CMS Forward RPCs: Bent RE1/2 Gas Gaps and Restoration

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Abstract

Thin bakelite gas gaps are used in the construction of Forward RPCs. It is important that these gaps meet rigorous quality controls. Stored in a vertical position, some of the large gas gaps to be used in the construction of RE1/2 and RE1/3 RPCs bent while in storage. In attempting to straighten these gaps, it was found that putting the gaps in a warm, humid environment and underneath a significant amount of weight yielded the best results.

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1 Introduction

1.1 Forward Resistive Plate Chambers

Resistive Plate Chambers (RPCs) are being used in the endcap of the Compact Muon Solenoid (CMS) detector at CERN, the European Organization for Nuclear Research. These chambers will be mounted radially on the endcap of the CMS, and are designed to detect the passage of muons resulting from the collisions in the Large Hadron Collider (LHC).

RPCs are one of three gaseous muon detectors being used on CMS, the other two are Drift Tubes (DTs) and Cathode Strip Chambers (CSCs). RPCs have an excellent time resolution, comparable to that of scintillators, and requisite spatial resolution [1], [2]. Their main purpose is to provide information to the trigger.

The RPC contains two layers of gas gaps with a sheet of Copper readout strips sandwiched between them, as shown in Figure 1. Gas gaps are made of two thin sheets of high resistivity bakelite which act as the electrodes. Within the RPC, the electric field is uniform. Exponential multiplication of the electrons released by the ionizing particles in the gas gap gives the signal amplification. The cumulative effect of avalanches gives the detected signal on the readout strips.

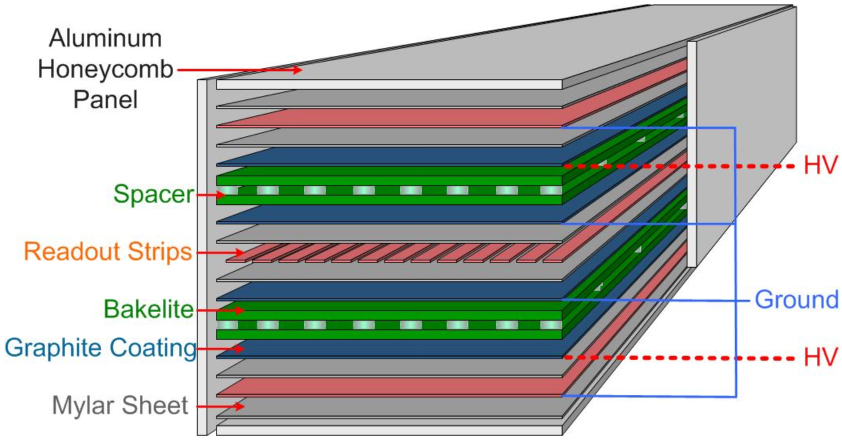

Figure 1: Schematic diagram of a CMS Resistive Plate Chamber.

The use of thin bakelite sheets allows for the construction of large and thin chambers, capable of operating at the desired rate with a high gas gain and without the development of streamers or sparks. Depending on the selection of resistivity and plate thickness, the rate capability of RPC can reach several thousand Hertz per square centimeter.

The thin gap and high gain of an RPC make it possible to precisely measure the small delay for the time of passage of an ionizing particle such as a muon. The time delay of pulse, the time resolution, and the efficiency of chamber are largely determined by the threshold setting of the chamber. The selection of an appropriate threshold setting allows for the detection of a signal dominated by electrons generated near the cathode. A measure of the muons momentum can be obtained by tracking the strip hits in conjunction with other inner detectors in CMS.

1.2 Production and Quality Control of Bakelite Gas Gaps

Three different sized trapezoidal gas gaps are required for every RE1/2 and RE1/3 [1] chamber constructed. The bakelite sheets for gas gaps were purchased in Italy where they have been cut to size before being shipped to Korea for gap construction.

The 2 mm thick gap is created by placing polycarbonate spacers at regular intervals of about 10 cm throughout the gap. Polycarbonate profile is used to hold the spacing around the edge of gap. Gas inlets and outlets are inserted at the four corners of gaps to allow for the flow of gas through the gap. The outer surfaces of gas gaps are coated with a thin layer of graphite, which is applied by method of silk screening. These surfaces are then protected by a thin Mylar sheet which is laminated to the surface using a hot melt procedure.

