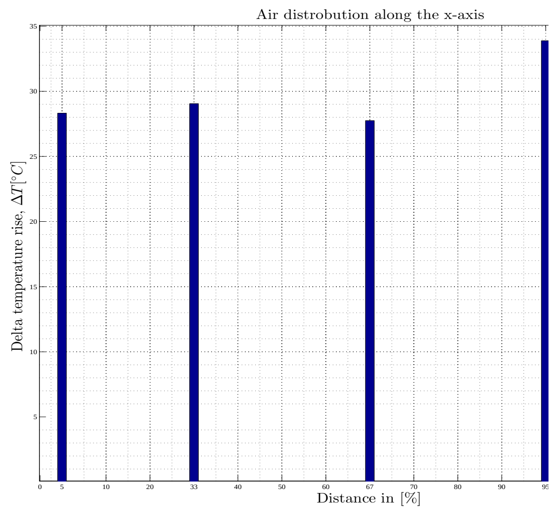


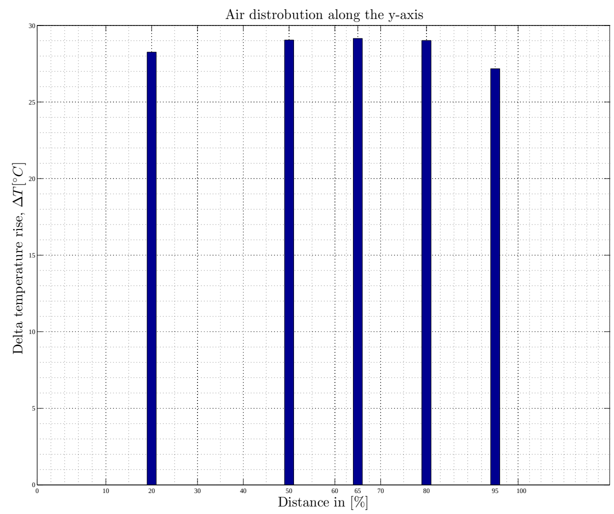
(c) text

Figure A.2: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

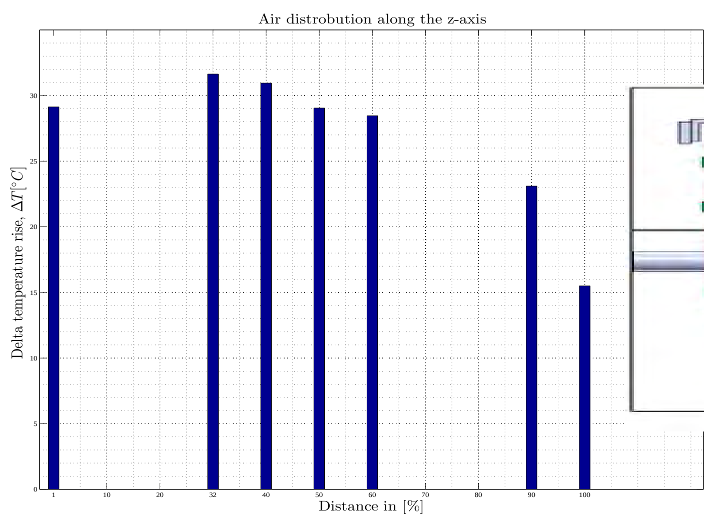
A.1.3 Thermal distribution surrounding of Plastic and sliding



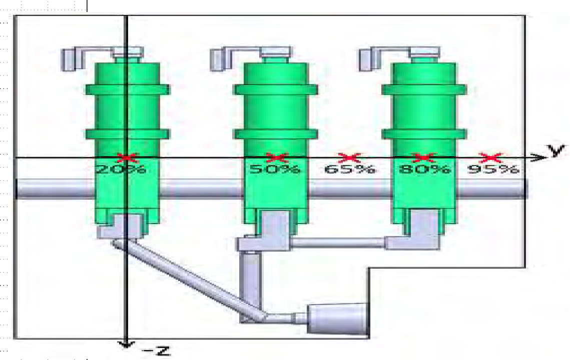
(a) Surrounding temperature along y-axis



(b) Surrounding temperature along y-axis



(c) Surrounding temperature along z-axis



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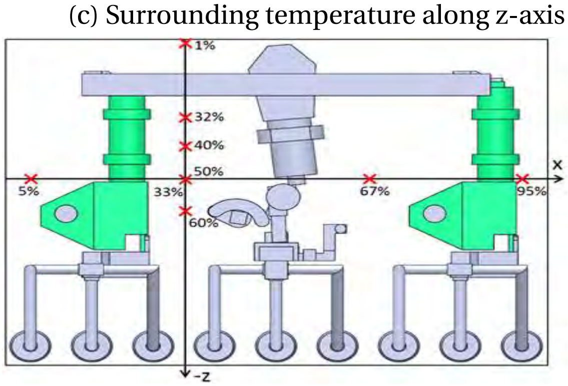
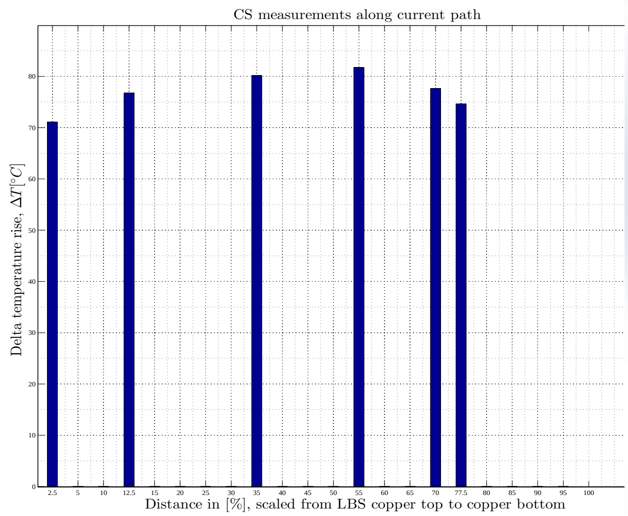


(e) text

Figure A.3: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

A.1.4 CS in and out distribution - Plastic and sliding



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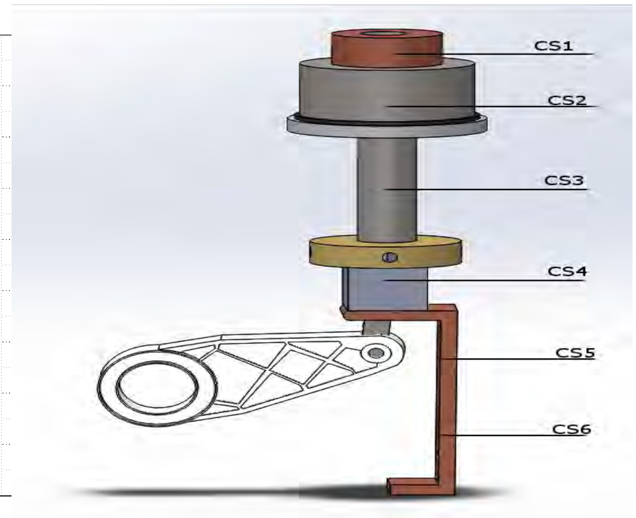

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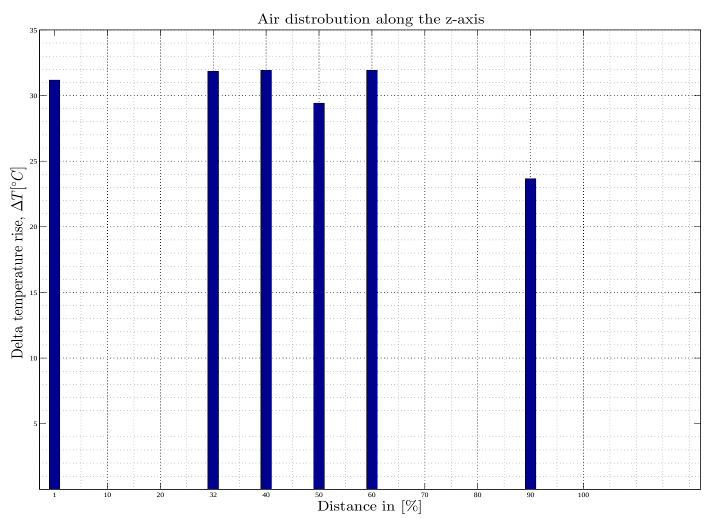
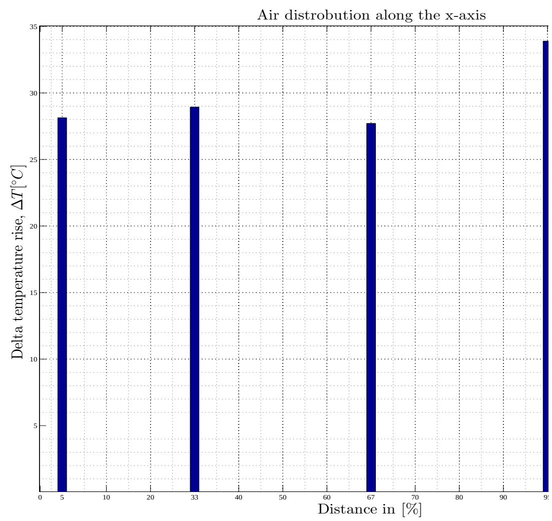


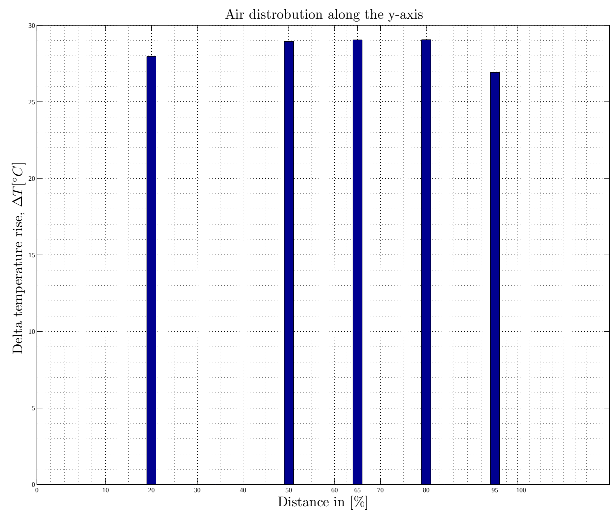
(c) text

Figure A.4: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

A.1.5 Thermal distribution surrounding temperature - AL



(a) Surrounding temperature along x-axis



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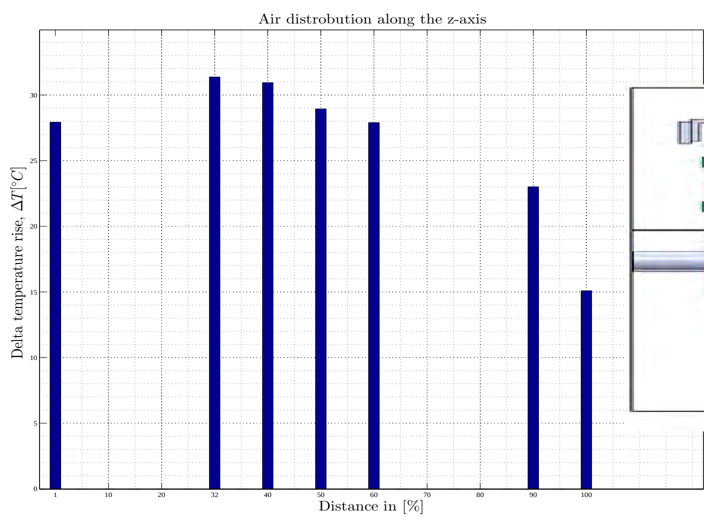
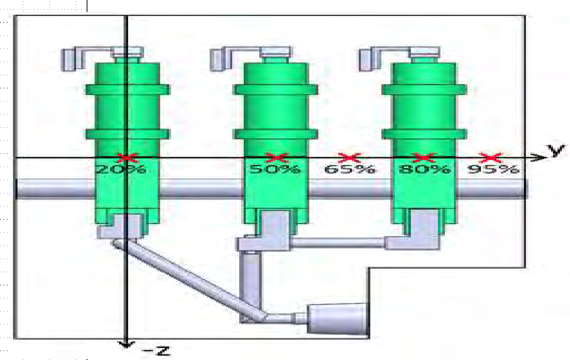


