IMPROVEMENT TO CONTACTING SHUNT FOR EXTERNAL FLOATING ROOF TANK LIGHTING PROTECTION SYSTEM

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by

Mohd Yusri B. Mohd Yusoff

Dissertation

Submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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(ELECTRICAL AND ELECTRONIC ENGINEERING)

Approved by,

____

(Pn. Hanita Daud)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JUNE 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHD YUSRI B. MOHD YUSOFF

ABSTRACT

This project is an improvement to the current FRT's lightning protection system to prevent the formation of electrical spark during a lightning strike; this is one of the main causes of rim fire on an external floating roof tank. During internship at PETRONAS Penapisan Terengganu Sdn. Bhd. (PPTSB), the engineers are trying to prevent more fire incident from occurring on their floating roof tank that are used to store highly volatile petroleum products. The sparking is caused by the gap between the contact shunt and the tank wall. When the tank roof stroked by lightning the shunt should provide a low resistance path to conduct the high current, but if a gap exist between them spark will be produced. To make things worse the current design of floating roof tank has place this contact at a location that has high flammable gas concentration. In this project, the current shunt contactors are improved so that no gap will be formed between it and the tank wall. At the end of this project, a prototype and a scaled down model of FRT are fabricated to show how the improved design will work. Some tests are done to the prototype to show that it worked.

ACKNOWLEDGEMENT

I would like to take this opportunity to acknowledge and thank everyone that has given me all the supports and guidance throughout the whole period of completing the final year project. Firstly, many thanks to the university and the Final Year Project coordinators, especially Ms. Salina that have coordinated and made the necessary arrangements.

I must also acknowledge the endless help and support received from my supervisor, Pn. Hanita Daud throughout the whole period of completing the final year project. Her guidance and advices are very much appreciated. Besides that, many thanks to all the staff in PETRONAS Penapisan Terengganu SDN. BHD. especially the electrical maintenance department, for giving me the chances to learn about lightning protection in storage tank during my internship.

I would also like to thank the lab technicians in UTP, especially Mr. Saiful for his endless support in terms of the preparation of material and machine during the fabrication process. His continuous support and help throughout the whole period of experiments are very much appreciated.

Finally, many thanks to my fellow colleagues for their help and ideas throughout the completion of this project. Thank you all.

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LIST OF ABBREVIATION

API	American Petroleum Institute
NFPA	National Fire Protection Association
FRT	Floating Roof Tank
RGA	Retractable Grounding Assembly

CHAPTER 1

INTRODUCTION

1.1 Background

External FRT are used to store highly volatile petroleum products and chemicals because it prevents the built up of flammable gas. This is achieved by eliminating any air space on top of the product in the tank using its floating roof. By having the tank roof moving up and down with the level of the product means that there is no permanent connection between the roof and tank wall for grounding purpose. The connection between the roof and wall are achieved by a number of methods; installing contacting shunts every 3m on the tank roof, wire connection, and metallic ladder with parallel wire [1]. These methods are API and NFPA standards for storage ground bonding system.

During internship at PP(T)SB, the engineers are trying to solve a problem caused by a gap between the contacting shunt and the tank wall. This problem has resulted in two rim fire incident in 2007 and 2008[2]; both are caused by lightning stroke. The solution for this problem came with the introduction of the RGA system which would provide a continuous low resistance path for lightning current to flow. This solution has cost the host company millions of ringgit for the implementation; the improved shunt design resulted from this project are hoped to prevent such high expenditure.

1.2 Problem Statement

The external FRT is an efficient way to prevent the buildup of flammable gas inside the tank. In an external FRT there are no connection between the tank wall and roof to allow the roof to freely move with respect to the product level. Connection has to be made between the roof and wall for grounding purpose, the conventional grounding method based on API and NFPA standards is by using; contacting shunts every 3m on the tank roof, wire connection, and metallic ladder with parallel wire. Over time the contacting shunt prone to get bent resulting a small gap between the roof and tank wall, during a lightning strike to the roof sparking will occur at this gap due to current nature that will take the shortest path to ground.

The shunt is located less than a meter from the seal that separate the product inside and the outside, its location is within the area where there are possibilities of flammable vapor existence. This is a very dangerous condition where any spark created by the shunts during a lightning strike could ignite the vapor.

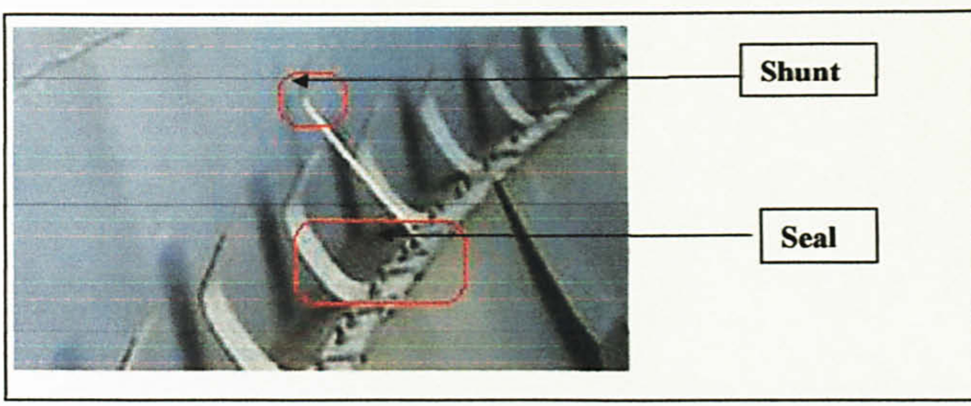

Figure 1: Locations of Shunt and Seal.

1.3 Objective and Scope of Study.

1.3.1 Objective.

In this project an improvement for the current contacting shunt design are done to prevent the formation of gap between the roof and tank wall of FRT that may result in sparking during a lightning strike. To do this, the current shunt design is improved so that at any duration and condition of usage no gap will be created. A prototype of the improved shunt and a scaled model of FRT are fabricated. The prototype will be tested to prove that it will work, while the scaled model of the FRT is to show how this improvement will be implemented.

1.3.2 Scope of Study.

This project would cover the effectiveness of the current lightning protection system for the external floating roof tank, the codes and standard that governs the installation of lightning protection in floating roof tank, the studies about nature of lightning and the design of an improved shunt contactor. Besides this, there are also a study about the relationship between the gap between the shunt contactor and the tank wall, and the voltage required to produce sparks.

CHAPTER 2

LITERATURE REVIEW

2.1 Floating Roof Tank

The usage of external FRT in storing volatile product has helped to eliminate the buildup of flammable gas over the product in the tank. To achieve this roof has to be made independent from the wall, this allows it to raise and fall with respect to the product level. In order for the roof to be independent from the wall there must be no permanent connection that can block the movement of the roof, but having no permanent connection means that the roof have no way of dissipating the high current in case striked by lightning. Because of this a number of methods have been used to provide grounding connection between the roof and wall such as; installing contacting shunts every 3m on the tank roof, wire connection, and metallic ladder with parallel wire. These methods are API and NFPA standards for storage tank ground bonding system [3].

2.1.1 FRT's Design[8].

External floating roof tank are commonly used to store highly volatile petroleum products in high volume. The basic structure is open- topped cylindrical steel shell and a roof that floats with respect to the level of product in the tank. Compared to a fixed roof tank, there is no vapor space in the floating roof tank (except for very low liquid level situations). This should eliminate breathing loss and reduce evaporation of the product.

