

## **The BaBar Gas Bubbler Upgrade and Evaluation**

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## Abstract

The BaBar Gas Bubbler Upgrade and Evaluation. YU GAN (Princeton University, Princeton, NJ 08544) CHARLES YOUNG (Stanford Linear Accelerator, Menlo Park, CA 94025).

The Instrumented Flux Return region (muon and  $K_L$  detection barrel) of the BaBar detector at SLAC requires careful monitoring of the gas flow through the detector array. This is currently done by a system of digital gas bubblers which monitor the flow rate by using photogate technology to detect the presence of bubbles formed by gas flowing through an internal oil chamber. Recently, however, a design flaw was discovered in these bubblers. Because the bubblers are connected directly to the detector array with no filter, during rises in atmospheric pressure or a drop in the gas flow rate (eg. when the gas system is shut off for maintenance), the oil in this chamber could be forced backwards into the detector tubes. To compensate for this problem, we upgraded the existing gas bubbler systems by installing metal traps into the old gas lines to capture the oil. This installation was followed by an evaluation of the retrofitted bubblers during which we determined a relationship between the bubble counting rate and the actual gas flow rate, but encountered recurring problems with baseline fluctuations and unstable bubble counting rates. Future work will involve the study of how these instabilities develop, and whether or not they can be mitigated.

# 1 Introduction

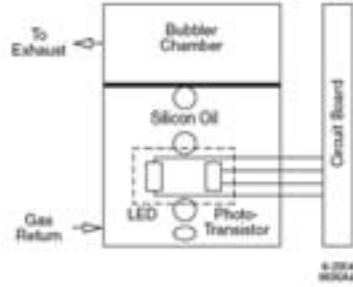
In the data collection for the BaBar detector [1] at Stanford Linear Accelerator Center (SLAC), the outer layer of the detector, the Instrumented Flux Return (IFR), is devoted to the identification of muons and detection of  $K_L$ . Currently, due to the discovery of serious design flaws in the Resistive Plate Chambers (RPC) originally installed in the IFR, the IFR is undergoing a large retrofitting process in which the RPC units are being replaced by the more robust Limited Streamer Tube (LST) modules, a process which started in the summer of 2004 and is scheduled to be completed in the autumn of 2006.

In order to achieve the so-called limited streamer regime required in these modules, the gas mixture (8% isobutane, 3% argon, and 89% carbon dioxide) within these tubes must be carefully regulated; to this end, we have been using a system of digital gas bubblers [2] attached to the end of the gas lines to monitor the outgoing gas rates. The bubblers, however, revealed a serious design flaw recently, wherein certain variations in the ambient atmospheric conditions would be enough to force oil found within the bubbler into the actual modules. This paper outlines the procedures and problems with the retrofitting process designed to mitigate this malfunction of the gas bubblers.

## 2 Materials and Methods

### 2.1 The Unmodified Gas Bubbler

The digital gas bubbler system currently implemented at the BaBar detector is based on a model originally installed at KEK for the Belle detector [3]. A schematic of an unmodified gas bubbler is shown in Figure 1(a), and a photograph can be found in Figure 1(b). A total of 16 gas lines, or channels, can be directed into a gas bubbler at one time. Gas enters the bubbler through gas



(a) Bubbler Schematic [2]



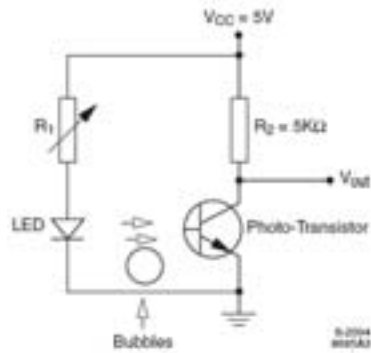
(b) Photograph of Bubbler

Figure 1: The Gas Bubbler

fittings in the rear of the bubbler, and these lines are fed directly into a front-mounted oil chamber. This oil chamber has a small amount of Dow-Corning 704 Diffusion Pump Fluid at the bottom which bubbles when gas is passed into the chamber, and the bubbles are restricted to 16 distinct positions where they pass by a photogate. The gas is then vented out into open air via the exhaust lines.