(c) Surrounding temperature along z-axis



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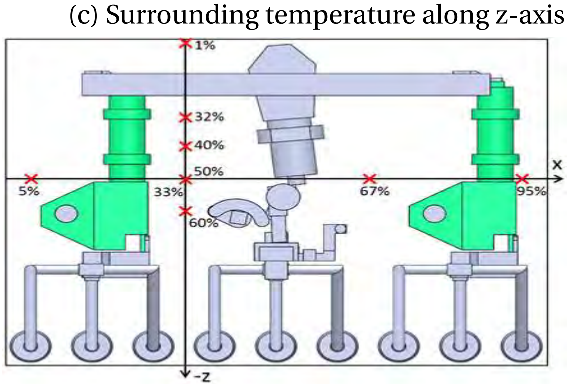
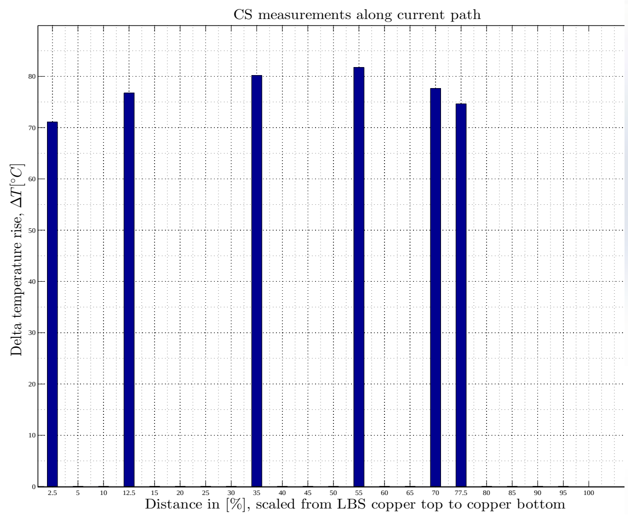


(e) text

Figure A.5: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

A.1.6 CS and in out distribution - al and sliding



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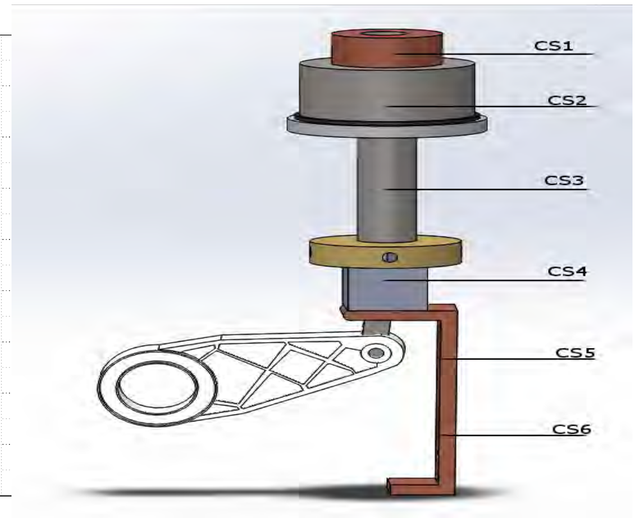

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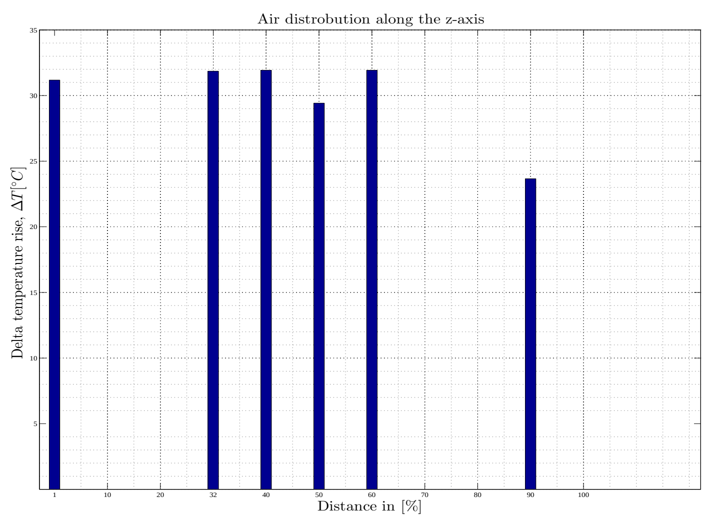

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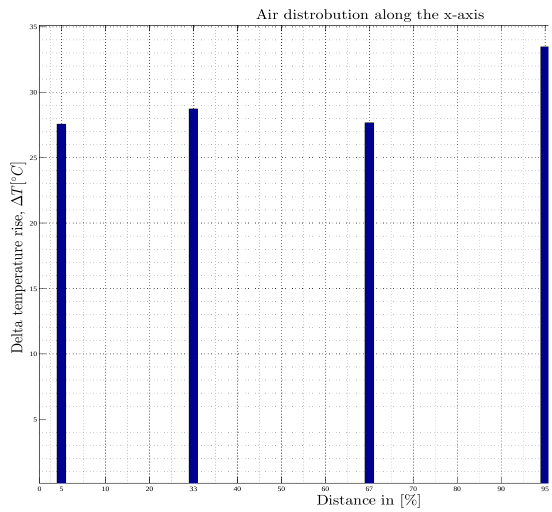
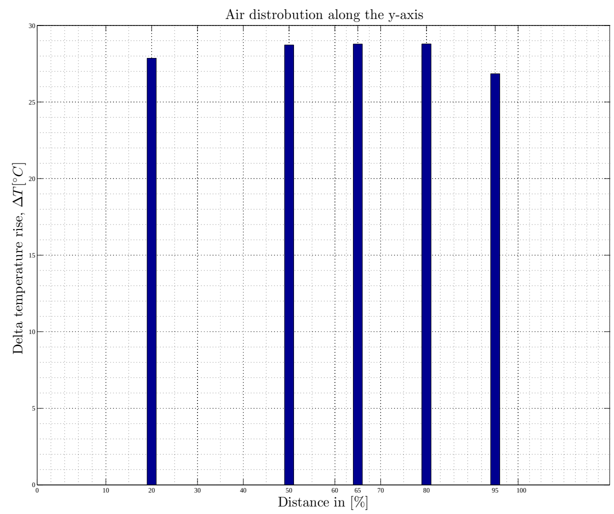
Figure A.6: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

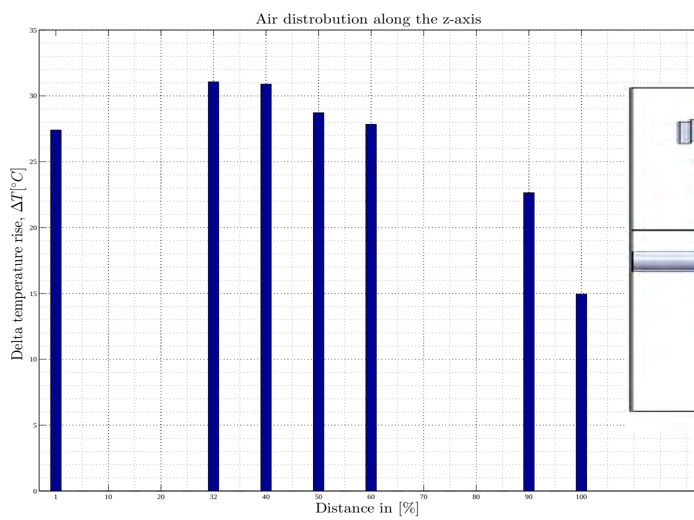
A.1.7 Thermal distribution surrounding temperature - AL ITC



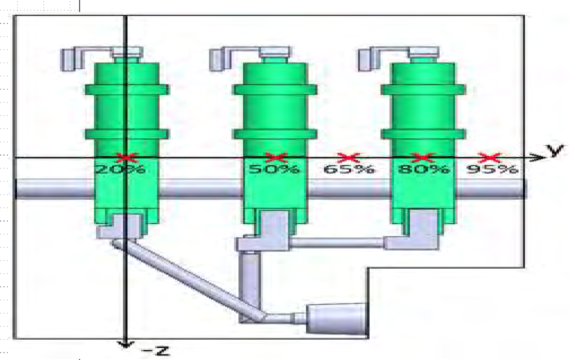
(a) Surrounding temperature along x-axis



(b) Surrounding temperature along y-axis



(c) Surrounding temperature along z-axis



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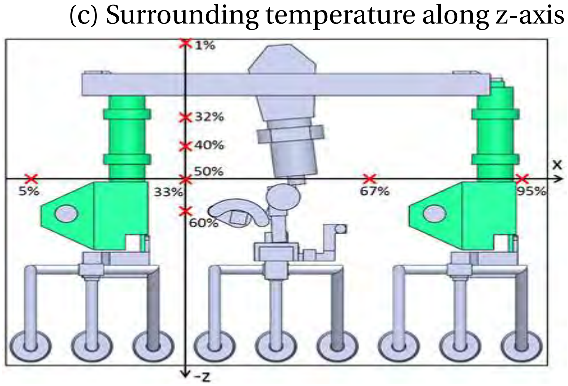

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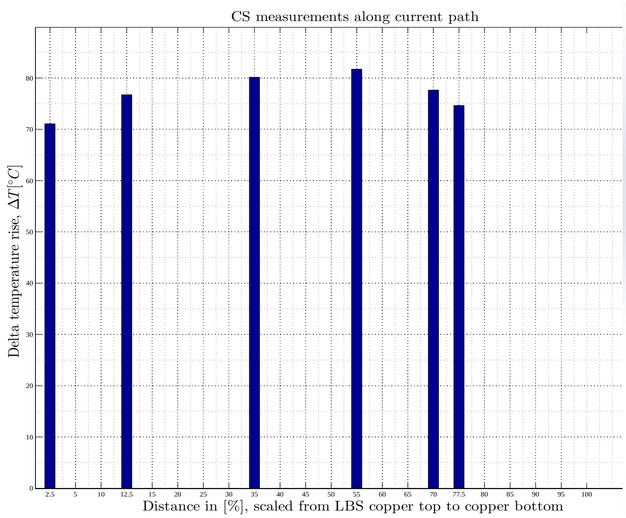
Figure A.7: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

A.1.8 CS and in out distribution - AL ITC



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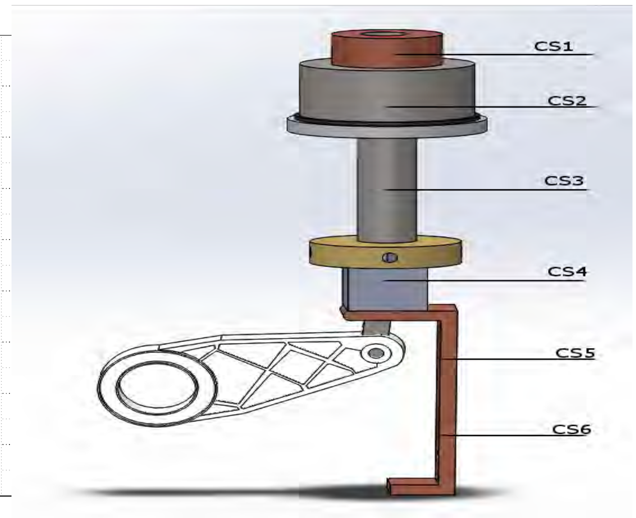

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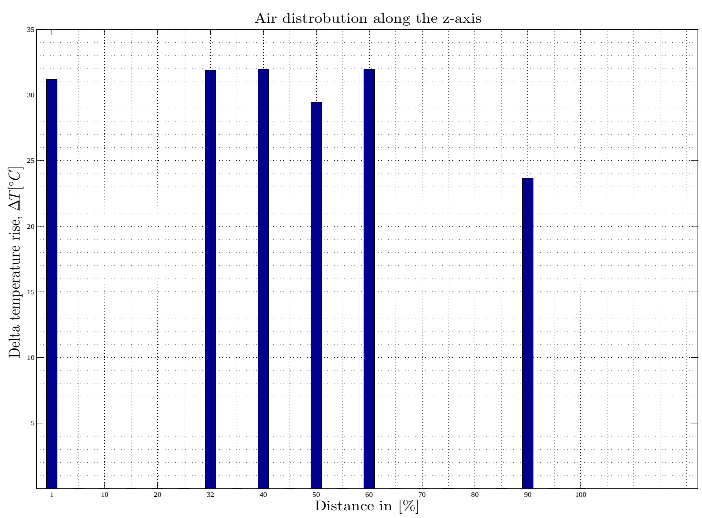

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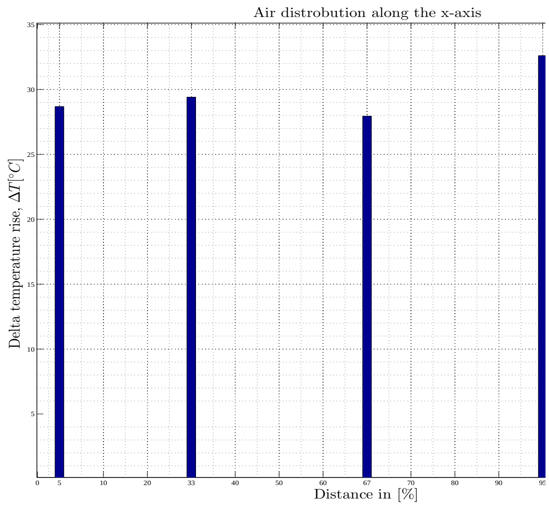
Figure A.8: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

