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Development of suitable method in connecting wires for Resistive Plate Chambers

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ABSTRACT: Present research work is focus on the development of suitable method for making long lasting strong connection of wires on glass, copper and Aluminium surfaces. The application of the developed method is very wide, especially in the area of experimental high energy physics. We developed this method, considering the requirements of the India-based Neutrino Observatory (INO) which is in progress to build an underground laboratory for the study of atmospheric neutrino oscillations physics, in which a 50 kiloton magnetised Iron Calorimeter (ICAL) detector, will be used. This experiment will have several millions of connections related to the high voltage and signal.

KEYWORDS: Resistive Plate Chamber, Attaching high voltage cable, Pickup panel, Soldering on Aluminium sheet, Ansol Aluminium soldering flux, Plastic honeycomb and Silicon Fiber Sheet based readout strip panels, Araldite glue.

I. INTRODUCTION

Now-a-days, high energy physics experiments are moving very fast from medium scale to large and super-large scale size. Such experiments have huge number of connections related to the high voltage and signals. Proper connection of signals and high voltage cables and their stability are playing one of the major roles in the performance and success of the experiment. Problems related to the proper connection and its stability with time becomes more severe as the size of the experiments and detectors are increasing. This forces us to develop a suitable procedure for making proper and stable connections for the experiment. For this purpose, we considered the requirements of India-based Neutrino Observatory (INO) which is in progress to build an underground laboratory for the study of atmospheric neutrino oscillations in which a 50 kiloton magnetised Iron Calorimeter (ICAL) detector will be used. The ICAL detector will consist of 28,800 Resistive Plate Chamber detectors (RPC) and each RPC detectors will be made up of two glass electrodes (or Bakelite) and for picking up the induced charge it will need two readout strip panel in orthogonal configuration, both having the same size of $2\text{ m} \times 2\text{ m}$ (meter). Resistive Plate Chamber (RPC) detector is an active detector element of Iron Calorimeter (ICAL) in the INO experiment. Which is a non destructive, charged particle gaseous detector and consists of two parallel glass (or Bakelite) electrodes of bulk resistivity (ρ) of the order of $2 \times 10^{12}\ \Omega\text{-cm}$ and whose one surface is painted with a semi-resistive Graphite paint of surface resistance $100\text{-}200\text{ k}\Omega / \square$ (kilo-ohms per square) [1] [2]. As INO is going to deploy RPC detectors, it means there will be 57,600 RPC electrodes and same number of readout strip panels [3]. Hence, at least, similar number of high voltage power cables connections will be used, for applying the high voltage (5,000 to 10,000 volts) one for positive and another for negative electrode of RPC detector. Also there will be very large number of connections (approx. 7.60×10^6) made up in the readout strip panels, only for making the ground connections (reference layer of pickup panel) of terminators and connectors only. In the application of power through high voltage (HV) cable on the glass electrodes and in attaching the connector's wire on the reference layer (made up of thin Aluminium sheet) of readout strips panel we faced various issues. It consider

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the situation if in a stack of 57,600 electrodes any of the power cables have problem related to soldering, will detach and may cause the dead of that RPC detector which means the experiment will run with less efficiency at that time. At the same time it may also lead to noise in the signals generated in other RPC detectors. Finding of these faults in a stack of such large number of RPCs and making correction in these will be very difficult and time consuming. In the second case, as we know that these signals generated in the RPC detectors will be captured by readout strips panel, a $2\text{ m} \times 2\text{ m}$ readout strips panel will consist of approximately 66 readout strips of width 28.0 mm each. Each strip will consist of one terminator at one end and one connector at the other end. Therefore, if any of these readout strips's connection will be loose; it may lead to the decrease in the position resolution. Hence, it will affect the accuracy in determining the position of occurring events. Ultimately, it may affect the performance of the experiment.

We will discuss the developed procedure in detail, starting from attaching of high voltage cable on the glass electrodes and finally making good contacts of terminators and connectors to the reference layer of readout strips panel.