The photogate consists of a traditional LED and photo-transistor arrangement. The circuit is sketched in Figure 2(a). When a bubble passes through the LED beam, the beam is refracted and fewer photons hit the photo-transistor. This produces a voltage spike which we can read with an oscilloscope or other electronics through test points on the bottom of the front panel (see Figure 2(b)). The voltage spike is inversely proportional to how much light hits the photo-transistor, ie. the more the light is refracted, the greater the signal strength. As seen in Figure 3, the light is refracted the most as the bubble enters and leaves the photogate (when the angle of incidence between the horizontal LED beam and the gas-oil bubble interface is greatest) and is refracted the least as the bubble's center passes the LED (when the LED beam is approximately normal

to the gas-oil interface).



(a) Photogate Circuit (diagram provided by Stephen Foulkes [2])



(b) The Front Panel

Figure 2: The Photogate



Figure 3: A photogate signal as read out on an oscilloscope

We require for our testing purposes that the spike's valley be between 2 and 2.5V. This is because of the fact that we actually count anything above 1V as a bubble, and by using the 2V threshold, we ensure that the valley will never dip below 1V. If the spike's valley were to fall below 1V, we would double count a single bubble—the first bubble would be the large incoming spike and then the first half of the miniscus before it falls below 1V, and the second would be

the rest of the spike as the voltage climbed above 1V. If the valleys are too low or too high, we can adjust the intensity of the LED by varying the resistance with a potentiometer mounted on the front panel below the oil chamber—if we increase the intensity of the LED beam, the entire amplitude of the spike rises, and the spacing between the valley and the peaks adjusts proportionally.

According to the original design of the bubbler, the incoming gas lines in the interior of the bubbler chassis directly fed into the oil chamber in the front of the chassis. It was soon discovered, however, that because the exhaust line was open to the air and thus sensitive to atmospheric pressure changes, if the ambient air pressure were to rise by one or two inches of water (as it may after a storm front moves out of the area), the pressure of the incoming gas flow may not be enough to prevent the oil in the chamber from flowing back into the gas return line, possibly reaching the connected modules.

This phenomenon has already been witnessed—Figure 4 shows one of the straight gas lines from the interior of the chassis which has several oil droplets within it. If oil were to flow back into the LST modules, the modules could potentially become unusable.



Figure 4: A section of the gas line with oil droplet contamination

It should be noted, however, that we have yet to have such a problem with bubbler performance with the LST modules; four bubblers were retrofitted during last summer's LST installation and they appear to be functioning well.

## 2.2 The Oil Trap Design

In order to compensate for the problem with the original gas bubbler, it was decided that installing cylindrical oil traps between the incoming gas line and the oil chamber would be the most efficient method given the dimensions of the chassis and the dimensions of the rack on which the bubbler is mounted. The traps, as shown in Figure 5, consist of a metal cylinder with two metal caps welded to the top and the bottom, the former having two holes for Poly-Flo gas fittings. The bottoms of these oil traps must be covered with plastic endcaps (Figure 5) to both insulate the metal and physically protect the motherboard underneath gas lines from wear and tear. Each oil trap has a volume exceeding the total volume of fluid in the oil chamber, allowing for the extreme case where 15 channels are functioning properly and all the oil flows back through the last channel. We have no way of checking the traps for oil, so if a major amount of oil were missing, we would have to open up the chassis and check each trap; this procedure will not happen very often if at all.

Gas fittings come in two flavors—the straight connector and the elbow connector (Figure 5). To most efficiently use the volume within the chassis, two oil trap configurations are used—the straight-straight combination, and the elbow-straight combination. In the past there was in fact an oil trap design that allowed the elbow-elbow combination, but this design was eventually replaced by the current oil trap design because this new type was easier to weld and less prone to damage. By using four or five elbow-straight oil traps with the gas channels 1, 2, 14, 15, and 16 (sometimes channel 14 can be done with a straight-straight, depending on how well-packed the middle channels are), and packing the straight-straight cylinders in the middle region as tightly as possible, all 16 channels fit snugly above the motherboard.

Each gas fitting must be screwed into the oil traps with teflon tape. The





Figure 5: Oil trap components clockwise from top-left: Metal Oil Trap, Endcap, Elbow Connector, Straight Connector

teflon tape wrapped around the threads of the gas connectors ensures a gas-tight connection between the oil trap and the gas fittings, sealing any oil into the traps.

### 2.3 The Retrofit

Before full installation can begin, we first had to remove the old gas lines and clean the inside of the chassis. There was frequently a lot of oil lining the inside walls of the chassis, or even the PC board itself. Following this cleaning, we had to cover the PC board and the power supply with insulating plastic to prevent any shorts from occurring between the metal oil traps and the electronics. We used a heat-resistant plastic, and taped the plastic down with 3M 471 Vinyl Tape.