A.1.9 Thermal distribution surrounding temperature - AL coated



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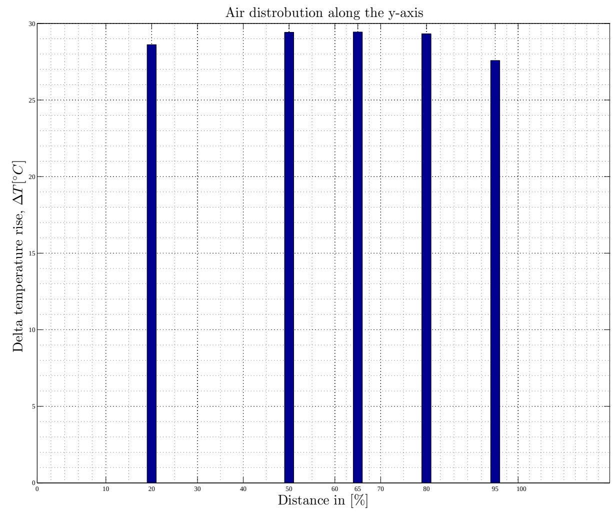
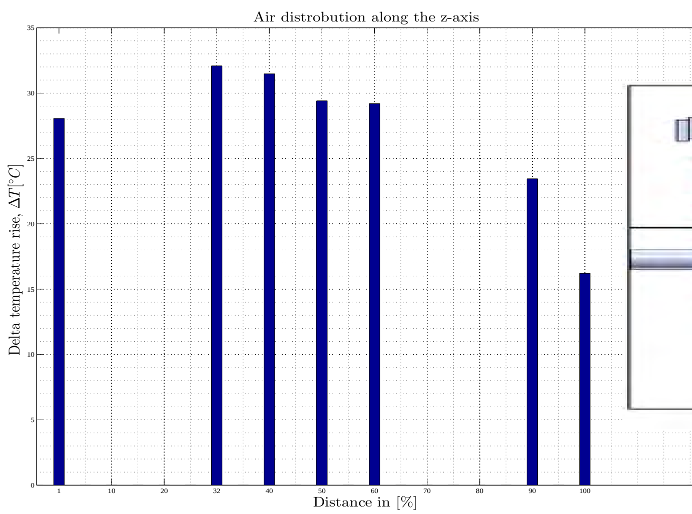
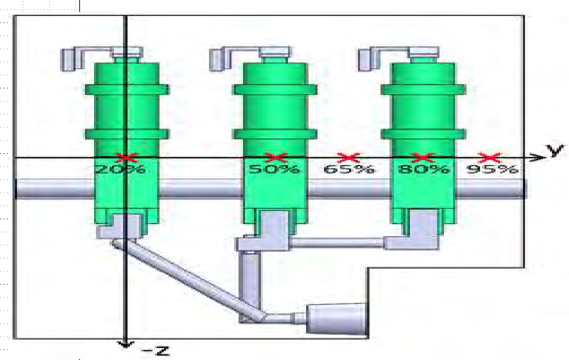


(b) Surrounding temperature along y-axis



(c) Surrounding temperature along z-axis



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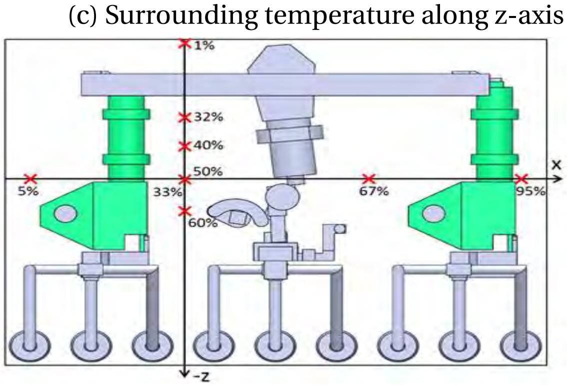
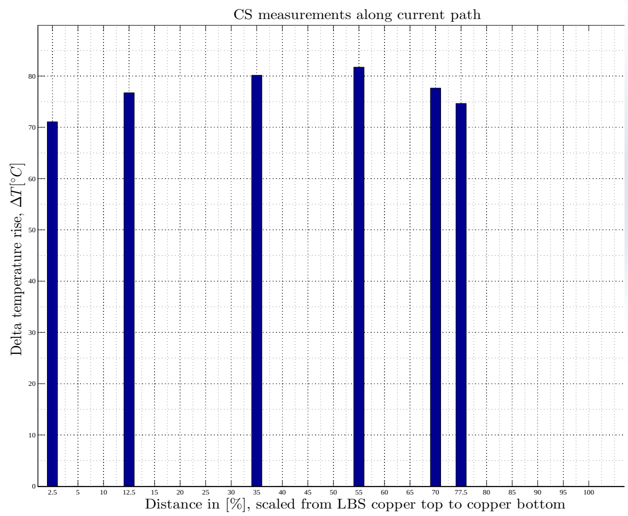


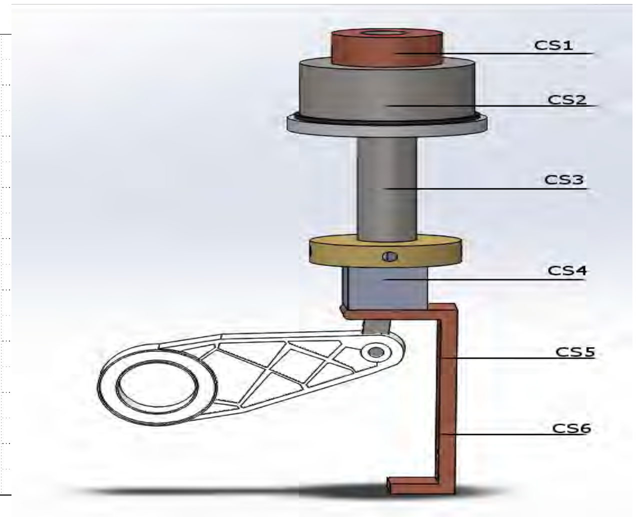
(e) text

Figure A.9: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

A.1.10 CS and in out distribution - AL Coated



(a) text



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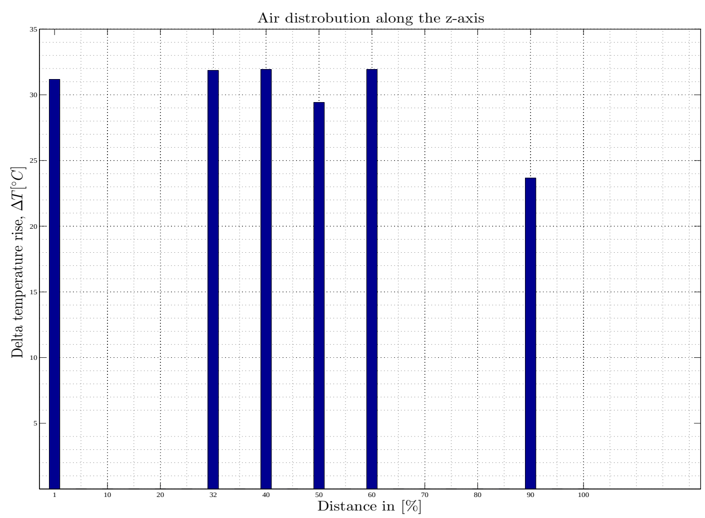
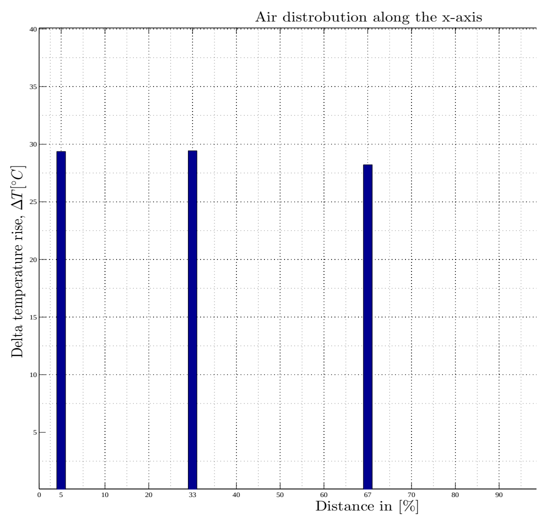


(c) text

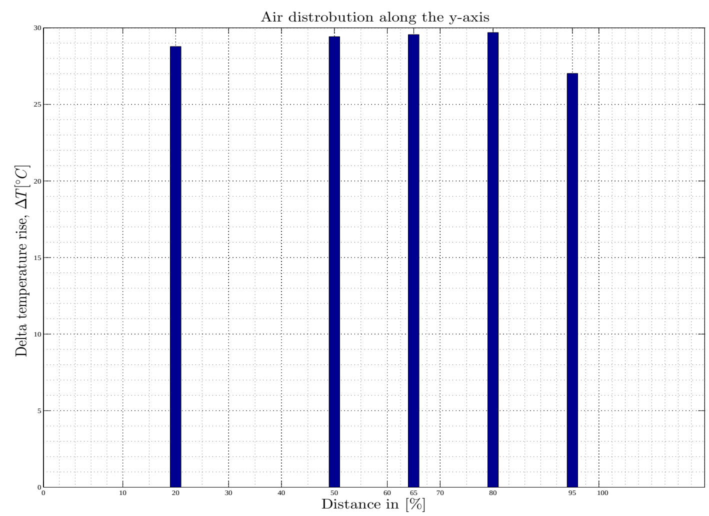
Figure A.10: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

A.2 Braided

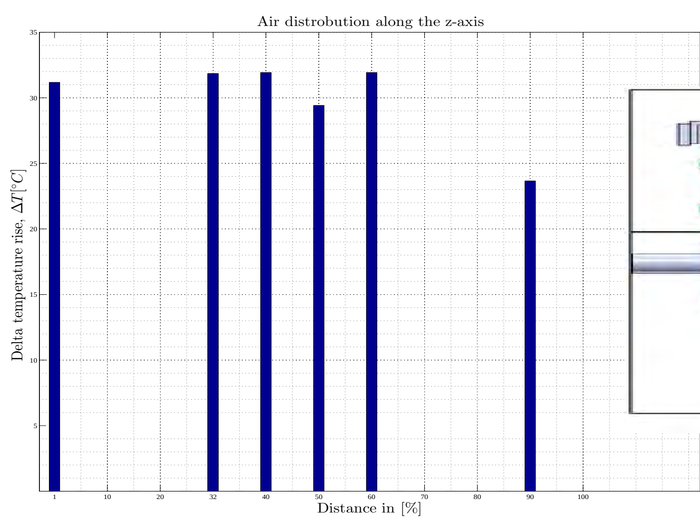
A.2.1 Thermal distribution surrounding temperature - Stripped Braided



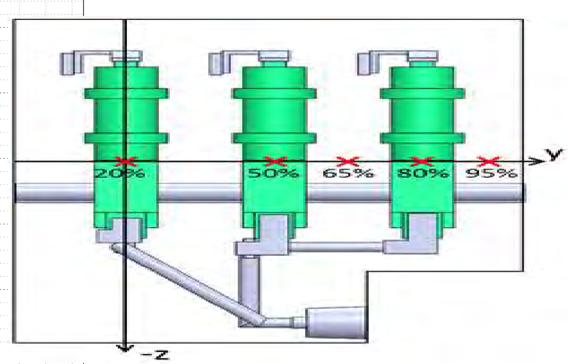
(a) Surrounding temperature along x-axis



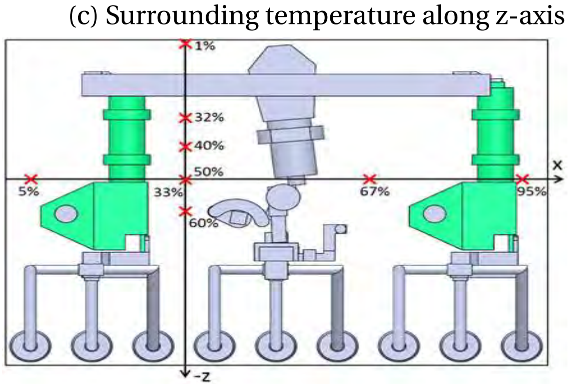
(b) Surrounding temperature along y-axis