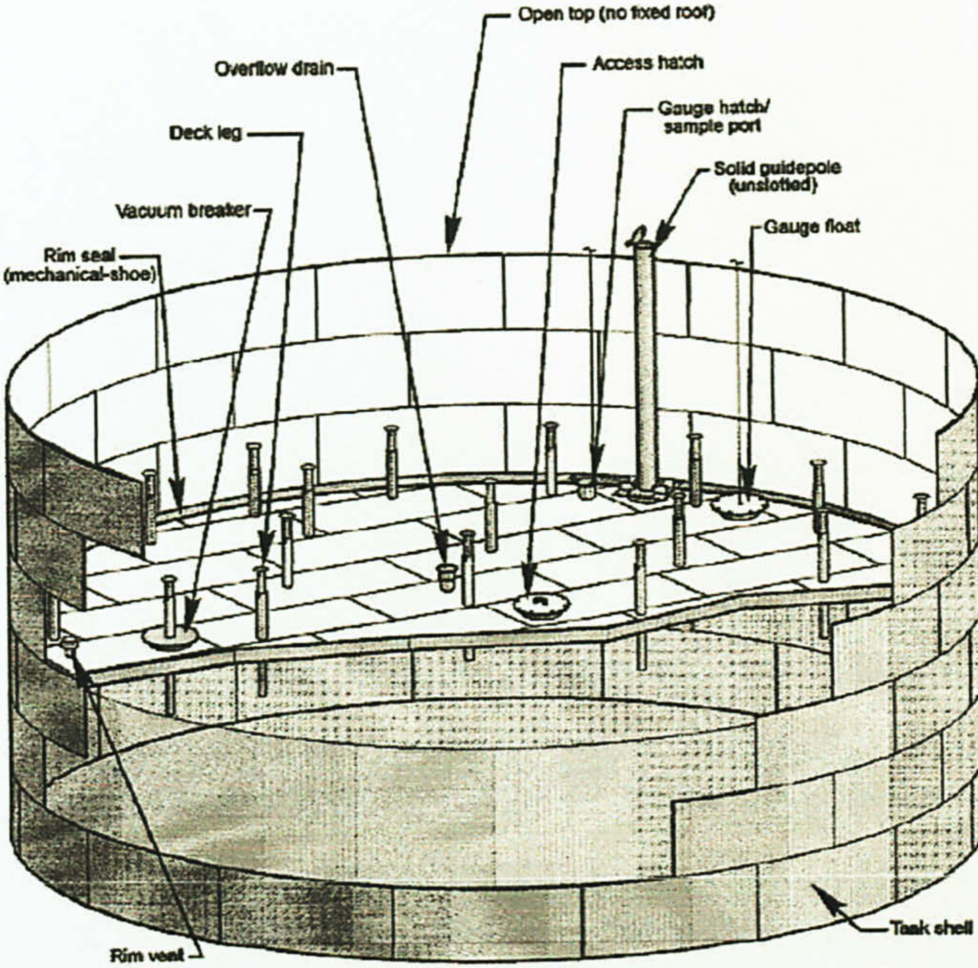

Figure 2: Floating Roof Tank Components.

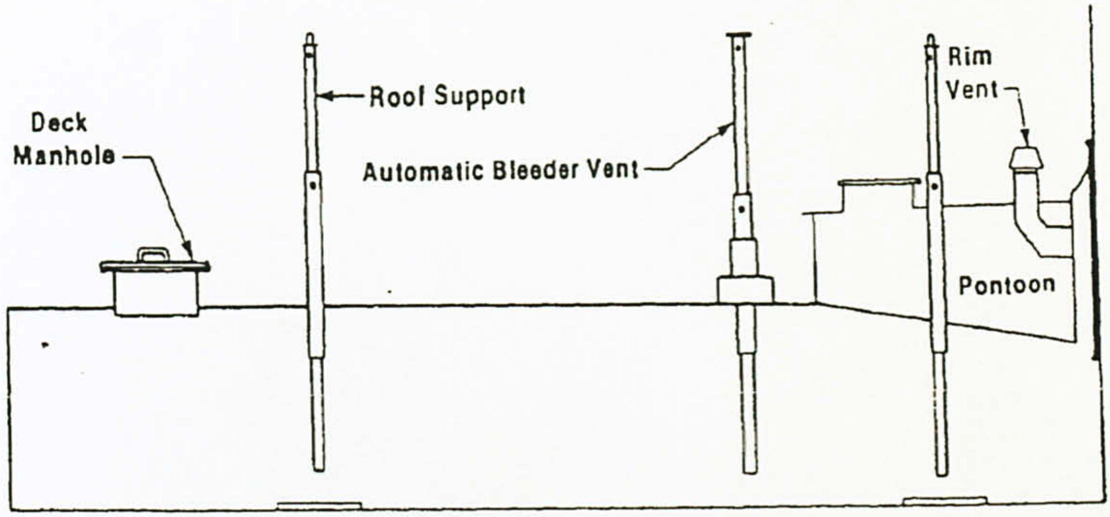

Figure 3: Tank Roof Fittings.

Among the components of external FRT are.

2.1.1.1 Wind Girders (not shown in figure).

As floating roof tanks are usually open-top tanks, the top of the shell has to be reinforced by a wind girder against 'blowing in" in high wind conditions. The size of the wind girder depends upon the size of the tank. In some cases, the wind girder is used as a walkway.

2.1.1.2 Roof Supports.

Roof supports are required to keep the roof from fouling the inlet and outlet lines or any tank heaters that might be in the tank. Roof supports or "legs" are constructed from pipe and sufficient supports to distribute the weight of this roof evenly.

2.1.1.3 Roof Legs & Vacuum Breaker.

Allow air to flow in when filling the tank and flow out when emptying the tank.

2.1.1.4 Roof Drains.

To remove any water that may settle on the roof, the roof is equipped with drains. The types most commonly used are:

a. The flexible hose drain
b. The pipe drain with swing joints
c. In each case, the pipe or hose runs from a well in the roof through the liquid in the tank to the ground via a valve situated outside the tank shell.

2.1.1.5 Roof Access Ladder.

Provide safe access from the top of the tank to the deck of the floating roof. The ladder is hinged at the top and is supported on wheels at the bottom, which run on tracks attached to the roof deck. In some cases, the stair treads are self-leveling.

2.1.1.6 Automatic Bleeders Vents.

Are fitted in the floating roof decks to vent air from under the floating roof on filling the tank initially. After the liquid has raised high enough to float the roof off its supports, the vent automatically closes. When emptying the tank, the vent automatically opens just before the roof lands on its supports, preventing a vacuum from forming.

2.1.1.7 Rim Vents.

Sometimes provided to release any vapor that builds up in the rim space.

2.1.1.8 Roof Seals.

The space between the rigid rim of the floating roof and the tank shell is closed by a seal. The seal consists of a metal sealing ring, the bottom of which remains submerged in the liquid or product. A continuous vapor-tight and weatherproof synthetic rubber-coated fabric is used to close the space between the sealing ring and the rim of the floating roof. The sealing ring is held against tank shell by pantagraph hangers. The pantagraph hangers also hold the roof centrally within the tank[8].

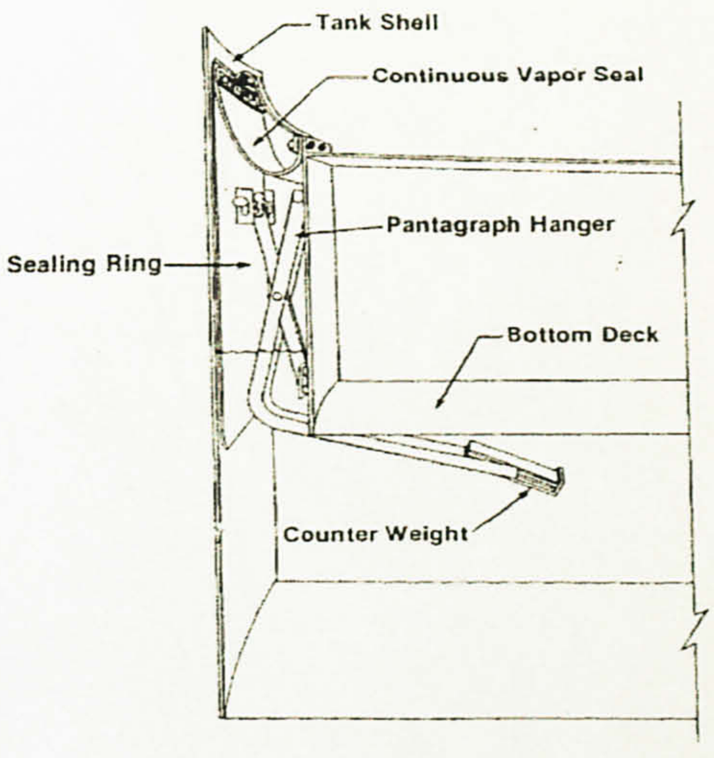

Figure 4: Roof Seal Component.

2.1.2 FRT'S Grounding System.

The grounding for FRT is achieved by; installing a contacting shunt every 3m on the top of the tank, wire connection, and metallic ladder with parallel wire[10].