The inner surfaces of gas gaps are coated with a very thin (0.5 μm) layer of linseed oil. This coating is applied by passing linseed oil through the gap via the gas inlet and outlet pieces. The linseed oil layer is cured by flushing the gaps with hot and dry air.

Each gas gap undergoes a quality control test in Korea before being shipped to CERN. A 20 mbar overpressure is applied to the gap to ensure that there are no gas leaks or popped spacers. A high voltage test is also performed, in which a nominal operating voltage of about 9.4 kV is applied to the gaps. The current through each gap is monitored; currents are typically a few micro-amperes and are not allowed to exceed 10 μA.

Similar quality control tests are repeated at CERN before the gaps are used in chamber construction. The tests for gas tightness and popped spacers are performed while the gas gaps are filled with Argon. To ensure gas tightness, the gap is filled to 20 mbar overpressure and the pressure is monitored. To test for unglued spacers, a force less than 5 kg is applied to each spacer; a significant change in pressure at the time the force is applied is an indication of a popped spacer.

For the high voltage tests, the gaps are placed in the high voltage (HV) stand and filled with the RPC working gas, a mixture of Freon (95.5%), Iso-butane (4%), SF6 (0.3%) with 50% relative humidity. A minimum of 20 volume exchanges must take place before any voltage can be applied to the gaps. The currents drawn by the gaps are measured at several voltages.

Once a gas gap passes the quality control tests, all that remains is to remove the protective Mylar coating and clean the surface of the gap with alcohol immediately before assembling it into a chamber.

1.3 Bent Gas Gaps

Although it is an inelastic material, bakelite will buckle, or bend, under certain circumstances.[1] In particular, bakelite will buckle if it is not clamped or somehow constrained in position. Thus gas gaps are stored and shipped vertically, as shown in Figure 2 They are clamped inside the box in order to keep them absolutely vertical. However, when the large bottom RE1/2 gas gaps arrived from Korea, several gaps were removed from the box and the remaining gaps were not clamped back into place. As a result, when the remaining gaps were unpacked about two months later, they were found to be curved.

The strongest curvature was across the width of the gap in the ϕ-direction, giving the gap a banana-like profile when viewed edge-on. There was also some curvature in the r-direction (lengthwise), which is apparent in Figure 3. The image on the right shows the strong curvature across the width of the gap; the image on the left illustrates the weaker curvature in the r-direction.

The RE1/3 gaps were unpacked upon arrival from Korea. Despite being clamped in position, eight of the 44 large bottom gaps were bent. For both the RE1/2 and RE1/3 gas gaps, only the large gas gaps bent. None of the top gaps were affected.

The gaps were shipped with a protective Mylar sheet laminated on one side. It was initially thought that the bending of the gaps was caused by increased humidity in the storage room. If this were the case, then the gaps would bend such that the Mylar-covered side was bent in the concave direction while the non-protected side expanded. However, while the bent RE1/2 gaps were bent in this manner, the RE1/3 gaps were not; the RE1/3

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[1] This has been observed by the companies manufacturing bakelite.

Figure 2: Storage of gas gaps for shipping. The metal clamp used to keep the gaps vertical can be seen in the crate on the right.

Figure 3: Bent RE1/2 gas gaps. Notice that in the image on the left, one can see right underneath the gap as a consequence of the lengthwise curvature.

gaps were bent such that the Mylar-covered side was bent in the convex direction. This possibility was thus ruled out.

The gaps were stored vertically for shipping and if they were not properly clamped, they might have been leaning to one side. This may have played a part in the bending of the gaps. But if this were the case, then the curvature of the gap would be asymmetrical; the point of strongest curvature would not be centered, but would be nearer the side of the gap that was on the bottom. But again this was not the case; for both the RE1/2 and RE1/3 gaps, the curvature was symmetrical along the base of the gap. However, this can be explained by the fact that the gaps were clamped in the middle.