II. MATERIALS AND METHODS

We have observed that making proper and strong soldering on Aluminium surface is difficult due to a layer of aluminum oxide (Al_2O_3) which is formed in the presence of moist air at the surface of aluminum sheet, due to which proper soldering is not possible on it [4]. To overcome this problem, we have searched for various soldering fluxes and methods for proper soldering. We found a very cheap flux called *Ansol Aluminium soldering flux* that can fulfil our goal under the application of proper soldering method. Therefore, we have made use of this flux to remove the moist air during soldering by placing a thin layer of it at the soldering point [5].

i. METHODOLOGY

We observed that; if we want a proper and hard soldering then the process of doing soldering plays a very crucial role. This soldering process is as common as the other, but in this process we have to take care of air bubbles that forms in the molten solder at the soldering point. These bubbles will lead to weakening of our soldering, because Aluminium forms its oxide in the presence of air. Therefore, to avoid air bubble formation we rubbed the Aluminium sheet with molten soldering wire at the soldering point by the soldering-rod until it starts spreading in the form of a thin layer at that point. When this spreading of molten soldering wire occurs, then we place the wire or cable which we want to solder and wait for few seconds. As a result we get a very good quality of soldering which fulfils our requirement.

ii. COMPOSITION OF ANSOL ALUMINIUM SOLDERING FLUX

During soldering we observed that little fumes were coming, due to the vaporization of this Ansol Aluminium soldering flux. To check the toxicity of the coming fume we performed elemental composition test of the flux with the help of X-ray fluorescence technique (XRF), to make sure that the used materials in the experiment is not health hazardous. The XRF report of the used flux is listed in Table 1.

Table 1: XRF report of the Ansol Aluminium soldering flux is listed.

Compound	Weight %	Std Err.	Element	Weight %	Std Err.
ZnO	91.08	0.42	Zn	73.17	0.34
PdO	1.96	0.14	Pd	1.71	0.12
Ag ₂ O	1.85	0.12	Ag	1.73	0.12
MoO ₃	0.844	0.042	Mo	0.562	0.028
Iodine	0.66	0.20	I	0.66	0.20
TeO ₂	0.66	0.22	Te	0.53	0.17
P	0.534	0.054	P	0.534	0.054

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Sb ₂ O ₃	0.48	0.18	Sb	0.40	0.15
WO ₃	0.328	0.54	W	0.260	0.043
Ho ₂ O ₃	0.302	0.061	Ho	0.264	0.053
SiO ₂	0.274	0.075	Si	0.128	0.035
Yb ₂ O ₃	0.232	0.037	Yb	0.204	0.032
PbO	0.218	0.085	Pb	0.202	0.079
Al ₂ O ₃	0.0206	0.057	Al	0.109	0.030
Ta ₂ O ₅	0.100	0.041	Ta	0.082	0.034
Dy ₂ O ₃	0.096	0.037	Dy	0.084	0.032
GeO ₂	0.081	0.040	Ge	0.056	0.028
Tm ₂ O ₃	0.048	0.022	Tm	0.042	0.019
NiO	0.0432	0.0086	Ni	0.0339	0.0067

From Table 1 we may see that the major content of composition is of ZnO. Although flux doesn't contain Sulphur, but it contains ZnO which may cause for *metal fume fever* which is an acute self-limited illness induced most commonly by inhalation of zinc oxide fumes. The affected individual characteristically experiences the rapid onset of intense shaking chills, fever, and body aches a few hours after exposure, and symptoms dissipate spontaneously. The other compounds are just trace. PbO compound is also present less than a quarter of percent in this flux which may affect our gum tissue, central nervous system, kidneys, blood and reproductive system, similarly it has Phosphorus, Al₂O₃, NiO etc. which can cause very serious health related issues to us [6] [7] [8] [9] [10]. Therefore, during soldering one must use proper mask and good ventilations system in operation. After work wash hands and mouth properly. Above mentioned procedure is very useful and successful if we are taking above mentioned precautions during soldering.

III. SOLDERING OF TERMINATORS AND CONNECTORS ON ALUMINIUM SHEET OF READOUT STRIPS PANEL

Using above described method and flux we have done the soldering on Aluminium sheet of readout strips panel for making ground contacts. After doing the soldering we have performed some tests, to check the quality of the soldering contacts. In following subsections we have given the details of these experiments.

i. TO CHECK THE STRENGTH OF SOLDERING: SUSPENDING WEIGHTS ON SOLDERED WIRE

To test the strength of the soldering on Aluminium sheet, we place an Aluminium sheet of thickness 0.175 mm over the plywood board using Araldite adhesive as shown in Figure 1. At the same time for checking the effect of heat on quality of soldering, we used three different power (15 Watt, 125 Watt, and 250 Watt) soldering rods. Using Ansol Aluminium Soldering flux we soldered the wires on the Aluminium sheet. We suspended weights in unit of kilograms in increasing order with the soldered wires in both the directions i.e. along and perpendicular to the soldered wire as shown in Figure 1 left and right, respectively. Until the soldered wire starts stretching or Aluminium sheet gets torn-off, we increase the weights continuously. Here we want to mention that, we have taken the simple plywood board as a sample material and not the plastic honeycomb or Silicon Fiber Sheet based readout strips panel on which we have to apply this method finally. This is because suspension of so much weight as mention in Table 2 may tear off them apart. The obtained results are listed in Table 2.