(c) Surrounding temperature along z-axis



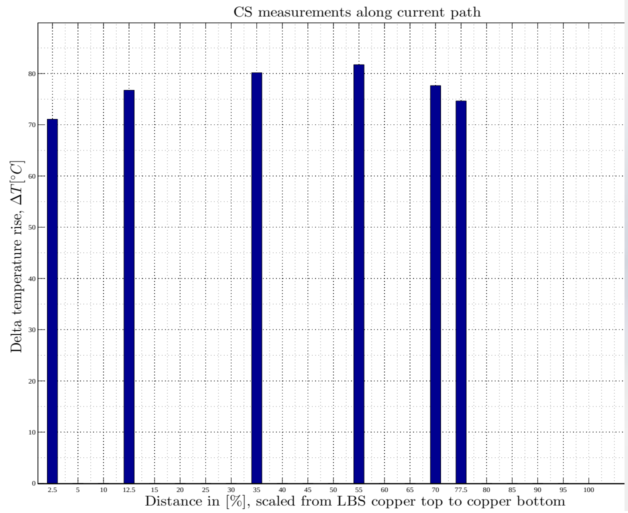
(d) Sensor placement for y-axis



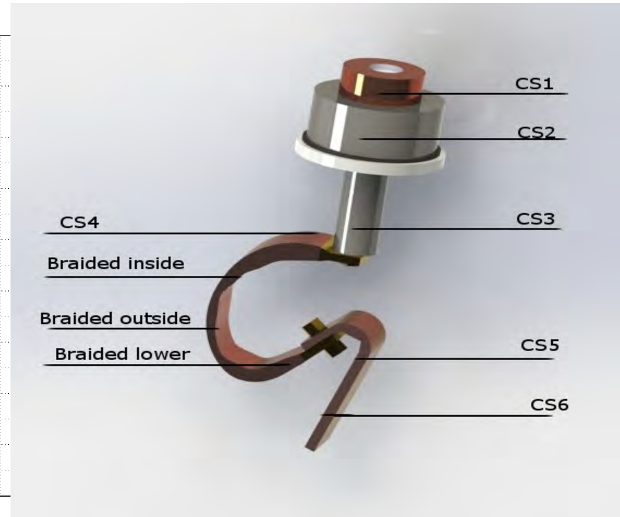
(e) Sensor placement for xz-axis

Figure A.11: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

A.2.2 CS and inside and outside distribution - Stripped Braided



(a) text



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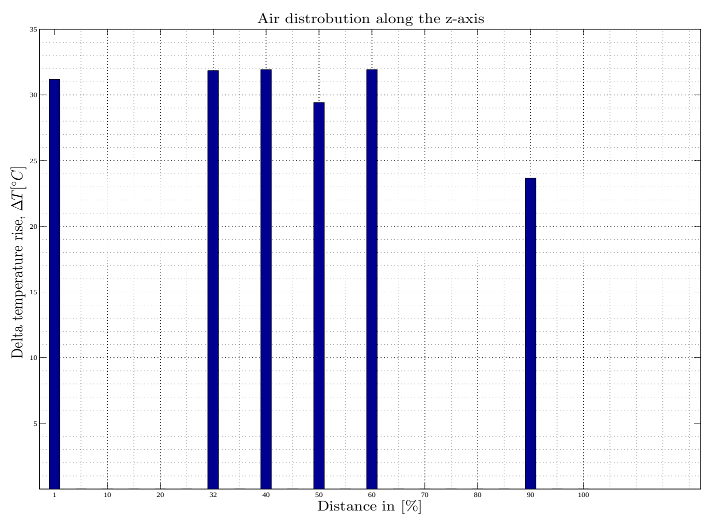
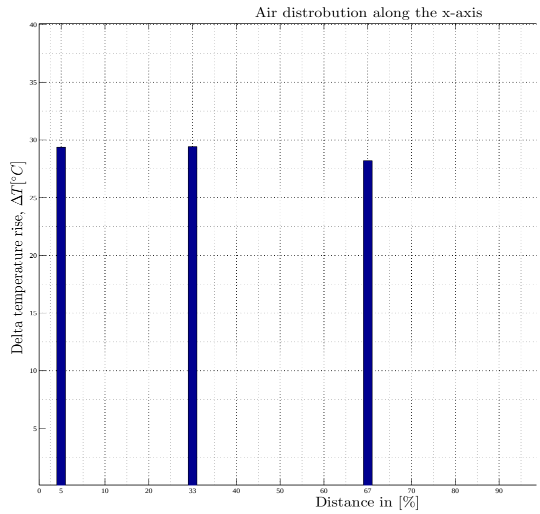


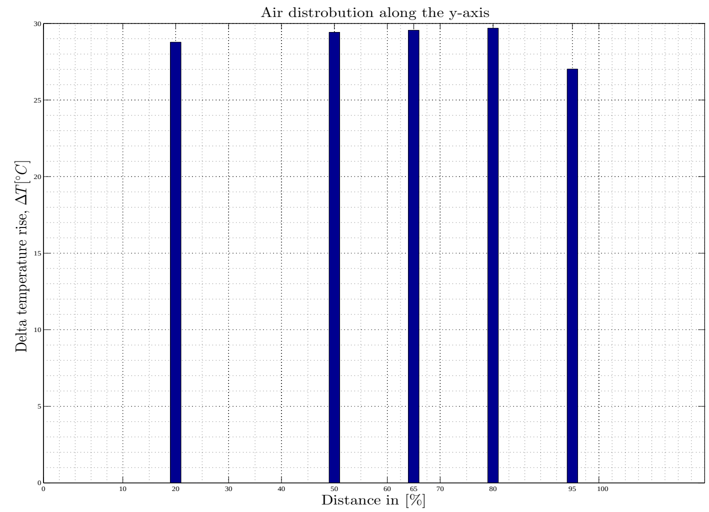
(c) text

Figure A.12: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

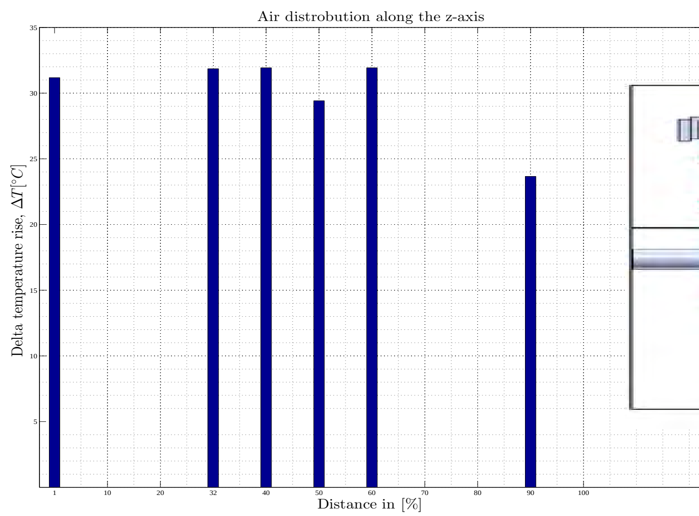
A.2.3 Thermal distribution surrounding temperature - Plastic and braided



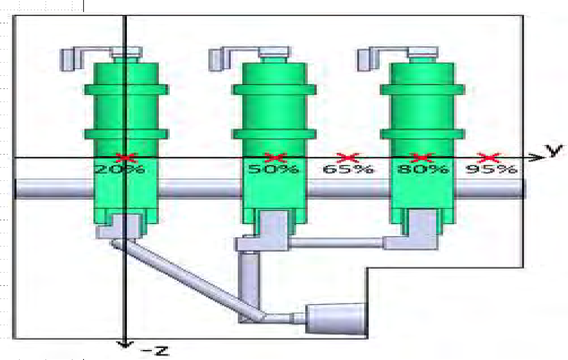
(a) Surrounding temperature along x-axis



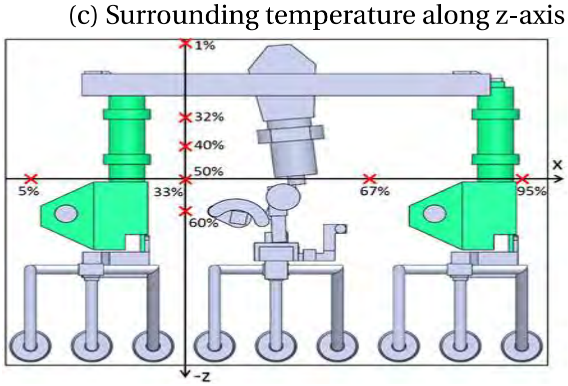
(b) Surrounding temperature along y-axis



(c) Surrounding temperature along z-axis



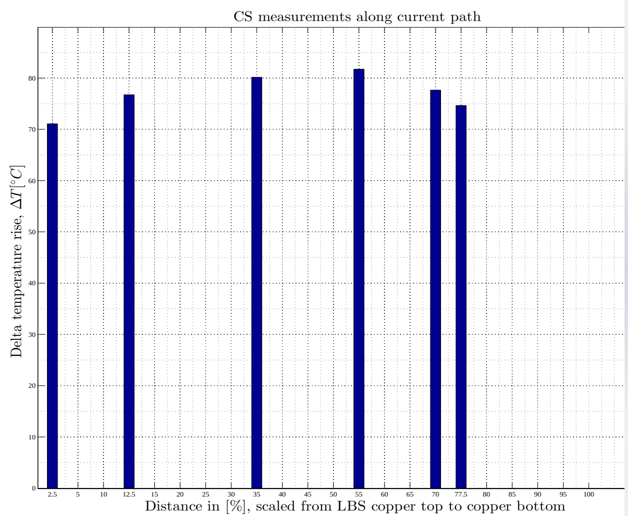
(d) text



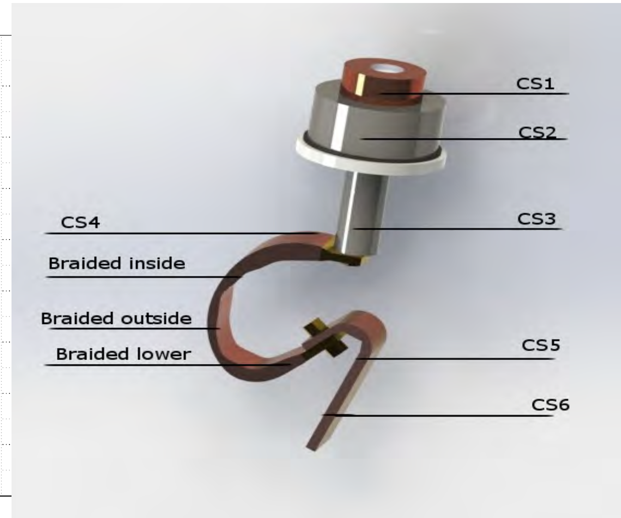
(e) text

Figure A.13: Temperature distribution along axis, for braided contact with plastic crankcase

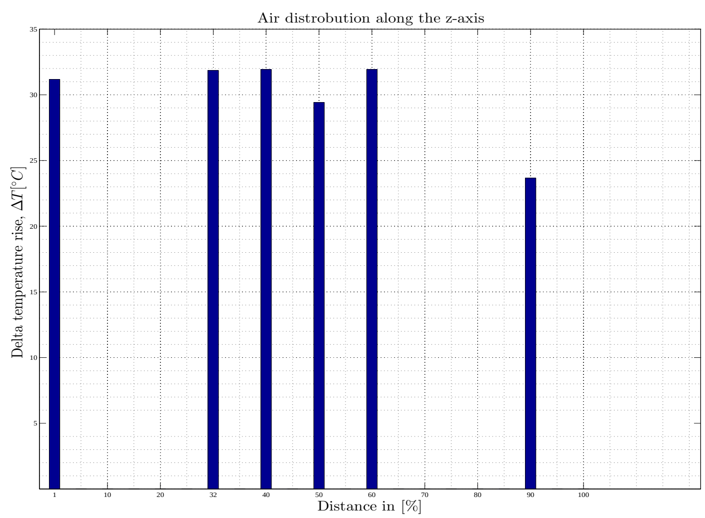
A.2.4 CS and inside and outside distribution - Plastic and braided