Once the plastic protection had been placed, we replaced the exhaust gas lines first. The long gas line measures 11.25 inches, and the short tube measures around 3 inches. Then, working from Channel 1, we installed each oil trap with tubing along the inside of the chassis. Because of the shortage of space within the chassis, we had to significantly bend some of the tubes to fit them into the box. To avoid putting kinks in the Poly-Flo tubing, the tubes were placed in

boiling water for several seconds before they were installed into the gas fittings, and then bent into shape. This “heat-bending” procedure does place moisture into the tubing, but because the gas bubbler system is placed at the end of the gas line, any moisture retained in the bubbler system should have no effect on LST operation, and in fact, by the time installation occurs, the moisture should have exited the system during testing.

Incidentally, all of the oil traps in the new chassis tend to weigh down the PC board, especially in the middle region where the tube lengths lead to lower-lying oil traps. The PC board could potentially drop so low that the readout and potentiometer access ports on the front of the chassis may drop below the holes in the front panel. Additionally, this added pressure from the traps combined with the warping of the PC board could break some of the more fragile solder joints on the board itself. In order to ensure access to the potentiometers on the front panel, we used styrofoam blocks taped to the bottom of the chassis to support the PC boards from below. These blocks are cut specifically for each chassis, depending on how much the board is pushed down, but the blocks are usually around 1 inch in thickness, and are placed below the potentiometers in the front of the chassis running backwards towards the readout port on the back of the chassis.

## 2.4 Testing and Calibration

After hardware installation, the upgraded chassis are attached to a gas distribution box that can flow gas into all 16 channels (Figure 6). The gas distribution box consists of an incoming gas hose that feeds regular air into 16 Dwyer RMA-151-SSV flow meters, which lead to gas tubes that can attach directly into the rear of the gas bubbler panel of the gas bubbler.

The flow rate for each channel can be set between 30 and 40 cc/min of regular



Figure 6: The Gas Distribution Box

air, and the gas bubbler is tested for any aberrant flow rates. We choose this flow rate because the LST's usually see a gas flow rate such that there is about one volume change per day per gas line. Each gas line services four modules on average, and each module is taken to have an average volume of 15 liters. After conversion, this becomes approximately 41 cc/min (around where we run calibration tests for the bubbler). One chassis, Bubbler 021, was calibrated for this paper.

Rather than use a computer to readout the bubble rate, a rough estimate of the bubble rate by hand is enough to confirm the bubbler's efficiency. We do this by putting test pins in the test points on the front panel of the bubbler and reading out any voltage spikes on the oscilloscope. We set all 16 channels at 10 cc/min and then calibrated each photogate readout until the valley of the spike fell between 2 and 2.5V. After we make this adjustment, we find a suitable viewing window for the oscilloscope display, and froze the display when we could see at least ten distinct spikes caused by bubbles. We then use the cursor function on the scope to find the amount of time we needed to see ten bubbles pass through our photogate, and we then extrapolate the actual count rate from this measurement. We repeated this procedure for 20 cc/min, 30 cc/min, 40 cc/min, and 50 cc/min, the maximum measurable output on the

flow meters.

### 3 The Retrofitted Gas Bubbler

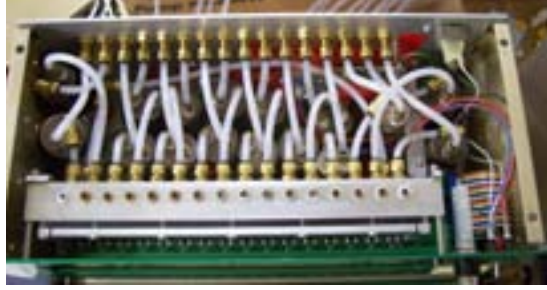


Figure 7: Aerial view of the interior of the retrofitted bubbler

The interior of the upgraded gas bubbler is shown in Figure 7. As can be seen in Figure 8(b), we have generally chosen to cross the gas tubes in the mid-section (ie. we have connected the gas fitting on the rear of the chassis to the oil trap gas fitting that is farthest away, and similarly for the gas fitting on the front of the chassis). This allowed us to bend the tubes with softer curves, and combined with the short lengths of the tubes in the midsection, we greatly reduced the stress on the PC board. The first completed chassis pushed the middle of the PC board down by about 2 mm, but when we shortened the tube lengths in the midsection to 2.5 and 4.5 inches and used the heat-bending technique, we were able to reduce this sagging to about 1 mm.