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Fig. 1 Photographs of suspended weights along and perpendicular direction of the soldered point are shown from left to right [5].

The above procedure has been repeated several times following the same method. Since the soldering quality will be affected by the room temperature and relative humidity, therefore, during all the above processes we kept these parameters constant and recorded the room temperature and relative humidity of our laboratory which were found to be 29 °C and 68%, respectively.

Table 2: Experimental parameters and obtained results of the above experiment are listed [5].

Power of soldering rod (W)	15	125	250
Amount of soldering flux used (small drop)	One	One	One
Maximum weight applied in horizontal direction (kg)	12.0	12.0	12.0
Maximum weight applied in vertical direction (kg)	7.5	7.5	7.5
Results	Still attached	Still attached	Still attached

From Table 2 one can see that the quantity of applied soldering flux is just one small drop otherwise it will spread and create mess. Therefore, one can easily understand that a strong soldering may be achieved in a cost effective way. We noticed that the soldered point is in well contact, up to the application of 12.0 kg weights in the horizontal direction. We also observed that if the applied weights still increases, there is detachment of Aluminium sheet from plywood board and the soldered wire starts stretching too and finally breaks. But still there were no adverse effects shown on the soldering contact. We observed similar results in both directions of weight application on the soldering contact. We may also infer from Table 2 that the application of weight in the vertical direction of soldered wire, soldering wire sustain little less amount of weights than the horizontal one, because in case of vertical direction the Aluminium sheet starts getting detached before stretching of the wire begins. It can be concluded that the soldered point may sustain very large amount of force, in terms of jerk, by any means. Currently we are applying above mentioned procedure in making the ground contact on reference layer (which is also made up of Aluminium foil) of connectors and terminators in readout pickup strips panel.

We used high heat to solder the electrical contacts of the signal and high voltage wires. It may be possible that due to the heat, pickup strips panel's dielectric material properties may change. The change of properties may reflect in terms of electrical noise or/and changing shape of the signal or/and may change the terminating impedance of the panel.

ii. TO CHECK THE QUALITY OF SIGNAL

To check the quality of signal including noise level, we have send the signals in the *SINE* wave form, from a function generator through a coaxial cable which was soldered at one end of an Aluminium sheet of thickness 0.175 mm. The output signal is taken from the other end of this Aluminium sheet by another soldered coaxial cable under the same flux

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and same soldering process. Finally, we have connected direct signal from the function generator and the signal coming through the soldered contact to the oscilloscope. The snapshots of the oscilloscope display are shown in Figure 2, in which purple colour *SINE* wave input is given to the soldered contact and green colour *SINE* wave is output taken from the soldered contact. For checking any visual variation in these two waves various snapshots are displayed in Figure 2.

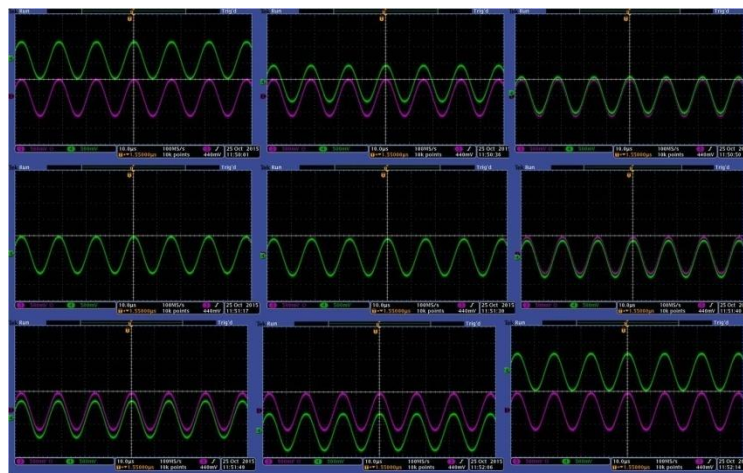


Fig. 2 The input and output of the signal applied on the soldered contact are shown in purple colour *SINE* wave and green colour *SINE* wave, respectively.