(a) text



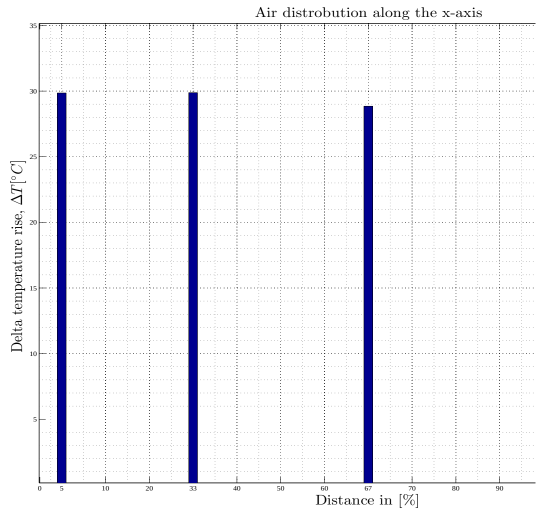
(b) text



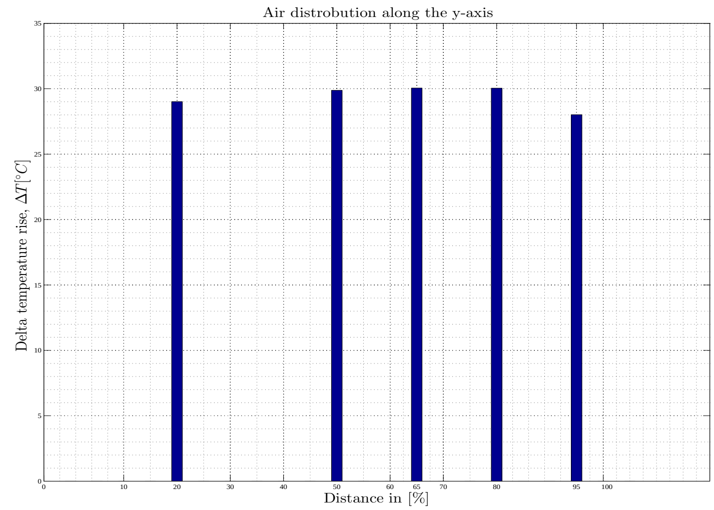
(c) text

Figure A.14: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

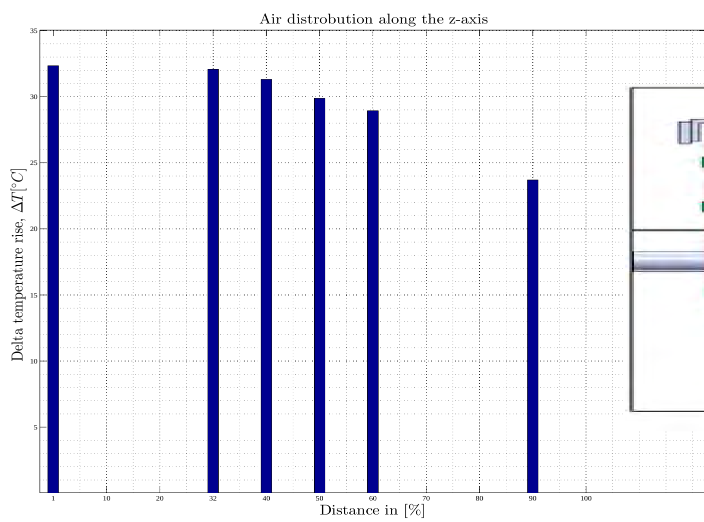
A.2.5 Thermal distribution surrounding temperature - AL braided



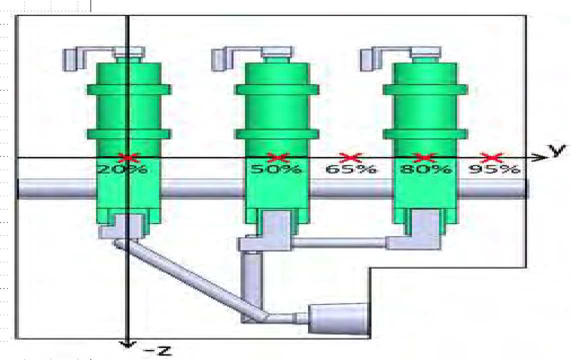
(a) Surrounding temperature along x-axis



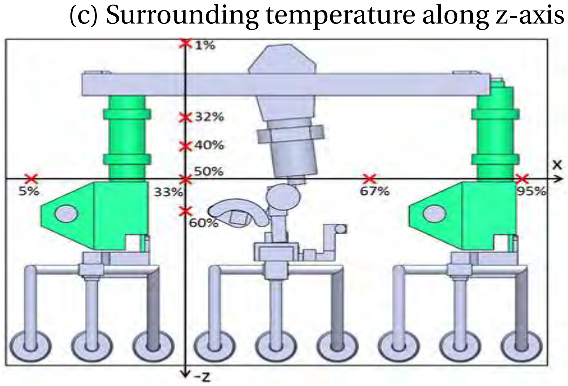
(b) Surrounding temperature along z-axis



(c) Surrounding temperature along z-axis



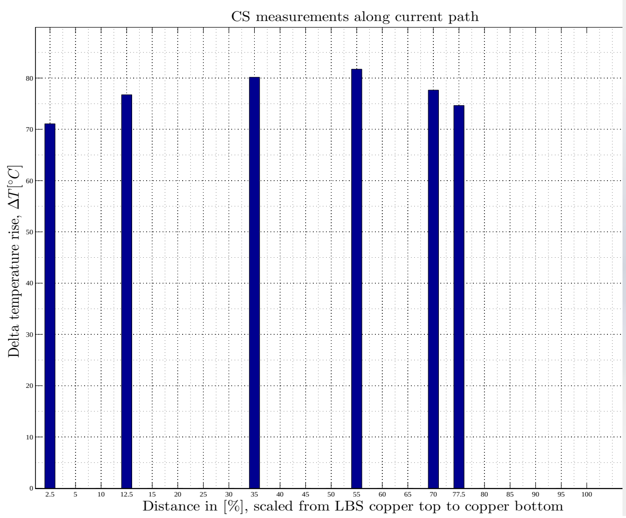
(d) text



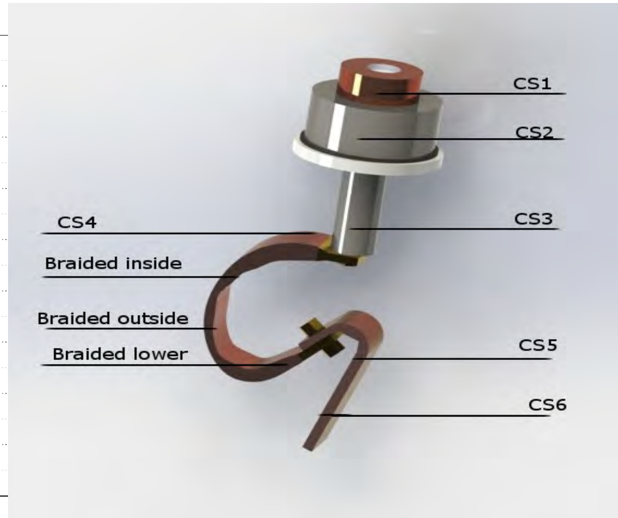
(e) text

Figure A.15: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

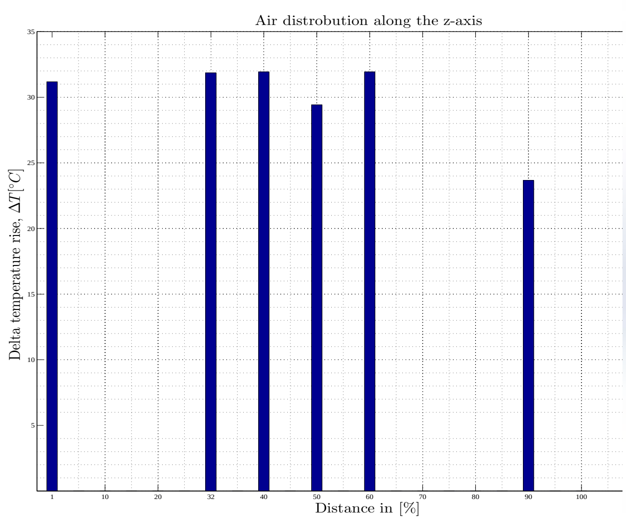
A.2.6 CS and inside and outside distribution - AL and braided



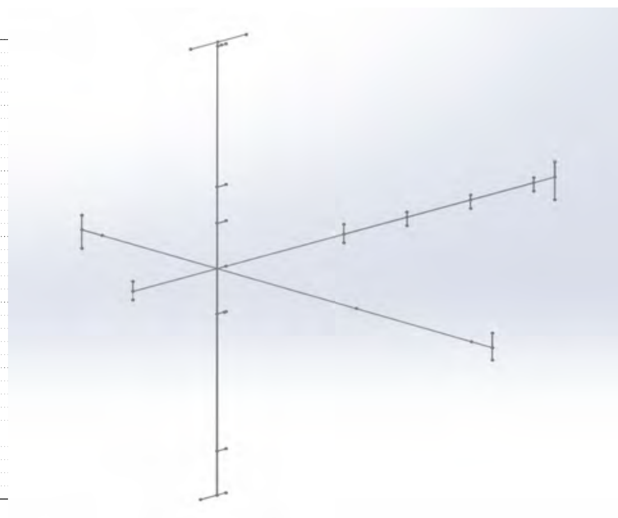
(a) text



(b) text



(c) text



(d) text

Figure A.16: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

Appendix B

Equipments used

> Science isn't about why!
>
> It's about why not
>
> Cave Johnson

In order to conduct the measurements done, some equipment is needed. The following equipment was used during the thesis.

B.1 ABB switchgear

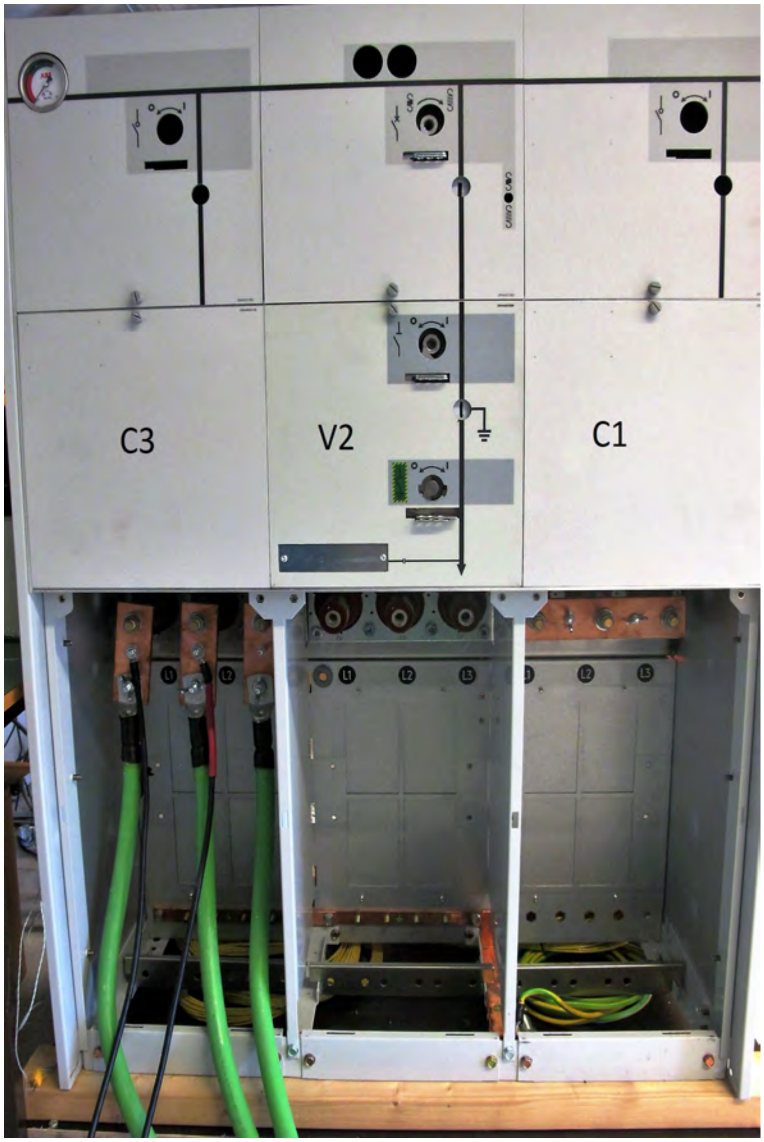


Figure B.1: Abb switchgear

B.2 Current injector

(a) Current injector backside

(b) Currrent injector front panel

Figure B.2: Hilkar Current injector

B.3 Infrared Camera

(a) Thermal camera from the side (b) Front view of camera

Figure B.3: Caption for this figure with two images

B.4 Wattmeters

(a) Allround high end wattmeter (b) Presission wattmeter

Figure B.4: Caption for this figure with two images

For power measurements

Figure B.5: Probes and coil for measuing the watt

B.5 The gift

B.5.1 HP E1326B/E1411B multimeter

HP E1326B is a register VXI instrument, no internal computer are present, i.e. any program made must be programed at register level.