Because of the restriction on the thickness of each chamber, it is not possible to use a gas gap with a large sagitta. It was then necessary to find a way to straighten the gaps to an acceptable level so they could be used in RPC construction.

2 Description of Techniques

2.1 Unsuccessful Attempts

A number of attempts were made to straighten out the bent RE1/2 gas gaps. Many of these attempts failed, and some showed mixed results. Only one method was found to yield consistently good results.

2.1.1 Humid Tent

The gaps were stacked on top of one another on a marble table with containers of water placed beneath the table. Foam insulation was placed on and around the table, covering the gaps. Some gaps appeared to improve in this set-up, but quickly deteriorated when removed. The gaps that improved were typically near the bottom of the stack, so it was concluded that the weight of the gaps above the improved gap caused the flattening of the gap. Once the improved gap was removed from the stack, or placed nearer to the top, the curvature worsened.

2.1.2 Humid (RPC) Gas

Several gaps were put in the high voltage QC stand and connected to the RPC gas. The results of this treatment were mixed; some gaps improved while others remained the same.

2.1.3 Lead Bricks

A plank was centered lengthwise on top of a gap, with the gap lying concave side down. Three 10 kg lead bricks were placed on top of this plank at equally spaced intervals. The flattening of the gap was temporary; once the masses were removed from the gap, the curvature worsened.

One gap was set on two metal bars, concave side down. On top was placed a long, narrow plank upon which several lead bricks were distributed. No long-lasting effect was observed.

When the RE1/3 gas gaps were unpacked, the bent gaps were placed in storage horizontally. On top of these gaps were placed a wooden plank and five 10 kg lead bricks.

2.1.4 Heated table

One gap was placed on an Aluminum table with the concave side facing up. The protective plastic on the high voltage (concave) side was removed. Using two heaters, the table was heated with the intention that the heat would flow to the bakelite gap. The heat appeared to have no effect on the curvature of the gap.

2.2 Warm, Humid Tent

The arrangement that yielded the most promising results was that of a warm, humid tent. Two containers of water were placed beneath a table, along with a heater. On top of the table, one gap was placed concave side down with its edges were resting on two long, metal bars. Five more gaps were placed on top of that one with alternating concavity as shown in Figure 4 and Figure 5.

On the edges of the top gap were placed two more metal bars. A wide wooden plank was placed on top of these metal bars, as shown in Figure 4. The metal bars were used underneath and on top of the gaps so the pressure applied by the lead bricks (see below) would be concentrated on the edges of the gaps.

Sheets of foam padding were placed over the gaps and around the table to form an insulating tent to house the gaps. To allow the warm, moist air to circulate from beneath the table to the gaps on top of the table, several wood blocks were placed on the table with a few centimeters hanging over the edge. Also, the wood plank on top of the gaps overhung the ends of the table. This pulled the insulation away from the edge of the table and allowed for better air circulation.

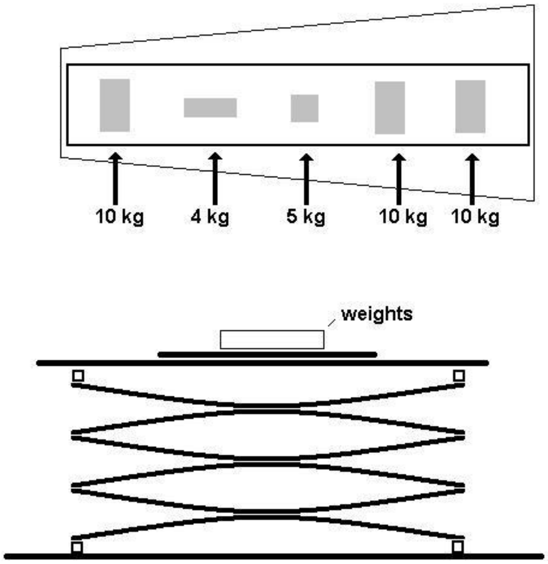

Figure 4: Schematic diagram of the warm, humid tent.