In Figure 2, initially we have shown the input and output *SINE* waves individually. Then we have proceeded to check the difference between them by superimposing them onto each other continuously by moving them. In the center one can see that both have merged completely. It means that there is no difference between input and output signals due to the developed method of using soldering flux. Both signals have same amplitude, width and on delay in time observed. Further we have taken the input and output waves slowly-slowly apart from each other (from overlapped position) and finally they look as identical. We have also tried to observe any additional activities in the output signal but they were fully absent i.e. output signal is completely free from noise. Therefore, we may conclude that the soldering or heat of soldering does not affect the signal's quality.

iii. HEATING EFFECT

For charge pickup strips panel the dielectric material used world-wide is polycarbonate (plastic) in honeycomb shape of thickness 4 mm. This polycarbonate material is not lighter in weight and having low melting point of about 155 °C [11]. Therefore it may melt due to the heat produced during soldering. It is possible that heat of soldering leads to the deformation of used dielectric material in making of readout strips panel and signal may show some adverse effect. Regarding the raised doubts we carefully observed the colour and shape of the material before and after soldering with the help of reflected light binocular microscope. There were no changes in its physical property observed at the place of soldering in the material, neither in case of Silicon Fiber Sheet which has 2100°C melting point [11], nor in polycarbonate plastic honeycomb based readout strips panel. We repeated above mentioned procedure of observation for contacts making with all the three soldering rods of 15 W, 125 W, and 250 W.

IV. SOLDERING OF HIGH VOLTAGE (HV) WIRE ON THE GLASS PLATE

We tried various methods to solder the HV wire on the glass surface strongly and details of failed method are not suitable for the scope of this paper. The best suited method for attaching HV cable onto the glass plates before doing the graphite coating on it is explained below.

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i. ATTACHMENT OF HIGH VOLTAGE (HV) WIRE ON ALUMINIUM FOIL PLACED OVER THE GLASS PLATE

For understanding this method one should focus on the Figure 3 in which we have shown it in a pictorial way for better understanding. In this method we considered Aluminium foil of two different thicknesses such as 0.175 mm and 0.001 mm. With the use of Araldite adhesive a small piece of such Aluminium foil is attached at one of the corners of the glass plate. Araldite took approximately 24 hours time to become hard. We observed that the Aluminium foils attached very well with glass plate. We attached two different thicknesses of foils on the glass plate. For soldering the HV wire on the Aluminium sheet we follow the procedure mentioned in section – II (i) [5]. We soldered the HV cable on Aluminium foils using Ansol Aluminium soldering flux as shown in Figure 3.

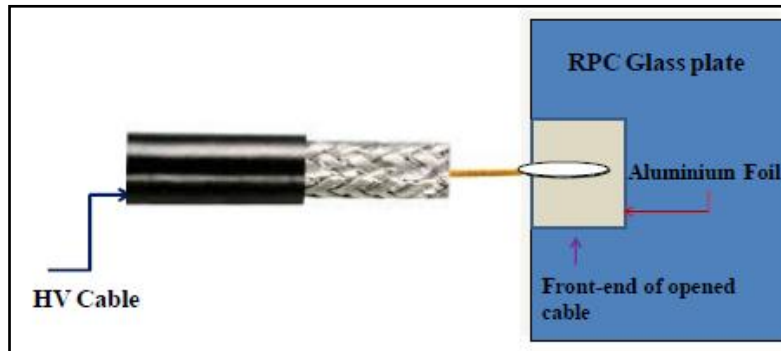


Fig. 3 Schematic diagram for soldering of HV cable on the Aluminium foil attached on glass plate [12].

ii. TO CHECK THE STRENGTH OF SOLDERING: SUSPENDING WEIGHTS ON SOLDERED HV WIRE

We follow the same procedure as described in section – III (i) to check the strength of the soldering of HV wire. We applied load from both directions on the joint as shown in Figure 4. In each test we applied the load for a certain time interval and kept increasing the load until either wire or soldering broke or pulled up the attached Aluminium foil along with glass pieces. We hung the weights in vertical direction to the glass plate rather than in horizontal direction because if it will sustain in vertical direction, then it will surely sustain in horizontal direction, since the major tension in the wire will be vertical to the glass plate of RPC gas chamber.

