Manufacturing Technics of Wire based detectors

12/2024 gabriel.charles@ijclab.in2p3.fr

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Outline

For a hardware lover and physicist like I am, wire based detectors have the fantastic advantage that you can build them from scratch. You decide the geometry, the number of wires, the type of wires, the mechanics, you group a bunch of skilled people, because stretching the wires is not an easy task, and let's go, you can build your detector, in house. That is fantastic, something breaks, the experts are here to assist and repair. I've seen physicist, students, post-docs, mounting wires.

This being said, after more than 50 years of existence, the invention of multi wire proportionnal chamber was done in 1968 by Georges Charpak, you can imagine that some refinments in manufacturing processes exist. In this lecture, you will learn how chambers were mounted and are mounted.

This presentation will primarily focus on how to attach a single wire. We will study two methods: soldering and crimping.

Once, you will know how to attach a wire, we will study straw tubes. Why the straw tubes? Because each straw tube has only one wire. This will allow us to study the mounting procedures of straw tubes.

In the two following parts, examples of cylindrical and flat wire chambers manufacturing will be presented.

Soldered wires

Let's begin with « soldered wires » and define both words.

The easiest one is « wire ». Here when I refer to a wire, it will be a cylindrical structure with a diameter comprised between 10-20 µm up to 150-200 µm that can be a few centimeters up to few meters long. Just to put this values in perspective, a hair is between 40 and 100 µm. The wire is composed of tungstate or wolfram covered with gold, we say plated with gold. The thickness of the platting is usually expressed in 100s of Angstrom. Wires can also be made of aluminum, platted or not, I've seen copper also, carbon based material, aluminum but usually not any aluminum. Aluminum called Al5056 is usually prefered.

The second word in « soldered wires » is soldered. What does it mean to solder wires? Soldering is a process by which you connect two components using a filler or flux for the joining.

It is different from welding process that includes the melting of the two parts to creating a joint.

I'm mentionning this because a welded wire becomes one with its junction, but a soldered wire keeps its dimension and IF it is not sealed properly it can slide from the soldering. That is especially true when we are considering wires thinner than a hair. Of course, once the problem is known, someone that wants to build a wire chamber will test this specific point. If the wire keeps falling or getting loose, most of the time, a drop of glue is added after soldering. Soldering allows for a good electrical connection while the glue ensures that the wire does not slide (slide 2). Know that conductive glue also exists. In this case, it is not mandatory to solder the wire, it can be glued only. Which means that we've just uncovered another way to attach wires: gluing (slide 3).

Personnally, I'm not fond of glue in detectors, especially when the plan is to run for a long time. Why don't I like it? First, during the gluing process, drops of glue can spread on the detector or on the wire, like one can see on this picture (slide 4). But also later, glue is dirty, it outgases which can speed up ageing of your detector and modify the gas purity. So whenever you can, avoid glue in the detector and if you can not avoid, choose it wisely. ESA and NASA are keeping up to date database with outgasing properties of almost all materials.

Now that we know what « soldered wires » means, we are going to investigate the stretching procedure (slide 5). It begins with a printed circuit board (PCB), for example, on which the wires must be installed. The PCB is placed in front of the wire spool. Then, the wire is unrolled, and a weight is attached to it. The weight is usually between a few grams to several tenth of grams. The weight with the wire attached to it is then slowly brought down and hang it in a such a way that the wire is now aligned with the position where it is supposed to be soldered. The wire is now stretched at the tension related to the mass minus the friction due to turns necessary for the procedure. As you want to keep the wire stretch at all times, the first point that is soldered is the one on the opposite side of the weight. Often the wire is tapped just next to the soldering point to ensure that it remains close to the surface on which it has to be connected. Once the wire is soldered on this side, it is then soldered on the other side. The little part of the wire remaining between this second soldering point and the weight must be cut and make sure that no little piece remains around the soldering point. If a little piece of wire is flying around it won't be good for the high voltage.

All those steps can be motorised, often in this case, instead of a weight, one will use a dynamometer. It can also be used when soldering the wires by hand.

How is the weight chosen? The mass of this weight depends on:

- the material composing the wire
- its diameter which both influence
- its tensile strenght and elasticity
- the mechanical structure hodling the wire
- the sag that is allowed
- the mechanical force on the wire must compensate the electrostatic forces due to the charges of surrounding wires or plans.

This weight can not be chosen randomly and needs a large understanding of the mechanics of a wire, the mechanical structure of the detector as well as the gain at which you will run which will tell you the electrostatic forces. Also, usually one avoid to stretch the wire at a higher value than 75 % of its elastic limit. Often, the quality of the wire is checked for each spool.

Crimped wires

Sometimes, another solution is prefered instead of soldering, it is crimping.

In this method, instead of being soldered the wire is inserted in a tube, a tiny tube, a very tiny tube. Once it is in the tube, the tube is crimped. Which means that the tube is shrinked, or collapsed if you prefer around the wire to block the wire inside. Here again, the wire can slide, so tests must be performed to make sure that it does not happen (slide 6).

The process to mount a crimped wire is essentially the same than when soldering a wire, except!, that the wire needs to be inserted twice in a tube. This step is not easy and only a few people are able to do it, although after a few tries it gets easier. Once the wire is inserted in the pins, it is tensionned, the pins further away from the system used to keep the tension is crimped and then the other one is crimped while the wire is still in tension. Once again, the little pieces of wire remaining must be cut.