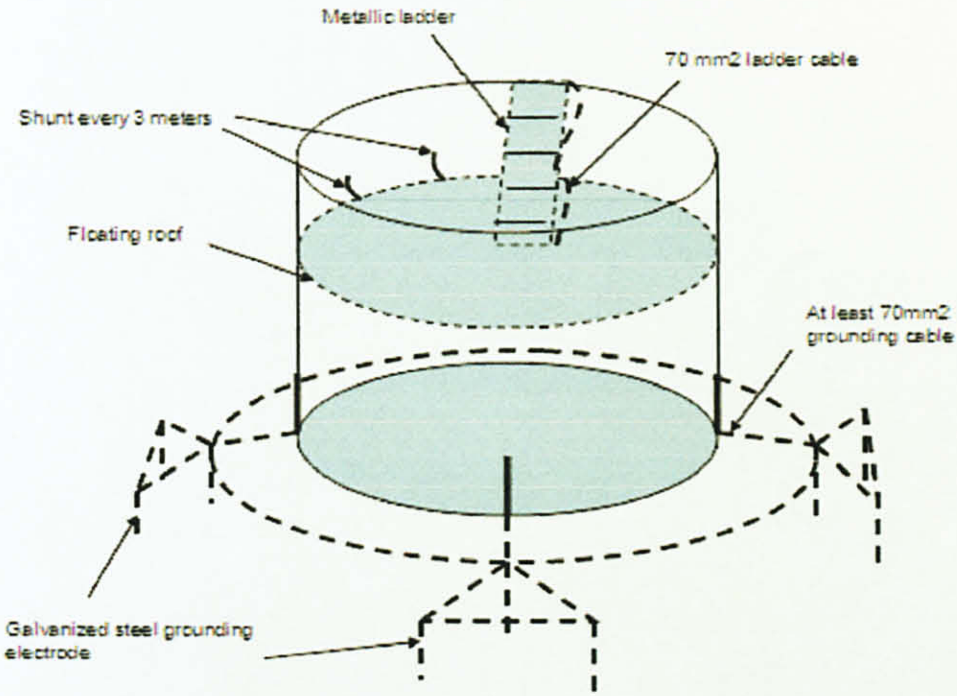

Figure 5: Overview of FRT Grounding system.

The grounding system used now are standards accepted by API and NFPA, but based on the research recently done by API, if there's a gap between the shunt and the wall there will be sparking if the roof are stroked by lightning. This has been proven by an experiment done by API RP 545 "Lightning Protection for Above Ground Storage Tanks" Task Group. The resulting sparking can be seen in Figure 6. In this project the current shunt design is improved to address the gap problem.

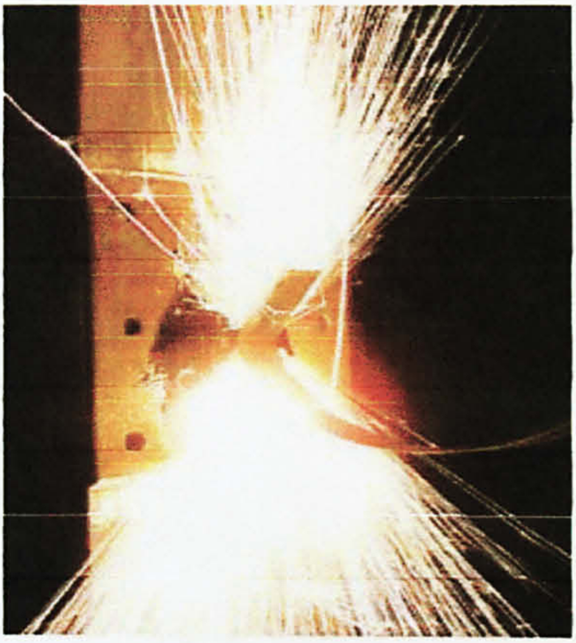

Figure 6: Simulated Electrical Impulse.

2.2 **Characteristics of Lightning**

Lightning is a natural occurrence that happens when the buildup of negative charge in clouds (especially cumulonimbus type) is discharged. A strike from cloud to ground in the form of luminescent strike comprises of an average 30 – 50 kA (maximum more the 100kA) or called downward lightning[10][4][11].

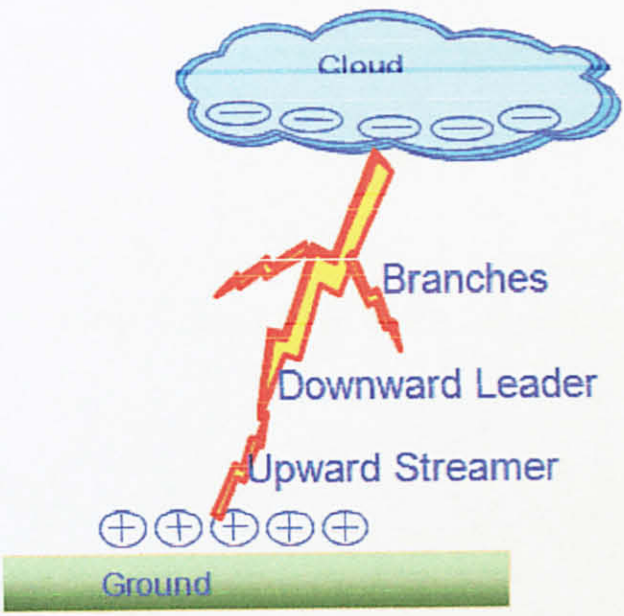

Figure 7: A Typical Cloud to Ground Lightning.

Besides that there are also cloud to cloud lightning strike, although its name suggest that it poses no threat to our tanking system there are several ways it can affect us. The damage and effects of lightning can be categorized by the types of strikes that hit the person or object.

Types of lightning strikes[10]:

- Direct Strikes; victim may suffer heart failure, brain damage, paralysis and high degree burns. Considered as an ignition source, can ignite the object that it strikes for example trees.
- Side Flashes; flash current travel through low impedance path nearby due to high impedance or faulty lightning protection.
- Surge Current; current flow produced by induction process of magnetic field created by direct strike current.
- Step and Touch Voltages; voltage gradient occur ground where lightning current enter ground or when a person touching an electrified object.

The frequency of lightning occurrence for the whole world can be seen in the figure below [12];

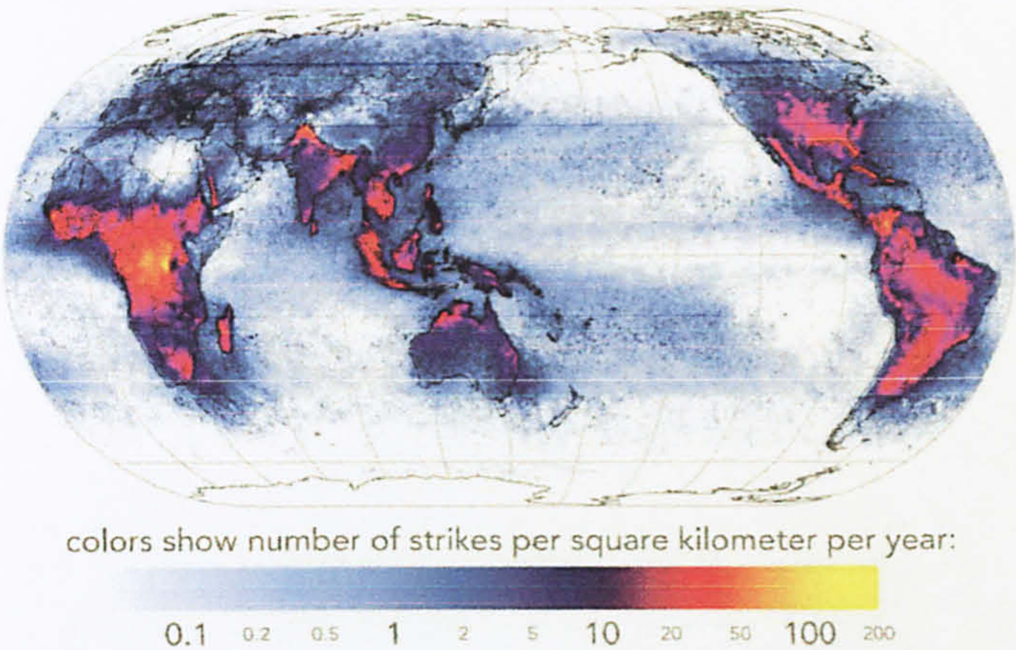

Figure 8: The Frequency of Lightning Strike Based on Location[10].