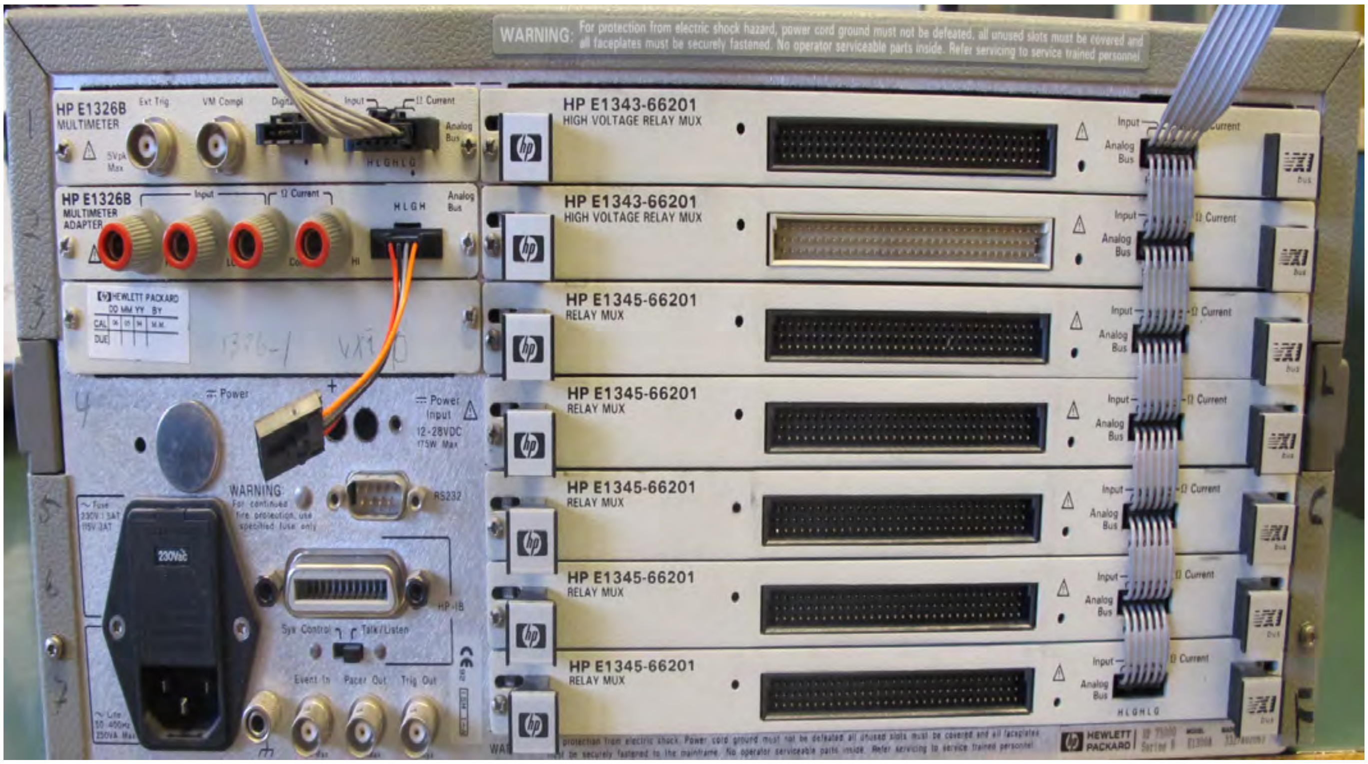


Figure B.6: HP multimeter

B.5.2 HP E1345-66201 Relay multiplexer

(a) $n = 10$ steps

(b) $n = 25$ steps

Figure B.7: Slots for thermocouple

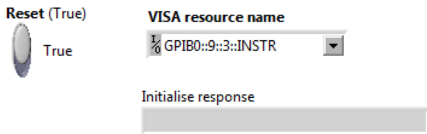
Appendix C

final one

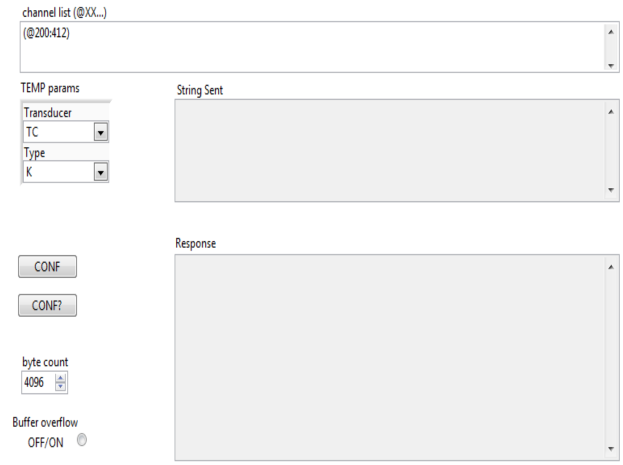
> We knew the world would not be the same. A few people laughed, a few people cried, most people were silent. I remembered the line from the Hindu scripture, the Bhagavad-Gita; Vishnu is trying to persuade the Prince that he should do his duty and, to impress him, takes on his multi-armed form and says, "Now I am become Death, the destroyer of worlds." I suppose we all thought that, one way or another.
>
> Julius Robert Oppenheimer

C.1 How to start the thermal logging

In order to start the program, one must chose which device to use, this is set in figure:C.1a. Next step is to chose which measurement range to measure from, the input (@from:to) eg (@100:715) reads all measurement channels. As seen in figure:C.1b. The next step is to start the measurement, click start once, to initialize the program, then press 'Continuous measurement', as shown in figure:C.1c to stop measurement click stop.



(a) Chose which device to use



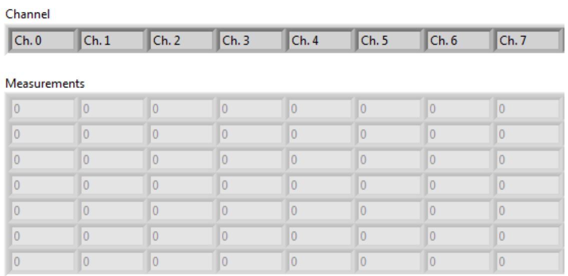
(b) Select measurements to read from

(c) Surrounding temperature along y-axis

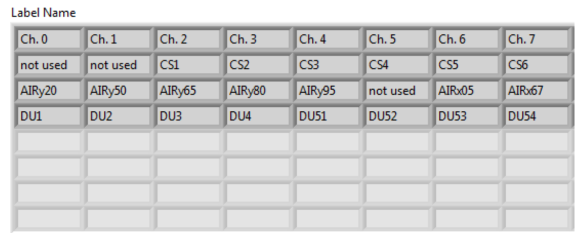
Figure C.1: Temperature distribution along x,y,z axis for Sliding contact with plastic crankcase

C.2 Display measured data

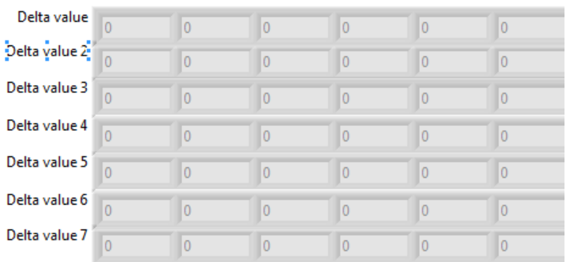
The labview program displays the temperature in a table, as shown in figure:C.2a In order to easier identify the value, one must enter in the measurement point names, as shown in figure:C.2b. In indicator to when the measurement have reached steady state, is present. Figure:C.2c show when the measurements have an temperature incrace of less then 0.5 deg C per hour. The data is plotted and save to file, figure:C.2d, show the tabs



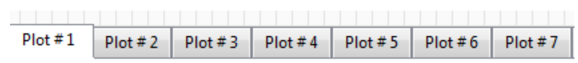
(a) Chose which device to use



(b) Enter label name



(c) Disply delta values

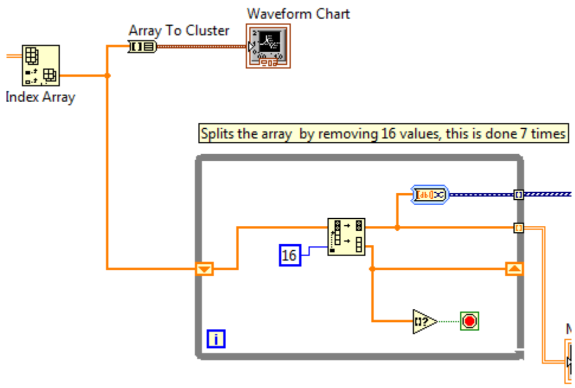


(d) Disply delta values

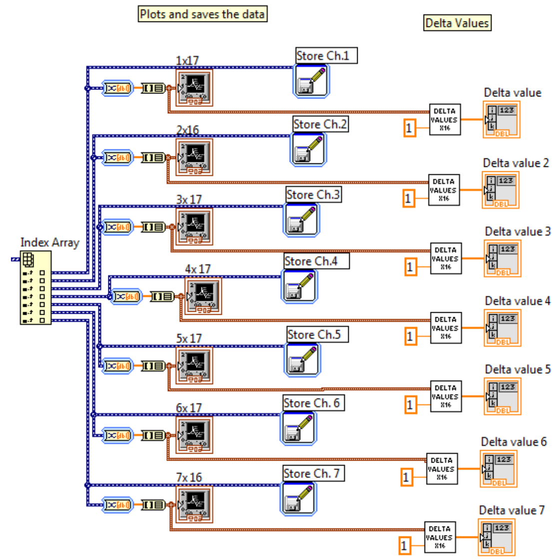
Figure C.2: Display measured data

C.3 Program operation

The program operations consist of: once measured signal is received, the data is indexed into a array, a while loop slices off 16 measurement and puts them in an array. Then the array is unbundled, such that one can manipulate individual measurements, like when it goes inti the delta value function which compares the measurement value form 30 min back and compares it to present data. After the unbundeling the data is converted into dynamic data and plotted and then stored in an excel file. Figure:C.3 shows the state flow as described above.



(a) Index and split data response



(b) Unbundle, store plot and delta value

Figure C.3: How the data is manipulated after being measured.

C.4 Manual for switching LBS and General practical information

C.5 Legal documents

Manual for switching an LBS and general practical information

Made by Peter Alexander Smestad

V.1 fro

Innhold

Equipment

Equipment list

Table 1 – list of instruments

Meter			Description
Fluke Ti25 thermal imager			Thermal Camera
Fluke 42II B thermometer			Handheld thermocouple reader
Metra hit 30 M			Multimeter
Metra hit Energy			Multimeter

How to use mechanical equipment

Calibration of torque

Connect the cables

Table 2, shows the bolt size needed and momentum.

Location	Wrench [size]	Calibration tool [momentum]	Momentum[momentum]
Injector	24		
Switchgear input	24		
LBS	14	30	30

