Summary of session 6: Aging effects in RPC detectors

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Abstract

Resistive Plate Chamber (RPC) detectors are a very important part of present and future large-scale experiments. The present B-factory experiments, Belle and BaBar, operate at much larger luminosity (>3×10^{33} $cm^{-2}sec^{-1}$) compared to their predecessors at LEP, where the RPC rates were not much higher than cosmic ray rates. Both Belle and BaBar RPC detectors operate in streamer mode. On the other hand, the LHC RPC detectors will operate in proportional mode, which is advantageous in terms of lower accumulated charge per track; however, it may be offset by considerably higher rates, assuming that the aging scales simply as total accumulated charge. The fear that the LHC RPC detectors may encounter similar difficulties as the B-factory RPCs prompted a very intensive R&D effort of rate-related deterioration.

1. Belle Experience.

The Belle RPC detector electrodes are made of ordinary float glass. After an initial successful start with full efficiency, the RPCs started to deteriorate rapidly. Fortunately, the Belle group decided to stop operation and to investigate the problem as soon as the high currents were detected. A massive R&D effort was initiated, which resulted in formulating the following model. Freon gas ($C_2H_2F_4$) together with water, in the presence of plasma, forms HF acid, which etched the glass surface. This, in turn, increased the current and caused the drop in detection efficiency. Indeed, it was found that initially the chambers operated with a large concentration of water in the gas (~2000 ppm). The water permeated through the Polyflow gas tubing. The solution was to reduce the water concentration from 2000 ppm to < 10 ppm by installing copper tubing.

There may be other troublesome effects that could destroy the integrity of the glass surface. For example, the BaBar/DIRC photomultiplier glass started to corrode in the presence of ultra-pure water [2]. Such water, hungry for ions, acted as a "vacuum pump" removing the sodium from the glass, which resulted in subsequent glass corrosion. Luckily for the DIRC group, the corrosion rates are slow and the detector is expected to operate for up to ten years. The equivalent process in the glass RPC would be a removal of ions from the glass into the gas by the electrostatic force. Another possible long-term concern is the conductivity of glass, which is provided by ions; this may not be a stable process resulting in electrode charging effects after a certain level of accumulated charge (see Section 2 on Bakelite RPC, below). One should point out that changes in glass conductivity were observed in the Micro-strip detectors, which prevented successful operation, and forced the designers to choose a special electron-conducting glass for the substrate [3]. However, based on the Belle experience, these processes are not significant up to this point.

2. BaBar Experience.

In BaBar, the RPC detector electrodes are made of Bakelite covered with Linseed oil. Again, after an initial successful operation, the detectors started to deteriorate. Unfortunately for the BABAR experiment, the group continued to operate at high currents. In retrospect, it appears that a high operating temperature (~35^0C) lasting for several months was the initial trigger for the degradation. The chambers started to draw current and lose efficiency [4]. This process is still continuing, even after the temperature was returned to 24^0C.

The BaBar RPC technology is similar to L3's RPCs at LEP, with one small exception. The L3 electrode side spacers and buttons have simple straight surfaces. In BaBar, they were modified into a "mushroom-like" shape to improve HV behavior. Unfortunately, these also acted as hidden storage cavities trapping "uncured" Linseed oil. During the initial BaBar operation, as temperature increased, the Linseed oil changed viscosity and leaked from these hidden cavities into the chamber's active volume. This resulted in gap variations and even bridges between the Bakelite electrodes in some of the regions, especially around the buttons and chamber edges near the bottom. Since the "uncured" Linseed oil has much smaller resistivity ($\rho_v \sim 8 \times 10^9$ Ωcm) than the Bakelite material ($\rho_V \sim 2 \times 10^{11}$ Ωcm), each gap-to-gap bridge represented a short of the gap voltage. This resulted in inefficiencies along some edges or near the buttons. In addition, continued HV operations with the Linseed oil in a liquid state inside the active region of the chamber, resulted in formation of whiskers inside some regions [5]. Finally, running at nominal

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RPC voltage, while having higher than room temperature, meant a certain over-voltage on the chamber. This is of little importance except in areas where the chamber was already "delicate" and might have started sparking, which in turn would show up as higher noise.