Based on this we know that our country experiences almost 50 lightning strikes per square miles per year. With such high frequency it is very likely for the FRT roof to be strike by lightning, this has been proven when two rim fire incident had happen in PP(T)SB in two years where both are caused by lightning.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

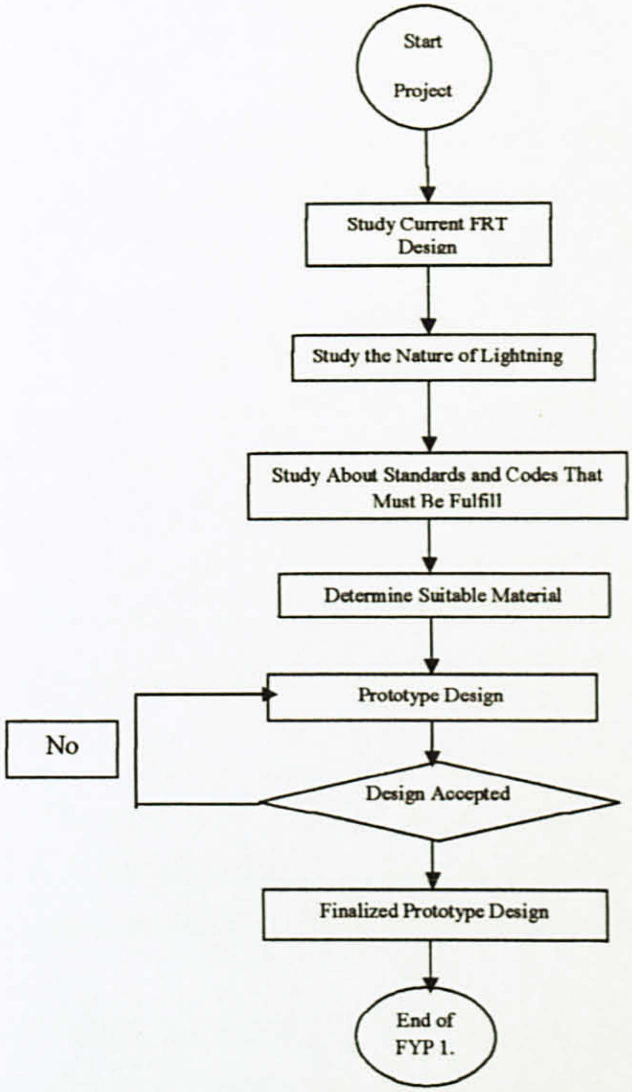

Figure 9: FYP 1 Procedure.

Information about the current contacting shunt design are gathered, this will help me to do improvement to it. Besides shunt design, other factor that can contribute to sparking are also considered. After all the factors are studied and the designs are finalized, a scaled model will be fabricated to give ideas to other on how it will eliminate the formation of a gap. A number of tests will be conducted to prove that the prototype has achieved its objectives. The model will show how the gap problem will be eliminated and will be the main task of this project.

The first task is to study the current FRT design especially regarding the grounding system. It is important to know how it works and its problem well before doing any improvement.

The second task is studying the nature of lightning; this is to know how lightning will affect the tank. There is other way besides striking that lightning can ignite the vapor on top of a tank. This will be looked into here.

The third task is to study the codes and standards that are needed to be fulfilled in order to improved the current system. Failing to comply with these codes may cause the final product to be discarded by the industrial practitioners.

The forth task is finding suitable material, although usually the current material is the best material to be used, other material are evaluated so that the product shows significant improvement in terms of quality and cost.

The final task of part 1 of this project is to come up with the design of the improved shunt contactor. Once the design is finalized, fabrication are done during the semester break.

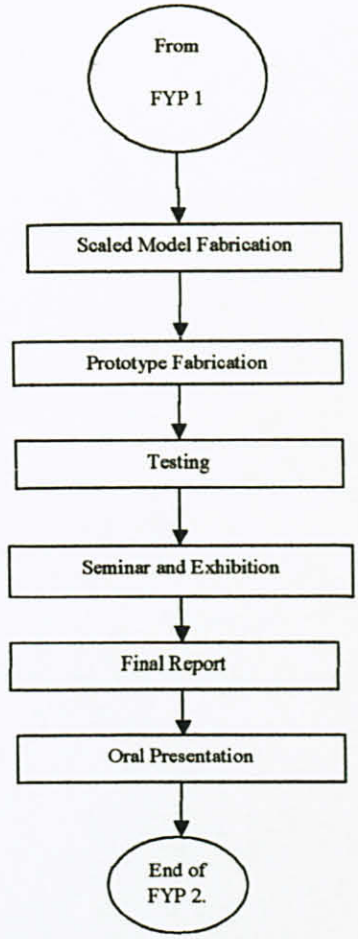

Figure 10: Fyp 2 Procedure.

The first task for fyp 2 is scaled model fabrication, the model are built based on real design with exception of some accessories that are too complicated to be scaled. This model is built so that demonstration can be done on how external floating roof tank works.

The prototype fabrication process began slightly later than the scaled model because of the need to focus on one job at one time. The prototype will help in giving the understanding about the improvement done. After both fabrications are completed, both are subjected to some test that will be explained later on.

3.2 Tools and Software

MATLAB are used to do calculation involving the voltage magnitude that causes sparking, this are done by comparing it against the gap that available. This relationship are given by the Paschen's law that will be discussed later.

Among the test planned for the prototype is as followed;

I. Conduction test against a metal wall; to make sure that the prototype will provide a low impedance conduction path for the lightning current.

II. Lightning simulation test, similar to the test done by American Petroleum Institute (API). High voltage will be flowed through the shunt against a metal wall; this is to see if any sparking occurs.

III. Friction test, to test whether the new design will cause too much friction during the rise and fall of the floating roof.

Based on this planning, the lightning simulation test cannot be done due to the possibility of serious damage to the model. But the remaining tests are successfully done and the results can be viewed later.

The fabrication process takes place mostly in the workshop at block 21, most equipment available there are utilized for this project. The fabrication process is assisted by two technicians from the workshop.

Paschen's law, which governs the relationship between the gap between two parallel plate and the breakdown voltage. Based on this, the relationship between lightning voltage and the gap between the shunt and wall can be plotted. Paschen's law stated that;

$$V = \frac{a(pd)}{\ln(pd) + b}.$$

Where *V* is the breakdown voltage in Volts, ***p*** is the pressure, ***d*** is the gap distance. The constants ***a*** and ***b*** depend upon the composition of the gas. For air at standard atmospheric pressure of 760 Torr, $a = 43.6*10^6$ V/atm-m and $b = 12.8$, where ***p*** is the pressure in atmospheres and ***d*** is the gap distance in meters.

Using this law, the relationship between the gap and voltage needed for sparking to occur are plotted into a graph using matlab. With this information, we can predict whether sparking will occur if certain gap exists at the shunt during lightning strike.

CHAPTER 4

RESULTS & DICUSSION

4.1 **Results**

This graph are generated by MATLAB, it relates breakdown voltage and gap;

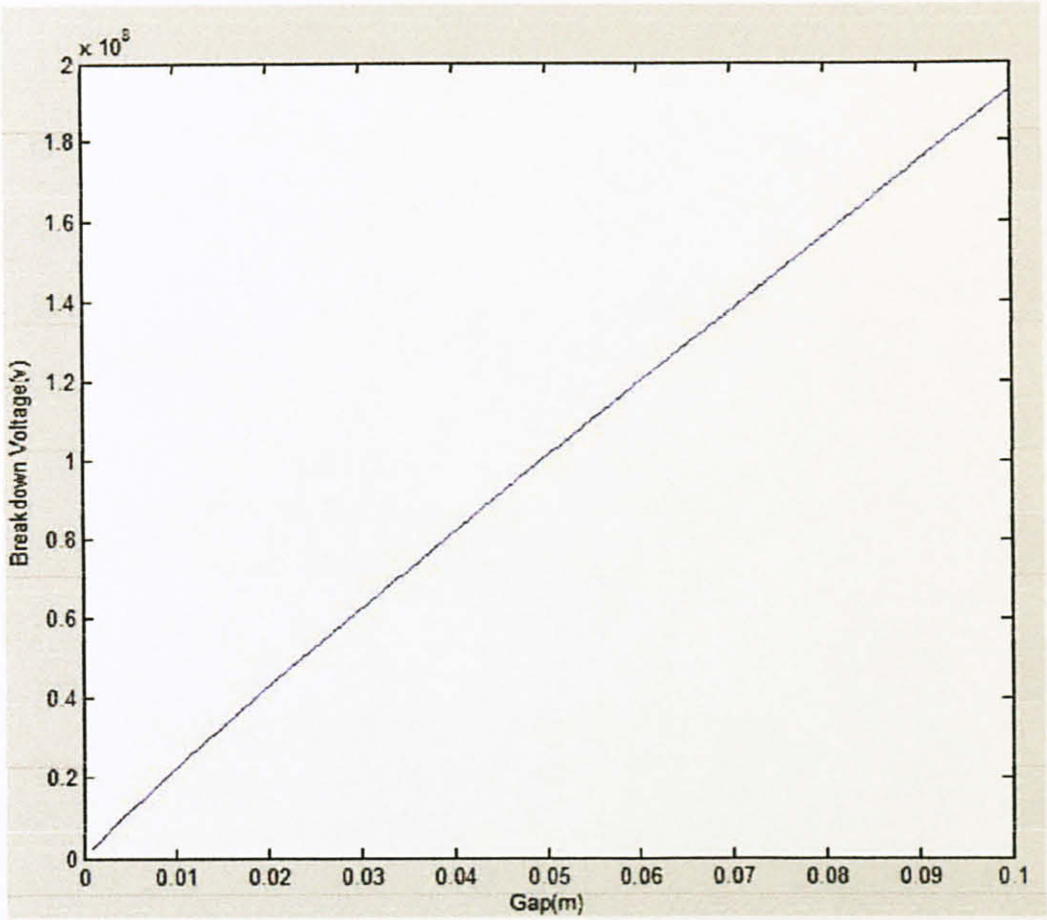

Figure 11: Relationship between Voltage and Gap.