Connect cables to current injector, then to switchgear, AC

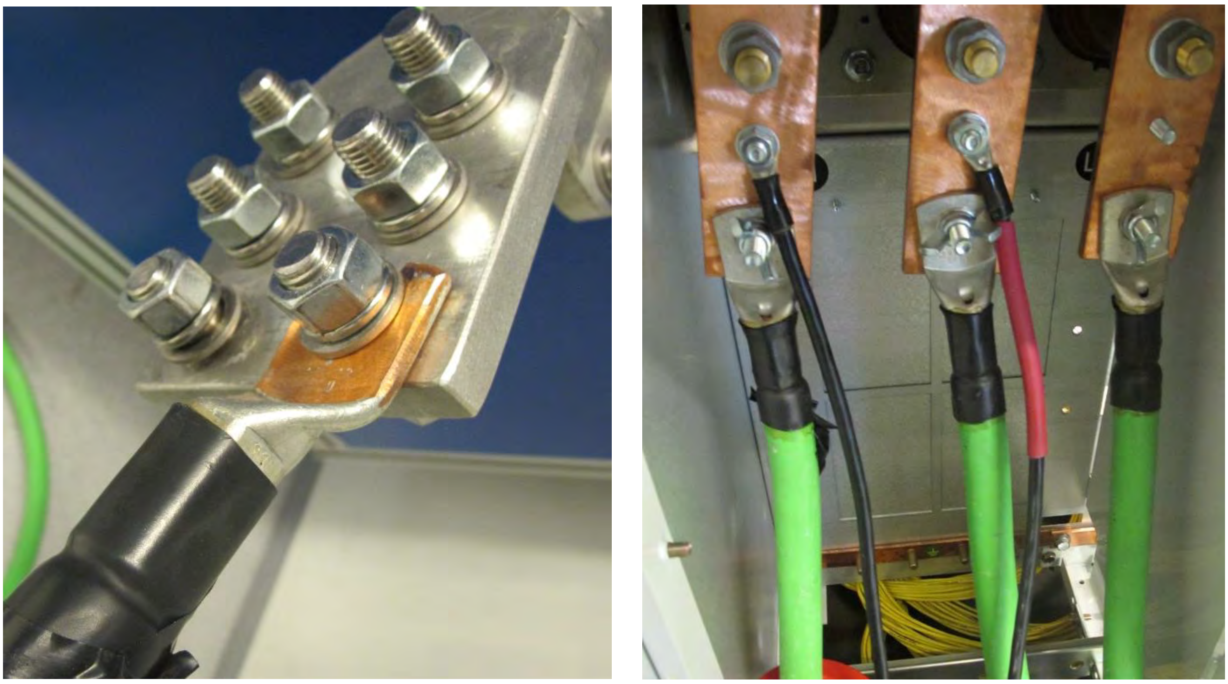


Figure 1 – how to connect cables

Connect cables to current injector, then to switchgear

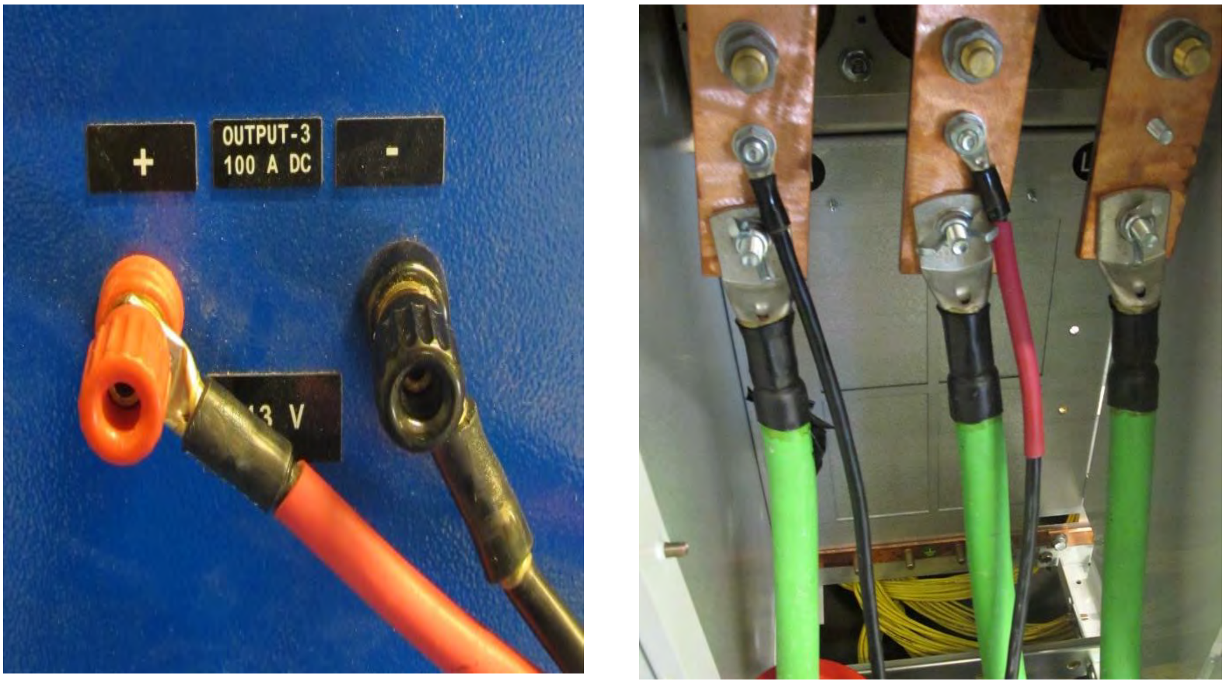


Figure 2 – how to connect cables

How properly secure the bolts

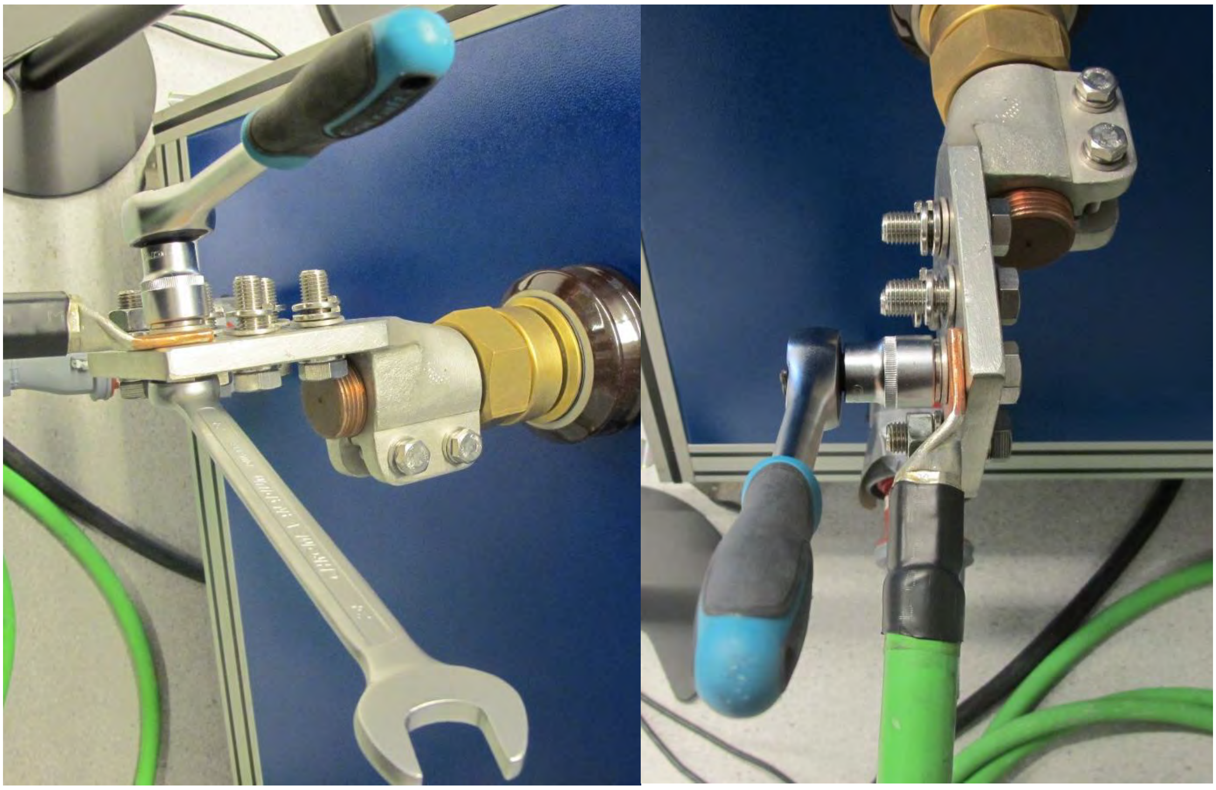
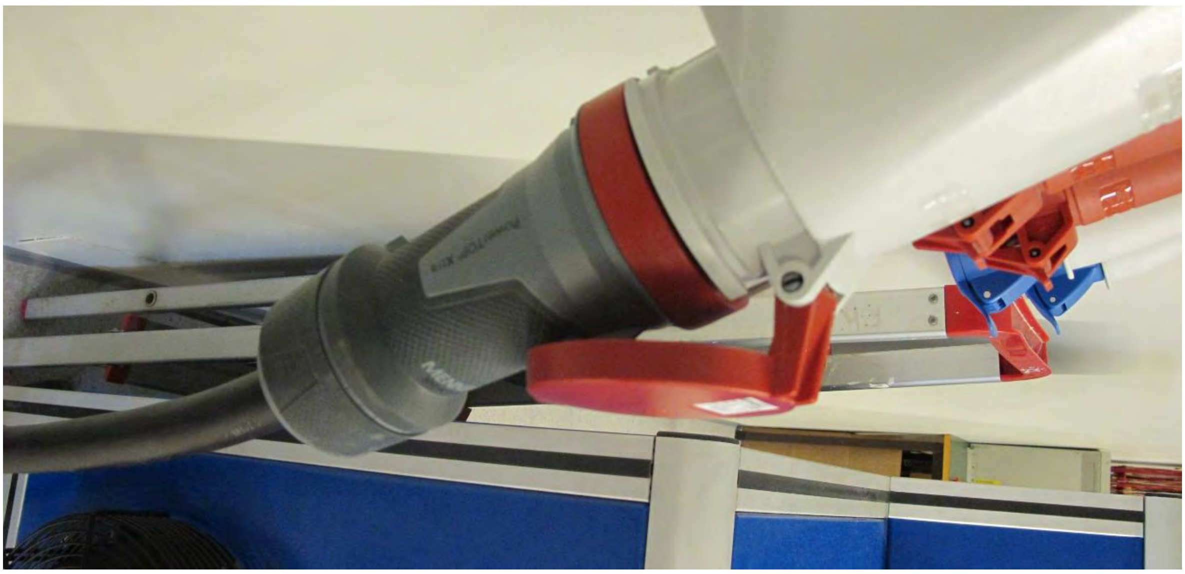


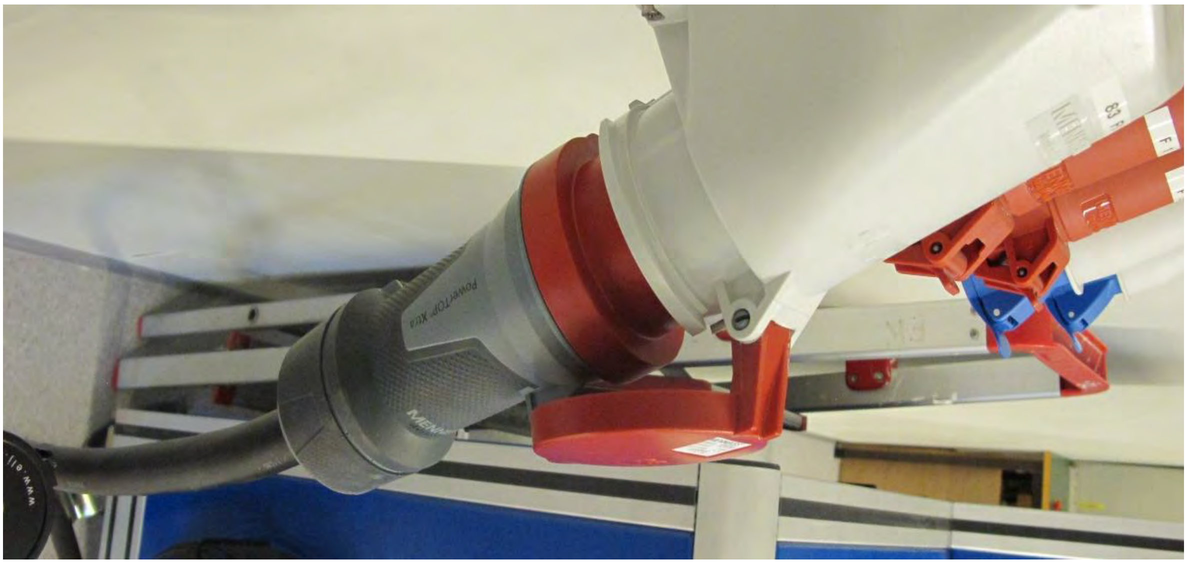
Figure 3a, shows how to properly secure and tighten the bolt, the least amount of strain on the current injector.

Figure 3b, shows the incorrect way and the way the puts the most strain on the current injector.

How to operate the current injector

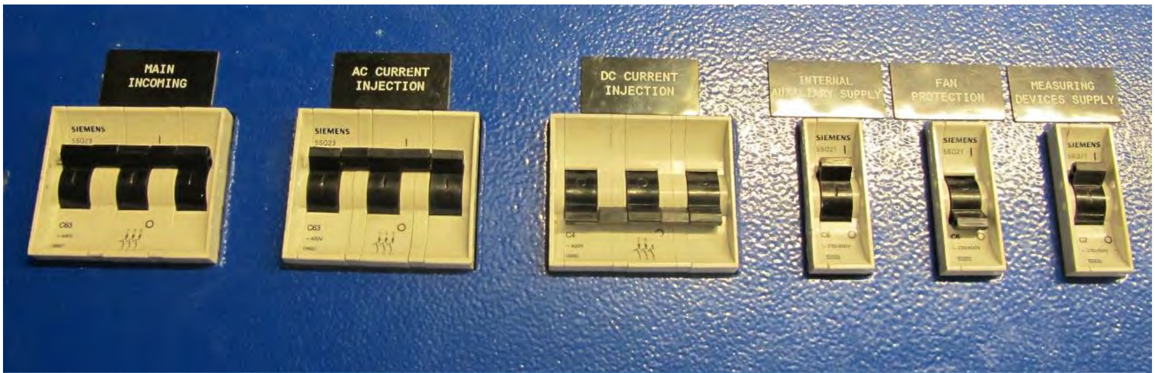
Plug in cable, the cable must be plugged in correctly. If not, fire hazard and/or incorrect power flow.