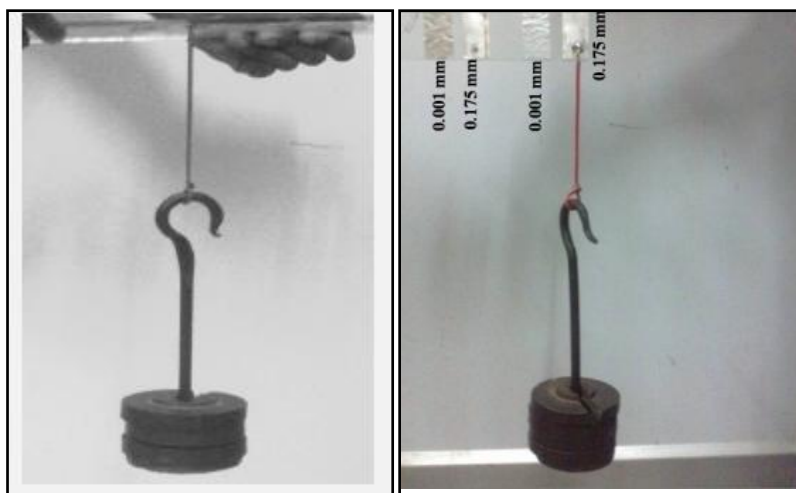


Fig. 4 Photographs of load application along the horizontal direction (Right) and vertical direction (Left) on the soldering contact mounted on the glass plate [12].

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In Table 3 we have listed the time taken to tear off the Aluminium foil from the glass plate along with glass pieces when weight is hung in perpendicular or vertical direction of glass plate. During the experimental procedure the ambient parameters were constant in the laboratory.

Table 3: Observations listed as applied load on the wire changes [12].

Thickness (mm)	Weight (Kg)	Time (hours)
0.175	3.0	03
0.175	2.5	03
0.175	1.0	04
0.001	3.0	12
0.001	2.5	13
0.001	1.0	12

From Table 3 we may observe that the 0.001 mm thick Aluminium foil is better for this purpose. It sustains similar load for factor of four, more than of 0.175 mm thick foil. But in case of less than a micrometer thin Aluminium foil, we observed that it starts melting due to the heat of soldering rod. Therefore we conclude that it is not suitable for this purpose, and therefore we did not have included this in above Table 3. Therefore we have proceeded in making HV contacts with Aluminium foil of thickness 0.001 mm.

After attaching the HV cable with this method on the glass plate we did the graphite coating to make the electrode slightly conductive. Then we observed that the place where we attached the HV cable was a little elevated than the other place. This might break the connection and also might cause serious problem in parallel placement of the pickup strips panel. Therefore, we adopted this method with little change which is described below.

iii. ATTACHMENT OF HIGH VOLTAGE (HV) CABLE ONTO THE GROOVES MADE ON THE GLASS PLATE

To avoid above mentioned issues, a 15 mm long and 1 mm width grooves were made at one corner of the glass plate surface by hand using a diamond tip glass cutter. In this groove we placed a small drop of Araldite glue and thin Aluminium foil was placed very gently and after that above procedure mentioned in methodology – II (i) was adopted. This procedure removes the elevation and wire sets properly inside the grooves. We observed a smooth surface at the place of HV contact. After the HV cable wire is attached properly, final process of graphite coating is performed. For safety of HV cable with any jerk or elasticity of cable we attached a safety holder with this cable, so that it should not detach very easily from the glass plate. This method is very useful and now we are proceeding with this method in making the glass electrode of RPC detector. We also found that this method is very effective and cheap.

V. RESULTS AND CONCLUSION

We tried to resolve various issues related to soldering of wire on different material surfaces and developed a robust procedure. The developed procedures were a need of current and planned experiments around the globe. We observed that the soldering point made, using developed procedure, is strong enough to sustain any kind of jerks during experiment and transportation. We found that attaching the HV wire directly on the glass plate is not suitable. In order to make a proper contact of high voltage wire, a groove was made in the glass electrode and a thin piece of Aluminium foil was placed gently into the groove and its lower surface was attached by Araldite, finally applying a graphite paint coating over it. Placement of HV wire following the above mentioned procedure is the best suited way of soldering on the glass surface. All the developed methods are very cheap and doable owing to the use of Araldite adhesive and at the same time it fulfills the entire requirement.

Doing soldering of wire on the Aluminum sheet became very easy job under the guidance of above mentioned procedure and using the Ansol Aluminium soldering flux. We have not observed any change in the signal quality under this soldering process. No significant effect on quality of soldering observed due to make use of three different powers

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15 W, 125 W and 250 W soldering rods. Under this method and using this soldering flux we did not observe any change in physical properties of dielectric material of readout strips panel.

From XRF report we observed that the Ansol Aluminium soldering flux may be hazardous for our health if we will not take prior precautions. Therefore, during the soldering use of good quality gas mask and proper ventilation is necessary.

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