From this graph we know that the relationship between the gap at the shunt contact and the voltage required for sparking to occur is a linear function, where the wider the gap, the more voltages are required to produce spark. Based on observation during internship most gap between the shunt contactor and the wall the top level of the tank is usually less than 1cm. Each bolt can contain up to one billion volts of electricity [8]. Given this information it is easy to conclude that sparking is going to happen if the roof are stroked, regardless the length of the gap as long as it exist.

Based on the tests done to the scaled model and the prototype, it is observed that the resistance it low when the shunt is touching the wall but fluctuates if the shunt moves. Most of lightning strikes occur when the tank roof is at the maximum level and stationary.

Based on the studies about FRT's design and the standard lightning protection package; it is known that the seals are not the only place where volatile vapor can escape. The volatile vapor can also escape during filling and emptying process. Despite this, flammable vapor that leaks through the seal poses more fire hazard because it accumulates under the contacting shunts.

Based on the table below, it has been decided is the best material for the design, copper alloy is used in the current shunt design. The electrical conductivity of copper is very close to that of the silver, but the price of copper is cheaper that silver making it the most ideal for usage as electrical conductor. The material used for this prototype has been changed to steel due to difficulties to get copper.

Metal properties (conductive materials:)	Electrical conductivity (10.E6 Siemens/m)	Electrical resistivity (10.E-8 Ohm.m)
Silver	62,1	1,6
copper	58,5	1,7
Gold	44,2	2,3
Aluminium	36,9	2,7
Zinc	16,6	6,0
Lithium	10,8	9,3
Tungsten	8,9	11,2
Brass	15,9	6,3
Carbon (ex PAN)	5	20,0
Nickel	14,3	7,0
Iron	10,1	9,9
Palladium	9,5	10,5
Platinium	9,3	10,8
Tin	8,7	11,5
Bronze 67Cu33Zn	7,4	13,5
Carbon steel	5,9	16,9

Table 1: Conductivity for Known Metal.

Silver is known to be the best electrical (as well as thermal) conductor of any known metal but it is more commonly used in electronics and photography devices due to its high price. While copper is more common to electrical devices due to its lower price. Both are considered as precious metal and were used as currency in the past.

The finalized sketch for the improved design is shown below. In figure 12-15, it is observed that the main components of this prototype are the contactor and the base plate which is connected by the hinge. This allows the contactor to move freely, spring is used to push the contactor so that is always touching the tank wall. The highlighted space in figure 13 is for conduction enhancement in case high resistance is measured across the prototype.

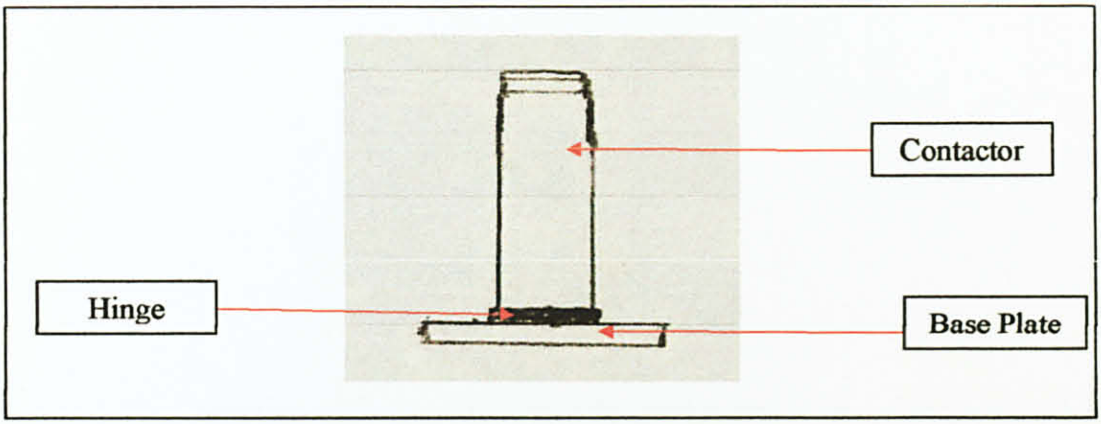

Figure 12: Front View.

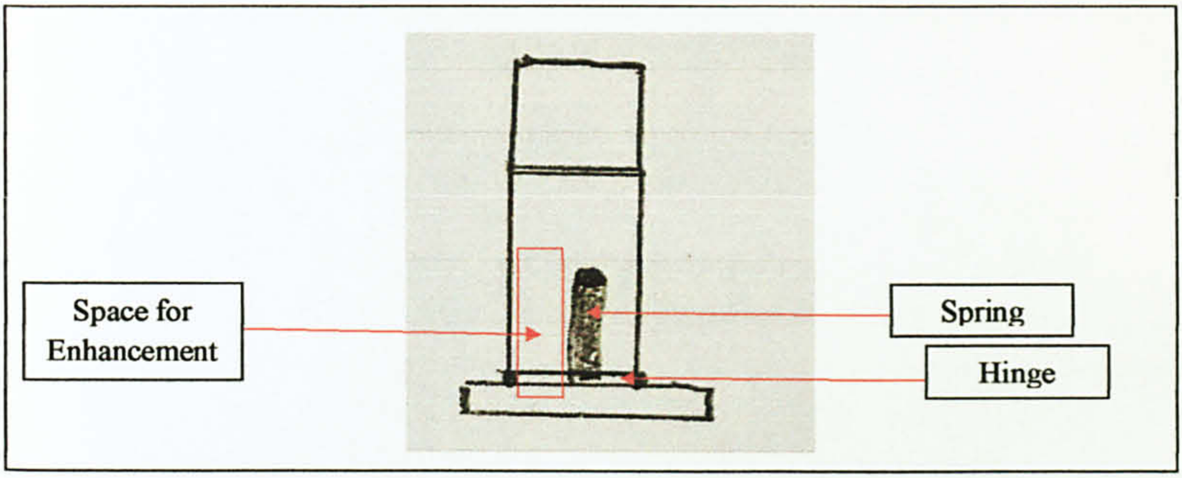

Figure 13: Rear View.

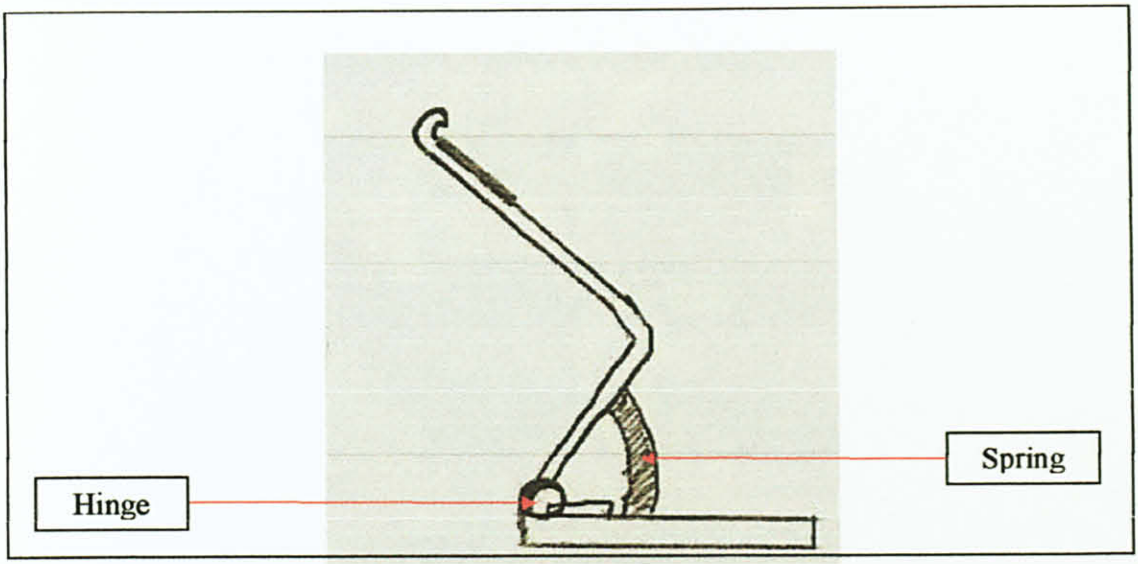

Figure 14: Side View.