One important aspect here is the plier. A secret lies in it. Indeed, with a standard plier, depending on how firmly one is going to close the plier, the pressure on the wire will be different, and hence its tension. If one wants the pressure on the wire to be always the same, to guarantee that the mechanical tension is also always the same, the pliers used to crimp must always close with the same pressure. It is often ensured with a system that makes the plier close and open in one movement.

Manufacturing straw tubes

Now that the three ways to attach wires, namely soldering, crimping and gluing have been established, we can discuss mounting the detector itself. We are going to begin with a detector using only one wire: the straw tubes. The principle of a straw tubes has been introduced in previous lectures but let me remind you the mechanical elements. It is composed of a wire surrounded by a cylinder. The wire is maintained at the center of the cylinder via end caps. The end caps must hold the wire, the walls as well as the gas circulation system.

If the wire is not centered properly the properties of the tube will not be homogeneous all around the wire. In every element one builds, tolerances must be taken into account. Therefore when choosing the material of the end cap and, the company that will manufacture it, it is important to make sure that the tolerances are lower than your maximum limit between the ideal center and where the wire will eventually be placed.

The tube can be made of a strong material if for example one works for neutron physics. I'm mentionning this just for the record, so you know not only thin wall straw exists. Though, most of the straw detector for high energy experiment are based on thin walls, 35 µm or so. Experts are even trying to make the wall thinner. I will come back to this point in a moment. The ensemble can be a few meters long, up to 5 meters long.

The high voltage can be applied to the wire like it is the case for COMET experiment for example or to the wall like for ATLAS.

There are two ways to build thin straws. The most common one is to take two strips of aluminized Mylar and wrap them around a rotating mandrel with a position difference of half of their width. They are glued in this position. The inner aluminization is used as a cathode. This kind of tubes are called S-type tubes. This type of tube can reach 35 µm thickness for a diameter of 10 mm. This is the most common kind of straw and the industrial way to build them.

The other way, called C-type are produced from a flat mylar film and a seam is welded with ultrasonic welder thus creating the tubing. The size of the seam must be carefully controlled. If it is too thin, the gas leak will be too high, if it is too large, the shape of the straw won't be round enough which will distord the electric field. The C-type straws can be as thin as 12 µm for a diameter of 5 mm. This kind of straws are usually produced in the lab (slide 7).

In both cases the straws are self sustained. Which means that the tube remains in shape and position even when without mechanical constraints such that no transverse material is required except the straw itself. It means that the structure of the straw is strong enough to hold the tens of grams applied to stretch the wire. This is not the case for a wire chamber for example. To keep the wire stretched, the end plates, will need to be connected somehow because the wires will not keep the end plates in place. Of course, they can be connected outside the active area but a mechanical bridge between the two plates is necessary.

Manufacturing drift chambers

To build a wire chamber, many wires must be assembled together. If the first ones were hand made and hand made wire chambers are still very common, I would like to show you wiring machines of different kind.
One way to build drift chambers is to develop a rotating wiring machine. The wire is rolled over a frame. Most of the time, the frame is rotating but sometimes, like for DUNE wire chambers for instance, it is the wire that is moved around the frame (slide 8).
In the case of a rotating frame, the frame, called transfer frame, is precisely placed on top of the detector and the wires are soldered and/or glued. One can see the advantage of this technic is for example, the wire can not be soldered. Gluing takes some time, as the glue needs to cure. If the wires are mounted one by one, there is no way to wait, even 1 minute, between each wire, the time needed for the glue to cure. While for the wiring machine, this is not a problem. All wires can be glued on the same.
Wiring machines also exists that deal with wires one by one. The machine grabs the wire, stretch it, then, solders on both side and finally even cut the remaining part of the wire before moving to the next steps. This kind of robots are obviously slightly more complex that the first kind. Though, they can be used for different geometry. The first robot for example deals only with flat geometry but does not need a transfer frame for each new shape of drift chamber. Then, there is the wiring robot for MEGII that can even deal with cylindrical shape and stereo angle (slide 9, wiring robot from GANIL, Caen, France).
The wires that will be stretched by hand or with the help of a wiring machine will be held by a mechanical structure.

Without entering the details of the calculations and simulations to design such a structure, we are going to present here a few key points to help undestanding the shape and the building processes of large drift chambers. The first thing that is important to understand is that, one wire stretch at 50g is easy to keep straight and designing a mechanical structure able to keep it in place can be simple. But when considering 200 (10 kg) or 2000 (100 kg) or 20 000 (1 T), the mechanical structure must be thought in details. Moreover, quantity of material must be taken into account and othen minimized in some areas.
To reduce the efforts on the end plate, one can consider using cone shape end plates. This shape increases the share of the efforts between the different parts of the mechanics and reduces the material budget.

Another key point when building this kind of wire chambers is pre-tentionning. Pre-tentioning is a process by which a tension is applied to the mechanics before all the wires are mounted to mimic the non present wires. Pre-tensionning ensures that all the wires remains at the wanted tension even when new wires are mounted as the forces applied on the end caps changes as more wires are mounted. Pre-tensionning can be done using specific tooling or the wires themselves: the first wires are mounted with a higher tension that the next ones.
These two aspects, pre-tensionning and end plate shapes are just two of the aspects I wanted to mention today as they always come into consideration when building a large wire chamber.

Conclusion

After following this class, I believe you now know what are the primary steps to stretch wires them being crimped, soldered or glued. We also have covered the principle of building straw tubes and seen different kind of wire chambers. In the process of designing a new detector you would hence be able to take into account part of the building constraints which is sometimes forgotten by physicists.