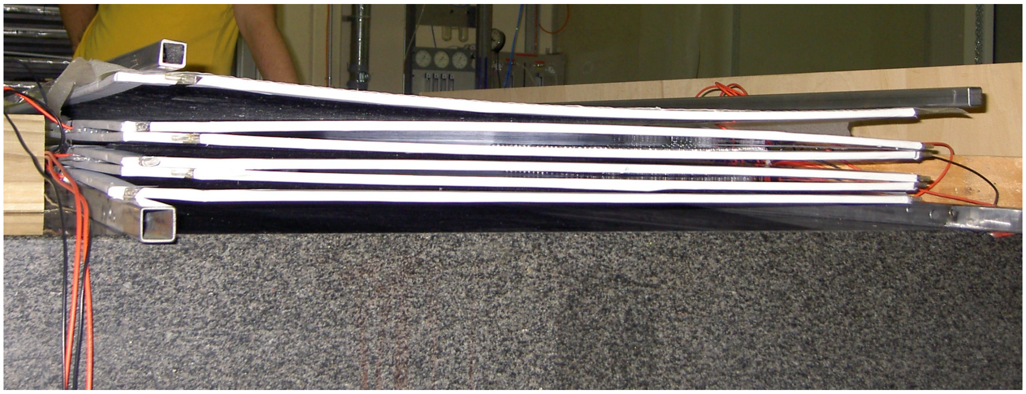

Figure 5: Stack of gaps inside the warm, humid tent. The effect of the increased mass can already been seen on the lower gaps.

On top of the foam was placed a narrow wood plank. Five lead bricks, totaling 39 kg in mass, were placed on top of this plank. Figure 4 shows the initial distribution of the lead bricks. After four weeks, a second plank and five more bricks were added, bringing the total mass up to 100 kg.[2] Figure 6 shows the distribution of the lead bricks.

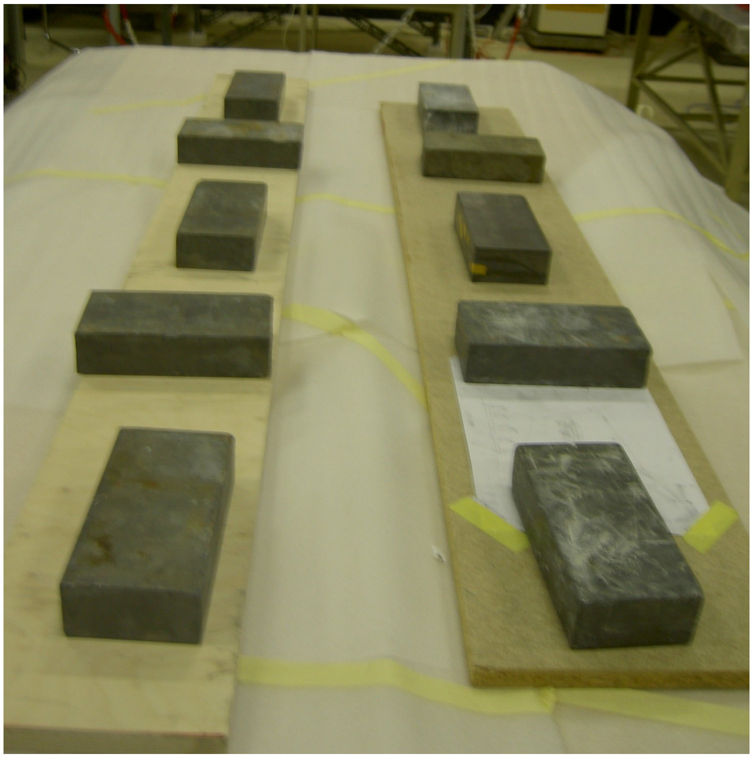

Figure 6: Distribution of lead bricks on top of bent gaps.

A temperature and humidity sensor was attached to one of the metal bars to allow for measurements of the temperature and humidity near the gaps. During the day, the heater was turned on to increase the temperature inside the tent to about 30°C. At night the heater was turned off, and the temperature within the tent typically dropped to somewhere between 20°C and 24°C. A complete record of the temperature and humidity measurements was kept.

The result of this set-up was a warm, humid environment in which to

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[2] At this time, the two small (4 kg and 5 kg) bricks were replaced with 10 kg bricks.

store the gas gaps with a large stress acting on the gas gaps in effort to flatten them.