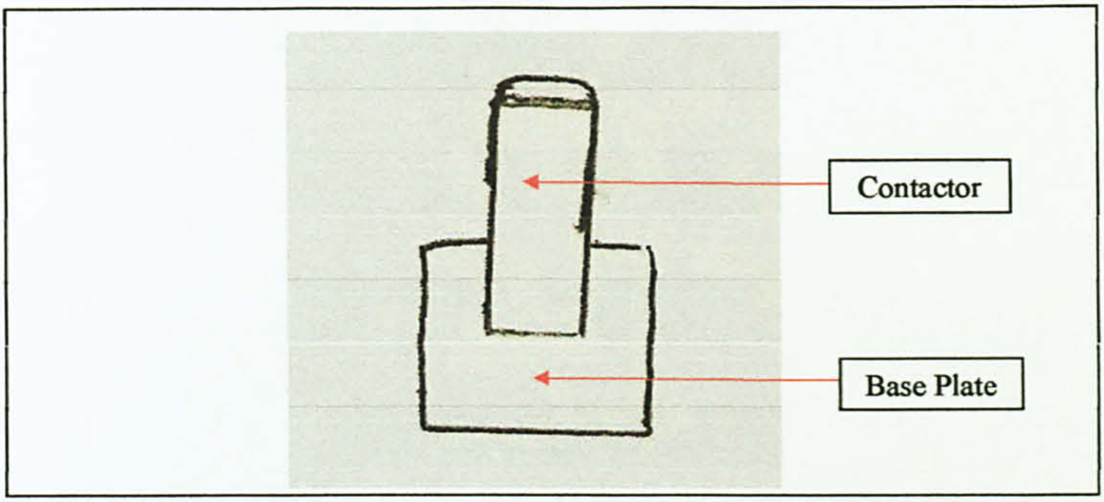

Figure 15: Plan View.

The most important part of this prototype is the copper hinge, where it allows the contactor to move. This component is readily available in the market and usually used for construction. This situation is an advantage, having the hinge; the base plate and contactor are fabricated to fit it perfectly.

Figure 16: Current Shunt design.

Figure 17: Improved Shunt Design.

The figures above are the comparison between current shunt design and the improved shunt. The new design will have to be modified to suite the condition on any type of floating roof.

The main material used for prototype fabrication is steel; this is due to difficulty to get copper. Despite this, the prototype still manages to fulfill the standard resistance value when tested against a metal wall.

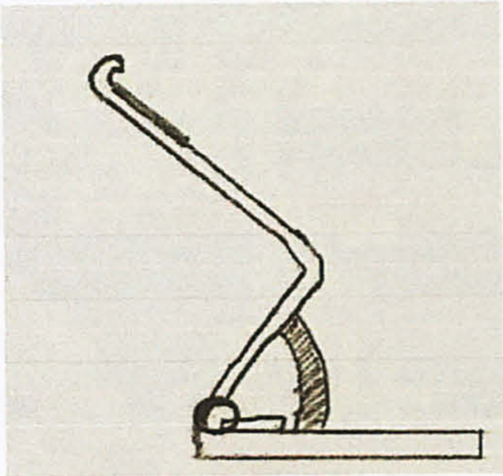

Figure 18: Prototype Design.

Figure 19: Finished Prototype.

The figures above show the progress of the fabrication starting from design up to completion.

The scaled model is built to demonstrate how external floating roof works. It will be used during oral presentation.

Figure 20: Real size FRT.

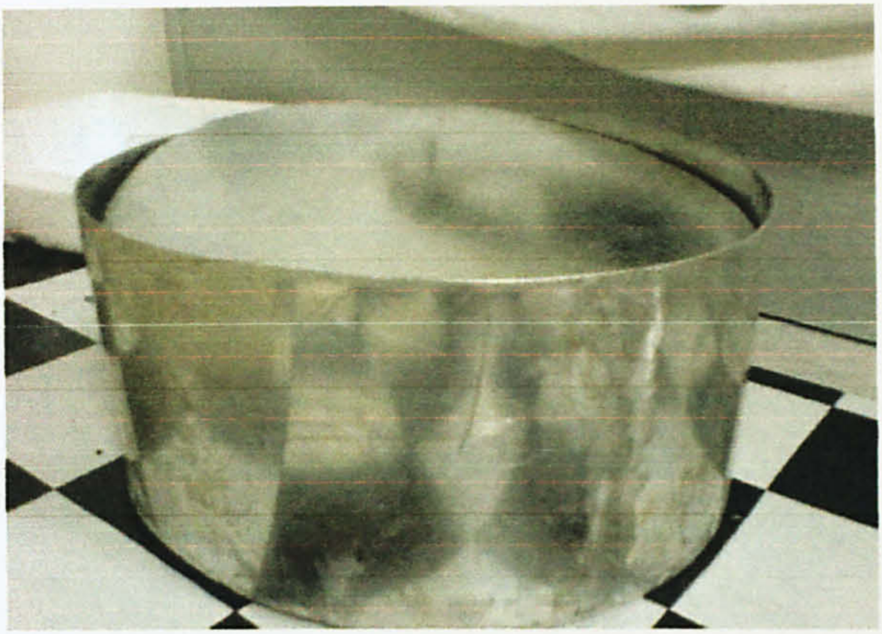

Figure 21: Scaled Model After Welding.

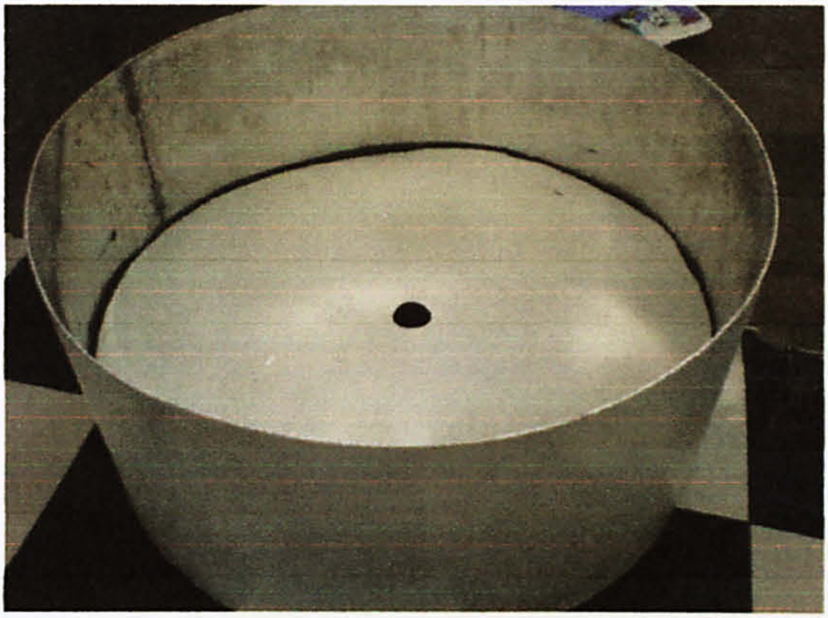

Figure 22: Scaled Model after Paint Job.

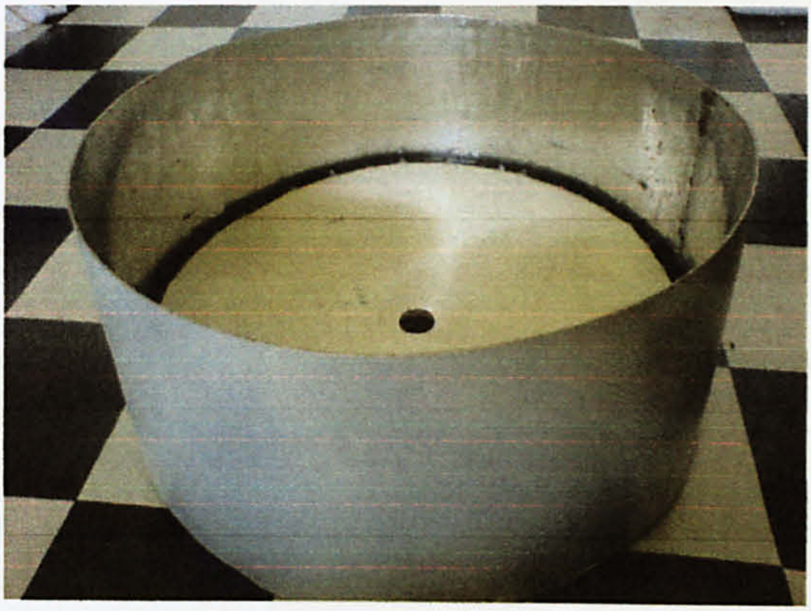

Figure 23: Finished Scaled Model.