Indeed, every tube was eventually heat-bent. We had originally planned on only heat-bending the tubes on the left and right sides of the chassis, but when we cut the mid-section tubes to 2.5 and 4.5 inches, the mid-section tubes required heat-bending as well. The tubes on the left and right sides of the chassis (the left side is shown in Figure 8(a)) still demanded the most heat-bending, especially the long tube leading into Channel 2 of the gas bubbler—the tension

within the tube combined with its length forced the tube well above the plane of the box lid, and we eventually decided to heat-bend the tube and then place the lid on the chassis while the tube cooled to condition the Poly-Flo.



(a) Left side



(b) Middle

Figure 8: Closer view of the retrofitted gas bubbler

## 4 Calibration Results

We can use the flow rate reading on the flow meter attached to the distribution box to approximate the correlation between the bubble rate and the flow rate; below is a table of the bubble rates we measured using the techniques outlined in Section 2.4.

	Bubble Rate (bubbles/min) at				
	10 cc/min	20 cc/min	30 cc/min	40 cc/min	50 cc/min
Channel 02	126	174	258	300	366
Channel 03	127	193	267	306	366
Channel 04	115	185	268	306	366
Channel 05	131	200	273	309	364
Channel 06	113	194	250	296	359
Channel 07	117	240	239	300	441
Channel 08	114	162	283	330	444
Channel 09	111	181	245	293	366
Channel 10	112	183	273	314	377
Channel 11	115	206	278	339	375
Channel 12	127	232	303	302	382
Channel 13	131	188	275	319	423
Channel 14	121	173	274	316	380
Channel 15	127	190	274	316	370
Channel 16	112	208	239	302	351

Table 1: Bubble rate vs. flow rate in Bubbler 021

We ignored the data for the first gas channel because the Dwyer flow meter knob was very sticky and the flow rate given on the meter was not very responsive to our turning of the knob. The error on these measurements is approximately  $\pm 5\%$  bubbles/min, which we get from the uncertainties in the cursor placement on the oscilloscope display.

In ramping up the flow rates, we also discovered that as we increased the physical flow rate on the flow meter, the amplitude of the voltage spikes (the initial and final rise as well as the valley) decreased without our adjusting the intensity of the LED beam, and vice versa. In fact, the behavior exhibited by the bubbler readout on the oscilloscope was extremely similar to the kind

of readout one would get from adjusting the LED intensity—changes in the difference between peak and valley of a bubble spike, changes in amplitude, etc. Figure 9 shows this flow behavior at a constant LED intensity.

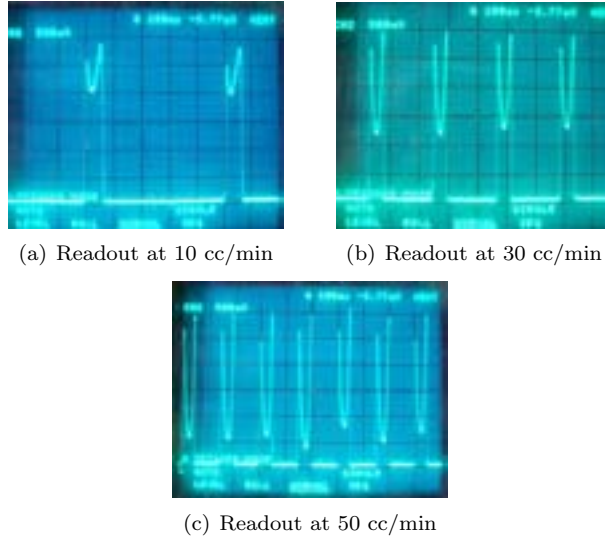


Figure 9: Oscilloscope readouts at constant LED intensity

It is important to note that adjusting the LED will *never* appreciably affect the count rate, so the flow rate affecting the scope readout in a way similar to the LED adjustment is peculiar.

Lastly, we encountered a few temporary instances of “baseline fluctuations” (Figure 10) in 4 of the 64 channels that were retrofitted for this project. As can be seen in Figure 10, baseline fluctuation is a situation in which the usually flat baseline between bubble peaks become jagged and erratic, sometimes jumping beyond the 1V counting threshold. The fluctuations generally disappeared after letting the gas flow for several hours or overnight.