3 Discussion of Results

To measure the curvature of the gaps, each gap was placed on a table with the concave side facing down. The sagitta, the largest space between the table and the top of the gap, was measured and recorded as the value ”a.” The thickness of the gap, 7.5 mm, was then subtracted to give the final value of a. Figure 7 shows this schematically.

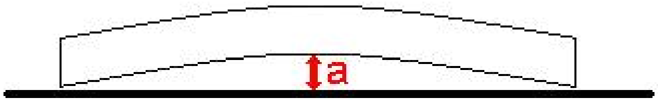

Figure 7: Measuring ”a.”

A record of the curvature of the gas gaps was kept for all bent gaps until the time they were put in a chamber. Table 1 shows the measurements for these gaps. By observing the measurements of ”a” up until October 5, it can be seen that the results of many of the attempts to straighten the gaps were mixed. Figure 8 shows this variation graphically. Overall, only four gaps straightened out enough to be put into a chamber before the warm, humid tent was begun.

A gap is considered acceptable for use in RPC construction when the sagitta is less than 10 mm. Once the gap is put into a chamber, the constraints of the Aluminum chamber casing keep it flat.

Table 2 shows the curvature measurements for all gaps that were in the humid tent, which was constructed October 5. All of these gaps showed an improvement after only a few days in the tent. This trend is visible in Figure 9. A slight increase in the curvature often occurred when the order of the gaps in the stack was changed and a gap moved upward in the stack. As expected, the greatest improvement was observed in the gaps near the bottom of the stack.

After about a month, all but one of the gaps within the warm, humid

Date	03	04	05	06	07	08	09	10	13	14	15
16/09/04	15.5	15	n/a	n/a	n/a	n/a	n/a	n/a	n/a	15.5	12.5
17/09/04	15.5	15	n/a	n/a	n/a	n/a	n/a	n/a	n/a	15.5	n/a
23/09/04	14.5	11.5	13.5	11.5	9.5	11.5	11.5	14.5	16.5	11.5	12
24/09/04	13.5	12.5	12.5	10.5	8.5	12.5	10.5	12.5	15.5	14.5	12.5
27/09/04	13.5	14.5	13.5	10.5	7.5	12.5	8.5	14.5	15.5	14.5	12.5
28/09/04	13.5	12.5	12.5	10.5	-	10.5	9.5	13.5	15.5	13.5	11.5
29/09/04	n/a	14.5	13	-	-	9.5	9	11.5	15.5	13.5	11
30/09/04	n/a	13.5	11.5	-	-	10.5	-	11.5	14.5	13.5	10.5
01/10/04	12.5	12.5	12.5	-	-	10.5	-	12.5	14.5	13.5	10.5
04/10/04	n/a	13.5	11.5	-	-	10.5	-	12.5	12.5	13.5	8.5
05/10/04	n/a	13.5	12.5	-	-	10.5	-	12.5	14.5	13.5	-
07/10/04	11.5	12.5	12.5	-	-	9.5	-	10.5	12.5	n/a	-
11/10/04	11	11	9	-	-	-	-	9.5	12.5	12.5	-
22/10/04	10	10	8	-	-	-	-	10	11.5	11	-
03/11/04	10.5	9.5	7.5	-	-	-	-	9.5	10.5	11.5	-
09/11/04	9	8.5	7	-	-	-	-	9.5	9	10.5	-

Table 1: RE1/2 botom (BO) gas gap measurements. The numbers at the head of the column refer to a specific gap, usually denoted in the form BO03.

Date	BO03	BO04	BO05	BO08	BO10	BO13	BO14
01/10/04	12.5	12.5	12.5	10.5	12.5	14.5	13.5
04/10/04	n/a	13.5	11.5	10.5	12.5	12.5	13.5
05/10/04	n/a	13.5	12.5	10.5	12.5	14.5	13.5
07/10/04	10.5	12.5	12.5	9.5	10.5	12.5	n/a
11/10/04	11	11	9	-	9.5	12.5	12.5
22/10/04	10	10	8	-	10	11.5	11
03/11/04	10.5	9.5	7.5	-	9.5	10.5	11.5
09/11/04	9	8.5	7	-	9.5	9	10.5

Table 2: RE1/2 bottom (BO) gap measurements for gaps in the warm, humid tent.

tent improved such that the sagitta was less than 10 mm. All of the gas gaps were removed from the tent and put outside for storage. They were stacked horizontally on a shelf with weights (totaling 100kg) placed on top.