The 3 figures above show the progress of the scaled model fabrication starting from design up to completion.

The model is painted in powder white so that it resembles the real floating roof tank currently used in the real world.

Figure 24: Floating Roof Tank.

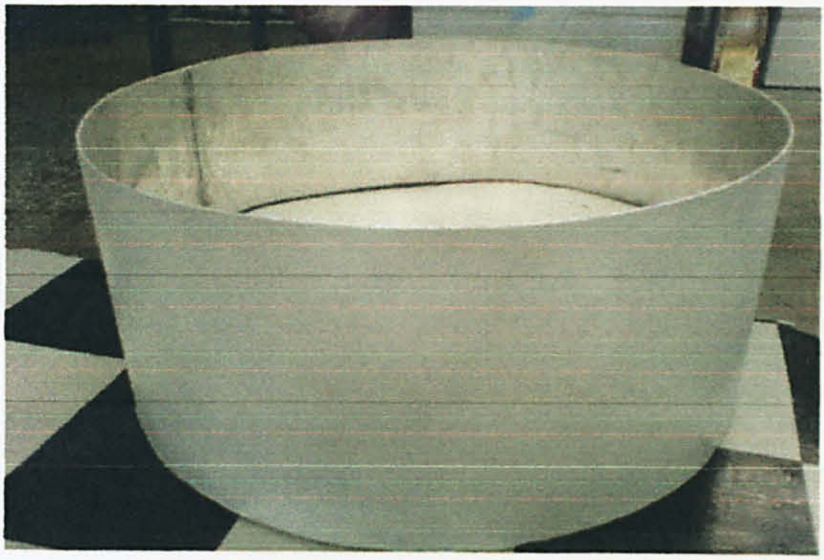

Figure 25: Scaled Floating Roof Tank Model

Besides this, the leakage problem faced after this model first finish welded has been addressed; this is achieved by using silicon glue similar to that used in making aquariums. After that, the fabrication of the floating roof model is initiated. The roof is made of zinc, which is lighter than aluminum that is used to make the tank body. Polystyrene are then placed under this zinc to act as buoyancy so that it floats.

An important part of the scaled model is the floating roof, for this part zinc is used for its lightness. Below are the progress pictures for the roof fabrication.

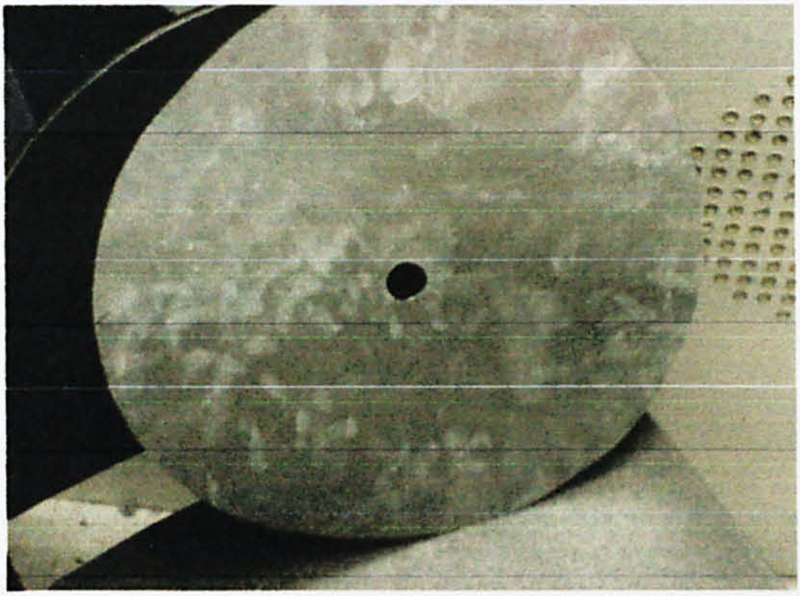

Figure 26: Hole for Input.

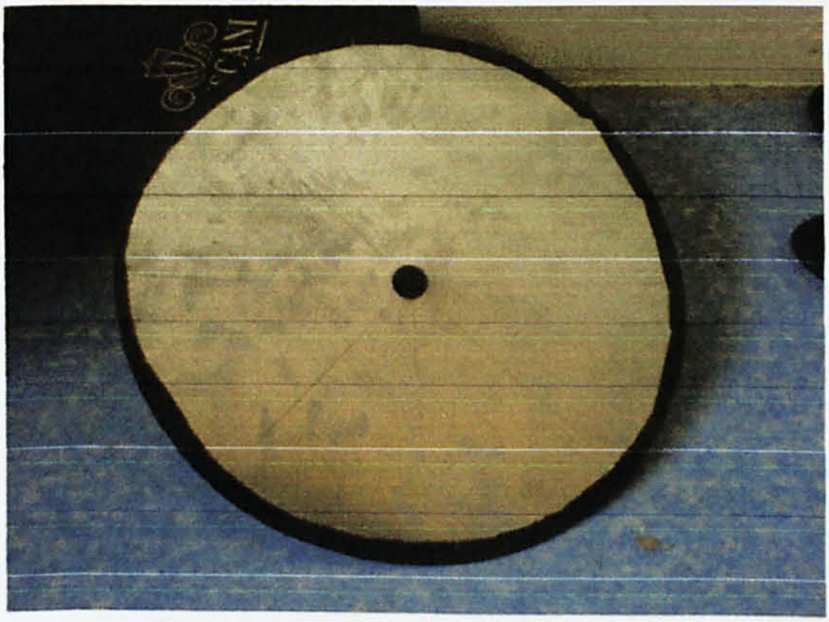

Figure 27: Insulation to the Edge of Roof.

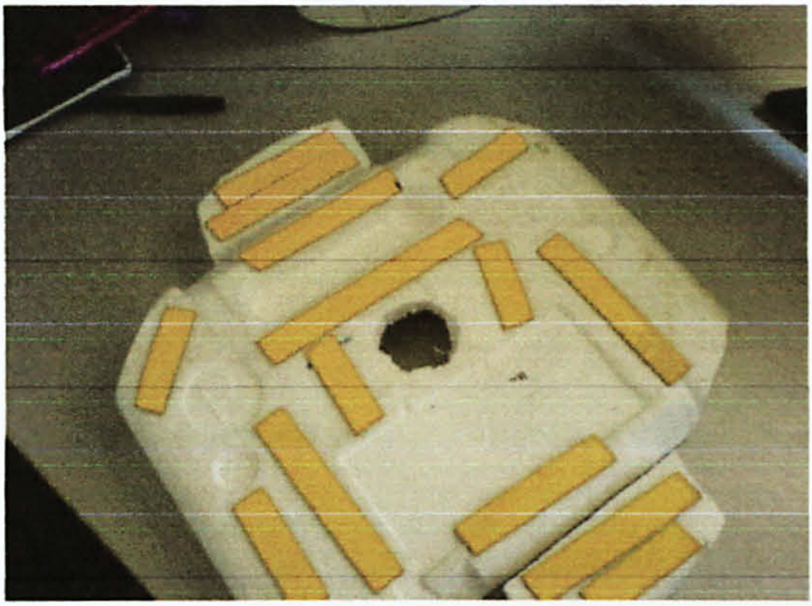

Figure 28: Buoyancy Used.