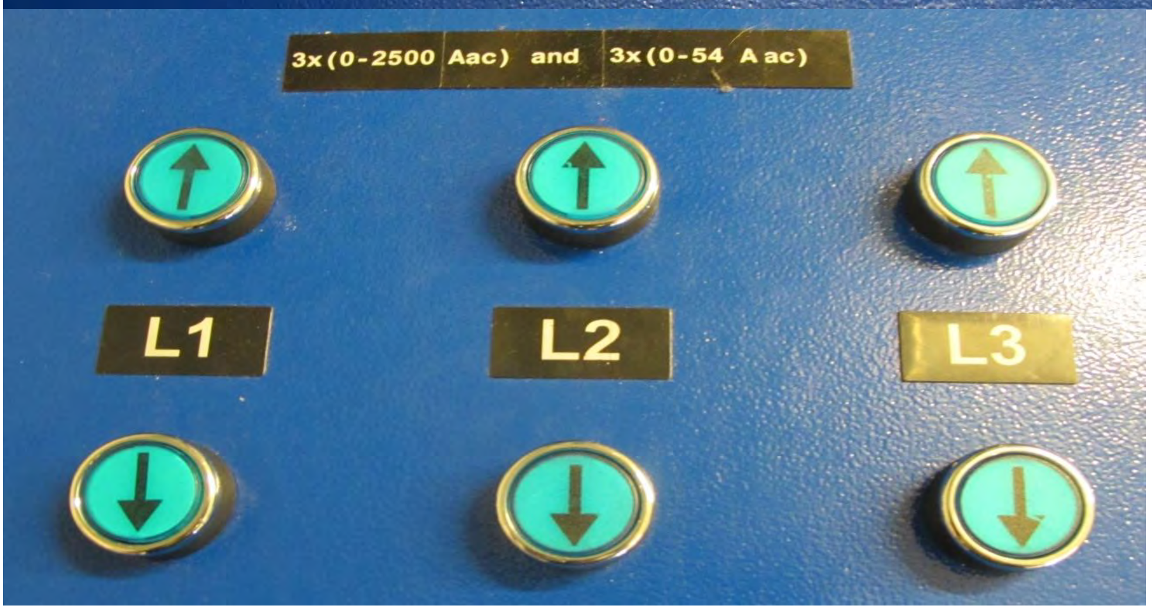




Current injector, AC, Manual

How to start the current injector

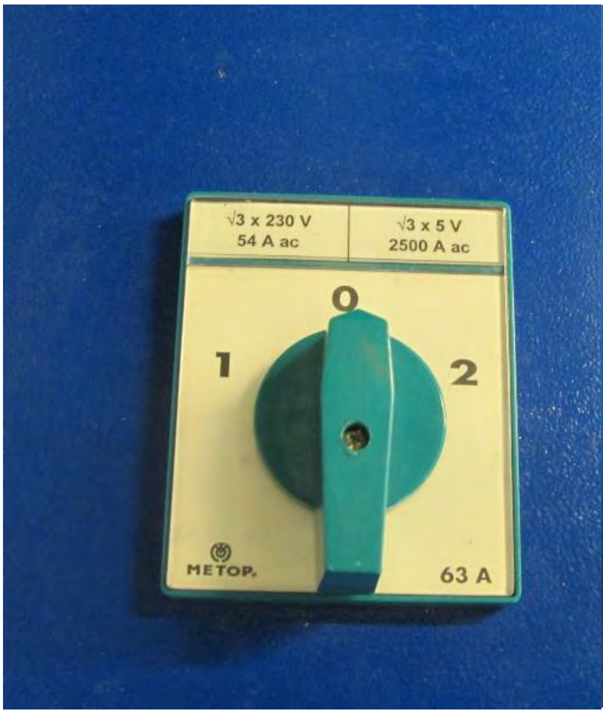




Current injector, DC, Manual

Turn off equipment

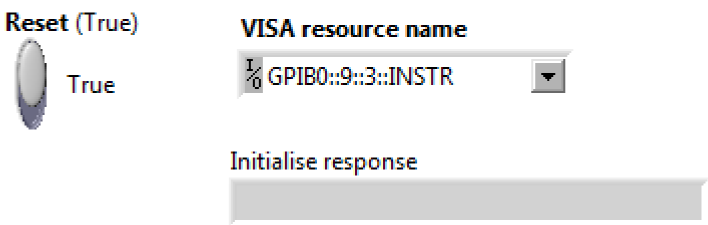
The equipment shall after every operation be returned back to zero.



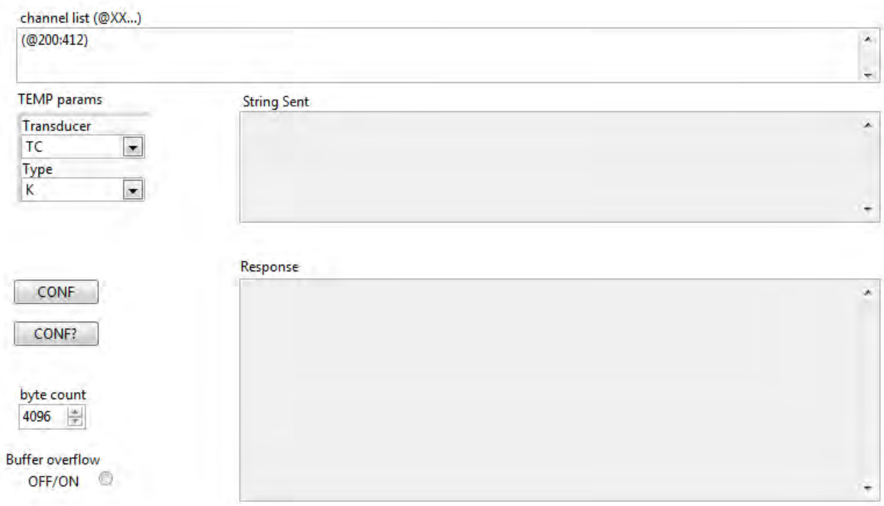
The figures illustrate how the values shall be after a run. The values are not always return to black zero value, this is the measurement equipment issue.

HP Thermal data logger

How to use program

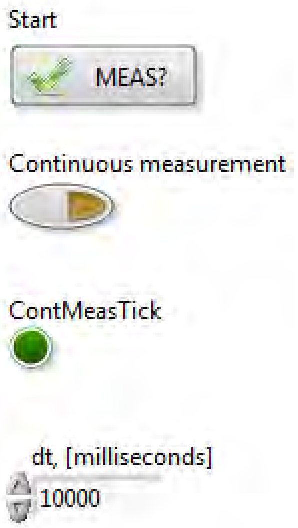


Set the correct instrument

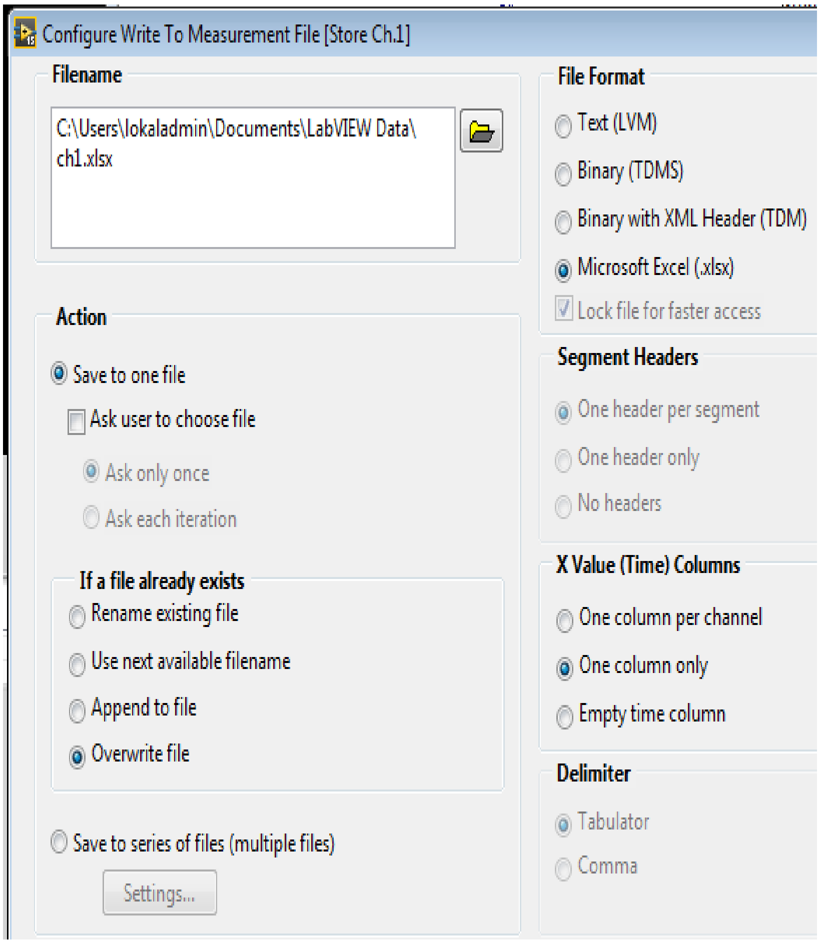


Select measurement range:
All: (@100:715)
Selective: (@xxx,xxx,xxx)

First x - channel
Second – from 0-15, measurement selection



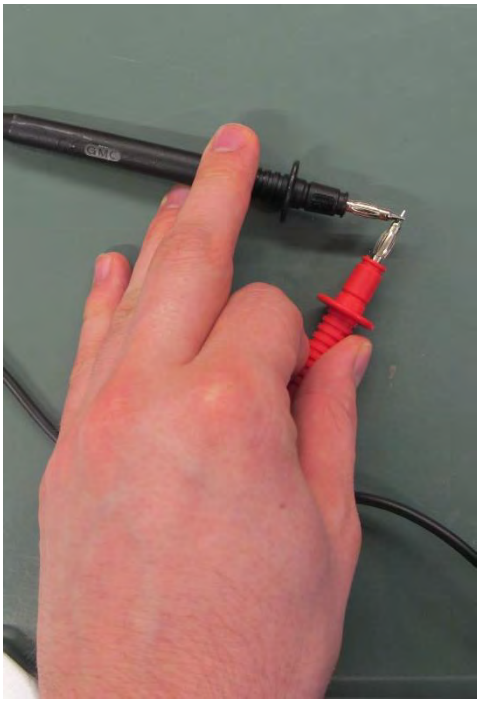
Click start once to initialize ,the press continuous measurement, press stop when done



If log data is to be change, these are the options.

Wattmeter

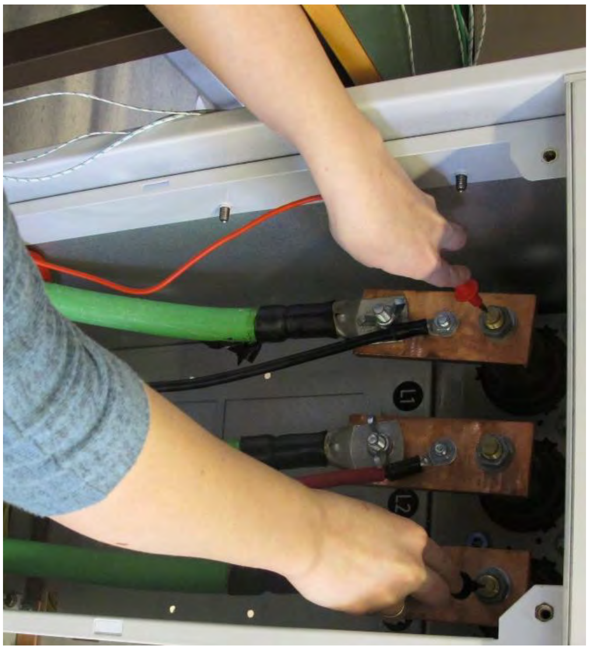
How to calibrate the wattmeter

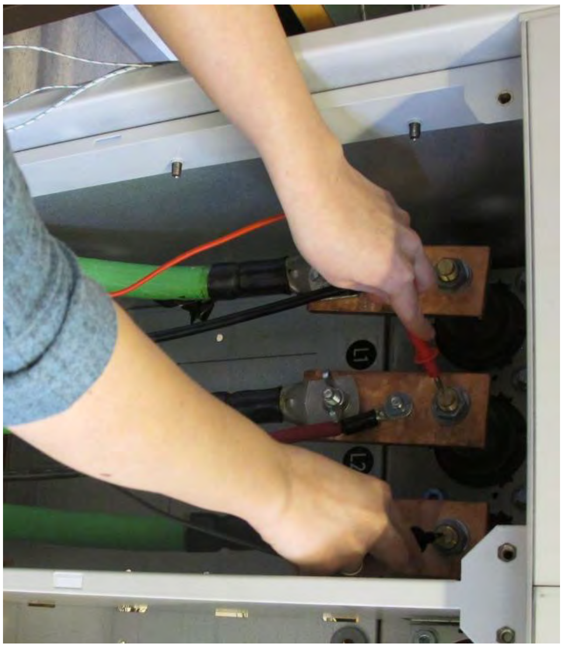


In order to calibrate the wattmeter, one must hold the wires together and press ZERO button, Figure x shows how this is performed for X, while figure X illustrates the same procedure for the Y wattmeter.

Power measurement

Measure L1-L3 and L2-L3





Resistance measurement

It is at these point one is to measure the resistance when the LBS is mounted inside the switchgear

Protocol on how to do a heat run

Assuming LBS is connected and back plate is secured and screwed into place

- Connect as in figure 1 and 2
- Plug in power
- Have the labview program running and logging
- Start the current, up to a set point
- Adjust so to keep at set point
- Wait until switchgear has reached steady state, stop logging
- Prepare for DC measurement. DO NOT remove back cover.
- Turn of AC and switch on DC.
- Now start to remove back plate.
- When the back plate is removed, be ready to immediately do a resistance measurement.