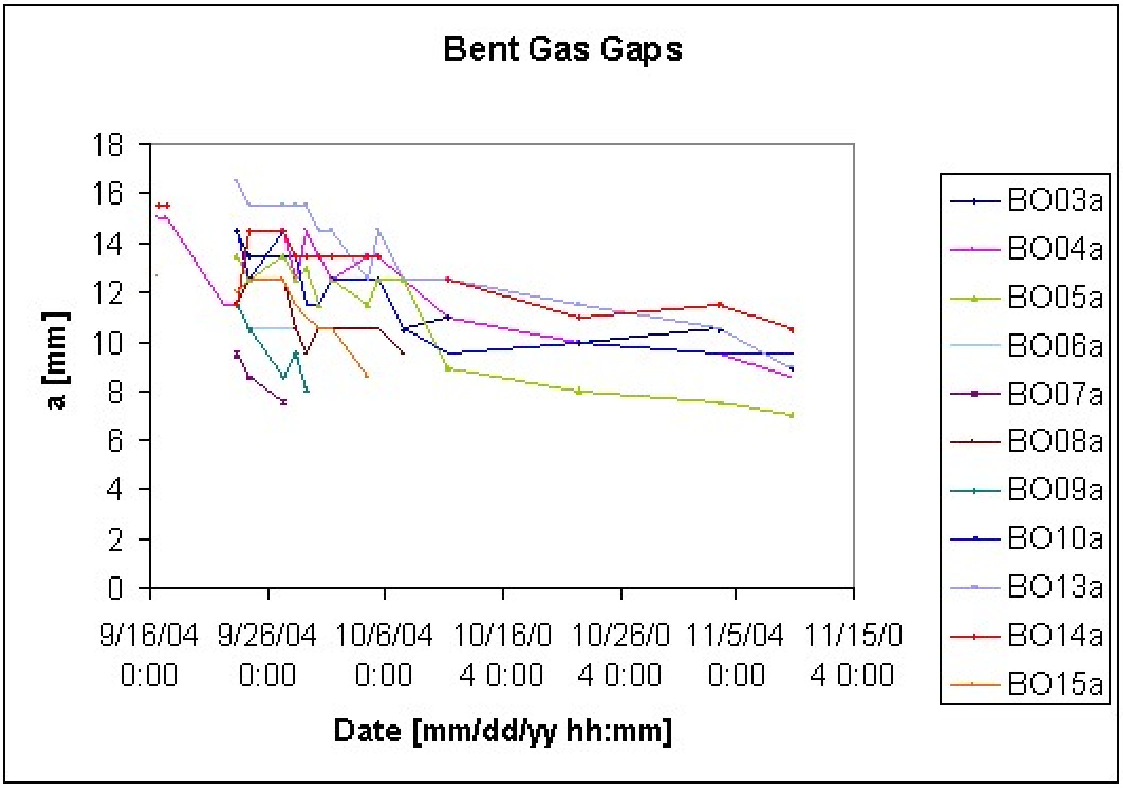

Figure 8: Progress of all bent RE1/2 gas gaps.

4 Conclusion

After a number of attempts, it was concluded that a combination of heat, humidity, and masses yielded the best results in correcting the bent gas gaps.

All gas gaps are now stored in a horizontal position, with a layer of foam between each of the gaps. Also, lead bricks (totaling 50 kg) have been placed on top of all gas gaps in storage. The bent RE1/2 gas gaps have a total of 100 kg of weight on top, as shown in Figure 10.

A close look should be taken at the way gas gaps are packed for shipping and storage. To avoid the extra work of straightening gas gaps, a method of storing the gaps so that they do not bend should be developed.