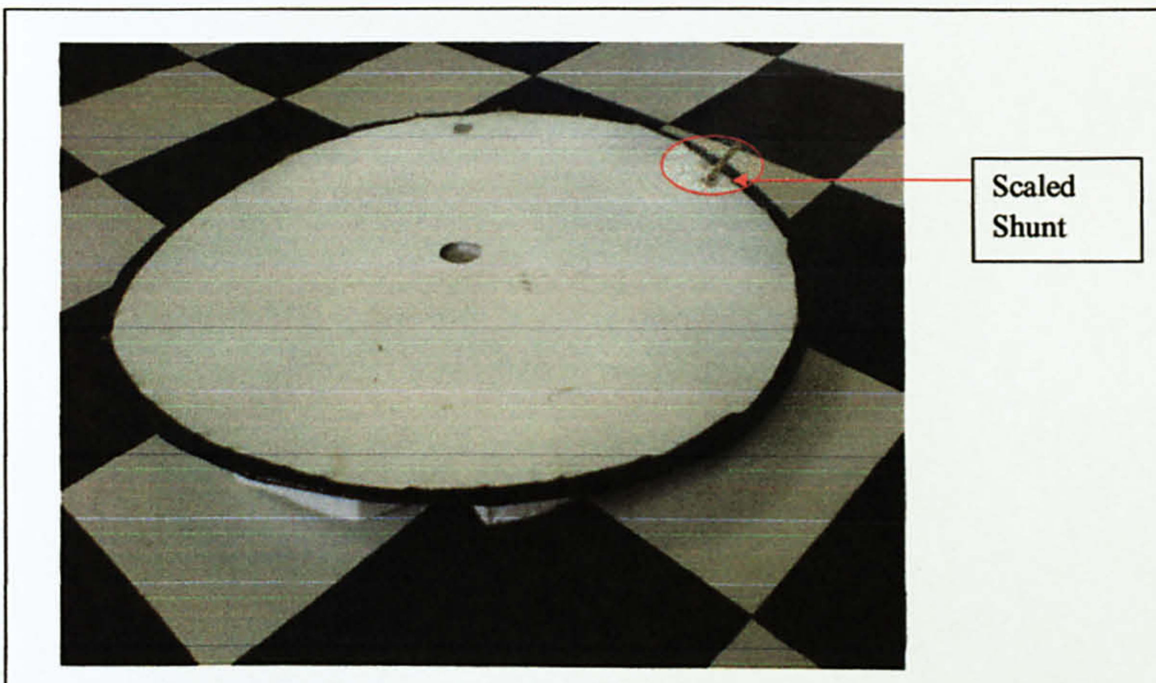

Figure 29: Floating Roof.

Based on the chronological picture above, the fabrication start with shaping the zinc sheet into the required shape. Input hole are required so that the floating roof function can be observed while filling the tank. The insulation are installed on the tank edge to simulate the real tank seal which are meant to prevent the flammable vapor from escaping the tank. Polystyrene are used as buoyancy so that the roof floats.

On the figure of the finished roof there is a scaled model of the shunt, resistance test on this shunt states that it is short circuited to the wall, giving no resistance at all. This is the most ideal condition for lightning protection and can only be achieved if the shunt touches the wall.

The test done to the prototype is quite similar, but on a bigger scale. The prototype is placed against a metal wall, like real application; see figure below. The resistivity are then measured. It yealds a value of 2.9-6 ohm, the limit of standard resistance for tank grounding installation is 5 ohm, the fluctualting value obseved in this test is due to the movement of the protype.

Figure 30: Test Setup.

4.2 DISCUSSION

After tested for resistance between the scaled shunt and the tank wall, the result showed that if at ideal condition when then shunt touch the wall a low impedance path are created is created (in this test a short circuit connection are discovered). The material for the prototype has been changed before the fabrication process is started due to difficulties to get copper plate. Despite this, after the prototype are tested against a metal wall, the measured resistance fluctuated between 2.9 to 6 ohm which is slightly over the limit of 5 ohm that is the standard for storage tank grounding installation.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

The floating roof tank is where industries keep their most valuable material which is their petroleum product and crude oil. The cost to purchase the crude and processing into petroleum product is already high, if something like fire occur during the time it been kept in the FRT it will be a big loss for the company. The cost of installing and maintaining an effective lightning protection system is very small compared to the loss suffer if there is a case of fire.

The usage of FRT offers a solution to breathing loss and vaporization of product, but this has cause fire hazard due to evaporation at the tank seal. Electrical sparking may occur during a lightning strike if there is a gap between the shunt and the tank wall, the spark cause by this could ignite the vapor escaping through the seal, thus causing rim fire. This project will solve this problem by resolving the gap problem. The prototype will give the audience a clear idea on how this issue will be catered.

5.2 Recommendation

The way forward with this project is to install it on a real FRT have it tested for grounding resistance. If it failed to fulfill the requirement, other material from the table 1 should be chosen for the fabrication of the next prototype. Another option to improve conductivity in case of the failure to fulfill grounding requirement is by placing conducting wire between the shunt and its base plate.

More research should be done to reduce the size of the prototype, this is because the space on the roof is quite small and having such big equipment will make it hard to do maintenance on the tank wall.

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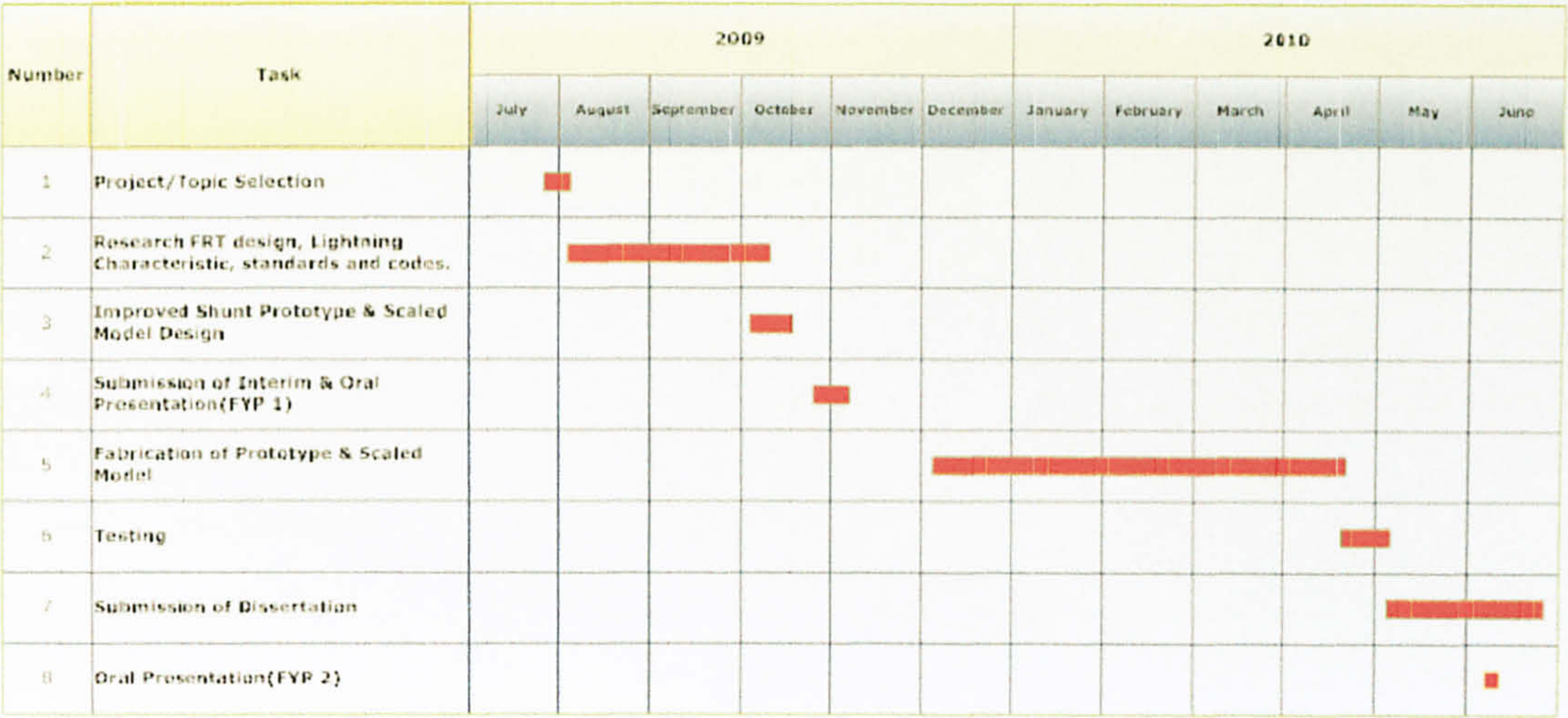
APPENDICES

APPENDIX A

Gantt chart



APPENDIX B

Matlab Codes Used for Simulation

```
a=43.6*10^6;

b=12.8;

p=760;

d=linspace(0.001,0.1,11);

v=(a*(p.*d))./(log(p.*d)+b)

plot(d,v)

xlabel('Gap(m)')

ylabel('Breakdown Voltage(v)')
```

APPENDIX C

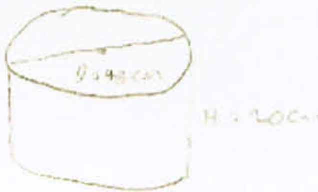
Model Scale Calculation.

real FRT

scaled by 60

$$D = \frac{24}{60} = 40\ \text{cm}$$

$$H = \frac{12}{60} = 20\ \text{cm}$$



scaled model [illegible]