If all of the BaBar RPC problems could be explained using the above mechanism, it essentially ends up as a trivial problem. However, it appears that some chambers may have a different mechanism for the efficiency deterioration [6]. Indeed, one could suggest a model that may play an important part [7] in RPC technology. The charge flowing through a Linseed oil layer and Bakelite is not conducted via electrons as seen in metals, but rather by ions. The Linseed oil, made from pressed seeds, is a very complex organic compound [8]. One could safely assume that the initial "cocktail of molecules" also contains water. Pure water does not conduct; however, when an acid is added to it, it does conduct very well through the ionic carriers. A molecule, which may facilitate current conductivity in the "uncured" Linseed oil, is a fatty acid R-COOH — an organic acid. A possible scenario for the sequence of events is as follows: (a) R-COOH + potential $\rightarrow$ H^+ = R-COO^-; (b) R-COO^- ion delivers the charge to anode and R-COO returns to fluid; (c) H^+ ion delivers the charge to the cathode, where it forms an H_2 molecule and escapes; (d) R-COO + $H_2O \rightarrow$ R-COOH + OH, which returns the fatty acid back into the cycle; (e) $2OH \rightarrow H_2O + 2O$, and $2O \rightarrow O_2$, which delivers oxygen near the anode. Here, the important point is that water modulates conductivity. If we remove water, R-COO^- will only deliver the charge, R-COO will just hang around, but it will not return R-COOH back into the current forming cycle, i.e. the current will slowly stop. Adding water back should restart the conduction. In fact, this was exactly what was observed in a simple bench-top electrolytic experiment that was conducted by the author [9]. One should also point out that the liquid was full of bubbles, indicating a trapped gas. This may suggest a possible explanation for two classes of BaBar RPC problems: In one group, there may be too much water in the RPC chamber, causing voltage-divider divisions of the gap voltage near every bridge formed by the Linseed oil. However, there could be another class of RPC chambers [6], where there is no water, and the conductivity through the Linseed oil is severely reduced, allowing charging effects at a high rate. The complexity of these problems can be further increased by a non-uniform distribution of the particle background throughout the RPC chamber geometry, causing non-uniform ionic currents even within a single chamber. This may lead to a non-uniform resistance distribution causing tangential electrode currents, and thus to a loss of gap voltage.

Unfortunately, this may not be the entire story. The current through the Bakelite, which is a Phenol-Formaldehyde polymer, is also of ionic origin. It is probably carried by ions of Phenol impurities, and water plays a similar role as in the Linseed oil. The ionic current through the Bakelite electrode must "mesh" with the current through the Linseed oil, probably through a charge exchange processes. The entire sequence and the conditions for the required constancy throughout the lifetime of the RPC detector operating at high rates is not well understood at present. However, it would appear that stable levels of conductivity could be maintained by adding the "right" amount of water (not too much, though, as it may short the gap voltage near the bridges).

In addition, the "uncured" Linseed oil has unsaturated bonds. The oxygen may play an important role satisfying these bonds, which would speed up the molecular cross-linking resulting in higher resistivity of the "cured" Linseed oil. So far, tests of adding oxygen were not completely satisfactory [5]. As if all this was not enough, the Linseed oil removed from the bottom of the BaBar chamber after one year of operation had even lower resistivity ($\rho_V \sim 2\times10^8$ Ωcm) than the nominal "uncured" Linseed oil ($\rho_V \sim 8 \times 10^9$ Ωcm) [9], which either means it had either a huge amount of water, or there is yet another chemical reaction involving Freons in the plasma environment.

Perhaps, one should take seriously a suggestion by F. Sauli to consider using a mineral oil instead of the infinitely more complicated Linseed oil.

3. L3 Experience at LEP

G. Carlino reported that the LEP L3 RPCs did degrade their combined efficiency per chamber from ~99% to ~94% in a period of six years, between 1994 and 2000 [10]. Since these were double-gap chambers, this means that the single gap efficiency degradation is not far from that of the BaBar RPC chambers, which occurred over a two-year year period. G. Carlino argued that the main reason in efficiency loss was due to electronics failures, gas leaks, and changes of gas, although he admitted that more investigation must be conducted in the lab. The L3 rates were essentially consistent with those obtained by cosmic rays. The electrode surface was smooth and non-sticky, which suggests that their treatment of Linseed oil impregnation was better than that of the BaBar RPCs.

4. LHC R&D Activity

The LHC RPCs will benefit a great deal from the unfortunate experiences of the B-factory RPCs. For example, they will operate in proportional mode. The Linseed oil, if used, will also be better treated with solvents to make sure that it is well "cured," dry, and non-sticky. However, the processes involved in RPC high-rate operation are sufficiently complex, and therefore they require further systematic R&D studies. This is exactly what various LHC groups are doing. For example, G. Aielli reported on test results with high rates influencing the behavior of various individual RPC components [11]. Tests were related to the development of the ATLAS RPC system. He observed a sharp increase in the Bakelite resistance after a certain charge. Presently, it is not clear if this increase is due to the Bakelite bulk change or due to a contact to the graphite coating. The resistance increase degraded the rate handling capability of the RPC. More tests are in progress. G. Pugliese showed test results with CMS RPC chambers exposed to γ and neutron radiation [12]. One RPC with Linseed oil coating was exposed to γ flux, and a charge equivalent to 10 years of CMS operation was integrated. The RPC efficiency remained unchanged and only a slight increase in noise rate was observed (< 10

Hz/cm^2). Similarly, two RPC chambers, with and without Linseed oil coating, were exposed to a neutron source. A total dose and a flux comparable to expected values for CMS have been accumulated and a noise increase was observed. More tests are in progress. G. Passaleva reported on tests with LHC-b RPC chambers, which were exposed to a ^{60}Co γ source [13]. A large increase in the Bakelite resistance and noise increase was observed after ~0.5 C/cm^2. However, the RPC is still efficient even at a noise rate of ~1 kHz/cm^2.

Are these LHC tests consistent with the BaBar experience? On the surface, it appears that they are not. However, it is possible that these tests were still short in duration, and the water level in the Linseed/Bakelite electrodes was still large enough to keep the conductivity constant, assuming that the above mentioned model is correct. Only more tests will prove that tests made so far are significant, and that only the author of these words is confused.

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