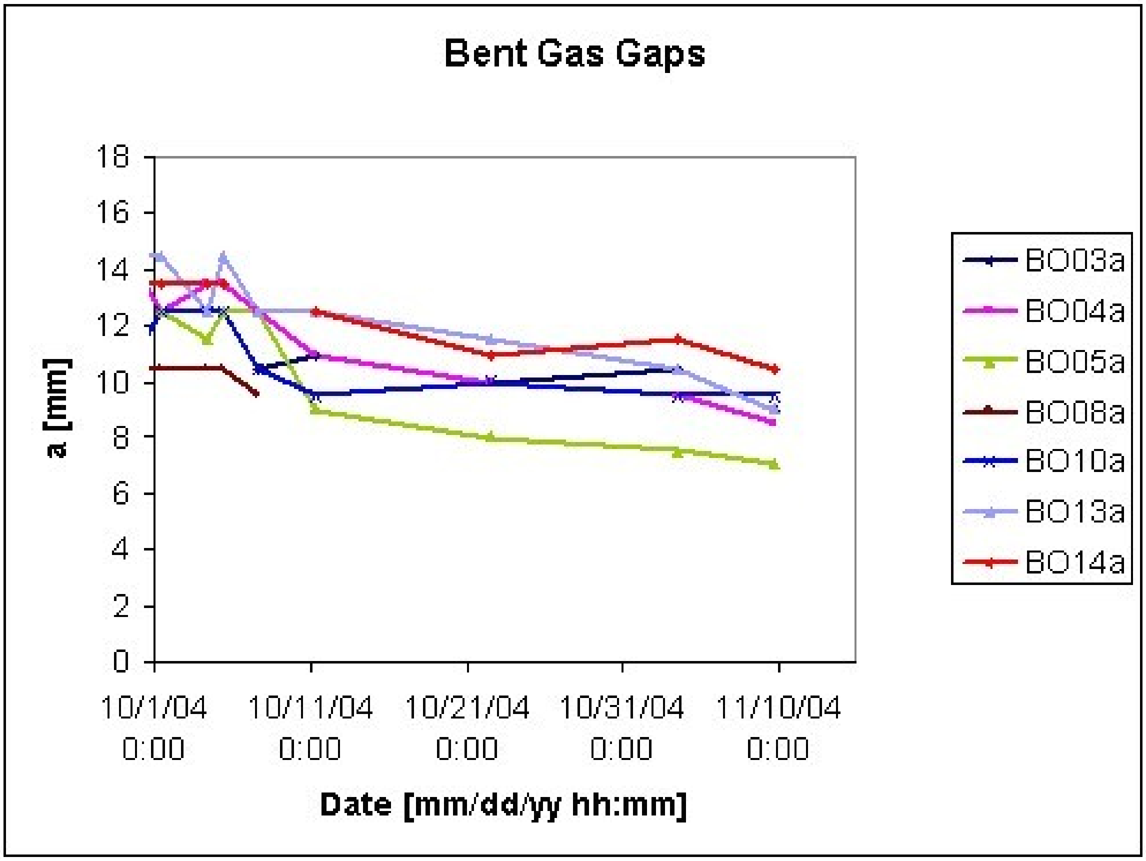

Figure 9: Progress of the gaps kept in the warm, humid tent.

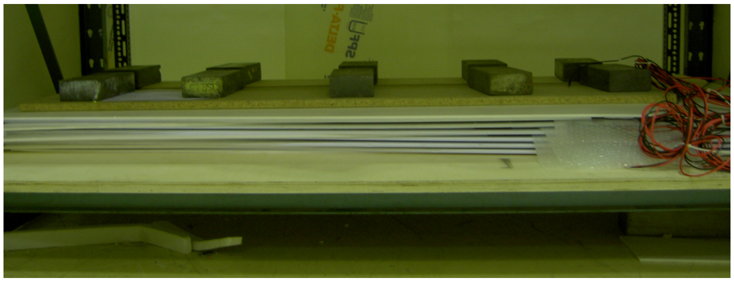

Figure 10: Storage of the bent gas gaps.

5 Acknowledgements

Suggestions from G. Iaselli, J. Va'vra, and K. S. Lee were very much appreciated.

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