Figure 10: Baseline fluctuation on the oscilloscope readout

## 5 Discussion and Conclusions

We expect that the flow rate is in no way affected by the oil traps. By taking the Reynold's number for the BaBar gas system, we can determine if the flow is laminar or turbulent. The formula for Reynold's number  $Re$  of flow through an arbitrary pipe is

$$Re \equiv \frac{VD}{\nu}$$

where  $V$  is the fluid velocity,  $D$  is the diameter of the pipe through which a fluid is moving, and  $\nu$  is the kinematic viscosity of the fluid [4].

The diameter of the Poly-Flo is documented at  $\frac{1}{4}$  inches, and this converts to 0.625 cm. The kinematic viscosity of the gas is well-documented, and we will assume for simplicity that the gas is 100% carbon dioxide. The kinematic viscosity of carbon dioxide at standard temperature and pressure (1 atm and 273.15 K is  $8.03 \times 10^{-6}$  m<sup>2</sup>/s [5]), and although the conditions in the testing lab are not quite at STP, using this  $\nu$  is a reasonable approximation of the actual  $\nu$  of carbon dioxide in the bubbler. We know the flow rate through each gas line is about 41 cc/min. We can now convert this volumetric flow rate into an average velocity for the gas by using the simple conversion



$$\text{Volumetric Flow Rate} = (\text{Average Velocity}) \times (\text{Cross-Sectional Area of Pipe})$$

which follows from the idea of a cylinder of volume 41 cc with a base area equal to the cross section of the pipe and moving parallel to its height at the average velocity indicated in the formula.

Using this conversion, we get a mean  $V$  of 134 cm/min. If we assume that our flow is turbulent, we approximate  $V$  by doubling 134 cm/min and substitute into our equation for  $Re$  and get 34.8 for our Reynolds number. A Reynolds number below 2320 is considered laminar flow, so even under the assumption that our flow was turbulent, we have a sufficiently low Reynolds number to achieve laminar flow. Often times the limiting factor of flow within a pipe is the pipe diameter, but our flow rate is so low that this is not even an issue.

Given this expectation, adding oil traps into the gas line should have had little effect, because even though we placed more bends in the tubing (which generally increase resistance to flow), our flow rate is so low that any bends the gas sees may be approximated as straight lengths of tubing. Indeed, we see this situation in the retrofitted gas bubblers. If we take the results from Table 1 and use Microsoft Excel 2003's linear regression function to find a linear correlation of the data, we get a reasonably strong correlation between bubble rate and flow rate as read from the flow meters (see Figure 11). This relationship is analogous to the conversion factor found in an earlier study on the unmodified gas bubblers [6].

We do not have error bars drawn on the graph simply because the level of accuracy we need is not remarkably high. The bubblers are not designed to give extremely accurate outputs of the flow rate in the modules; rather, they are designed to confirm that flow is occurring in the gas lines, and also to

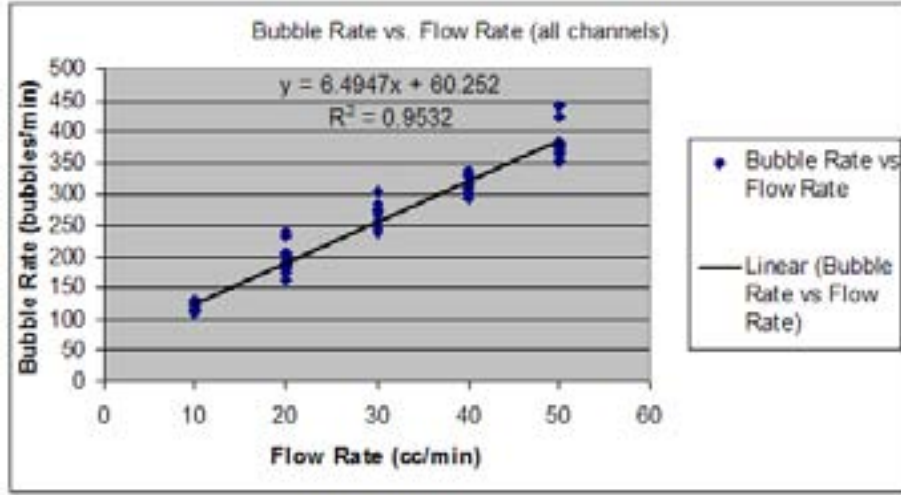


Figure 11: Microsoft Excel output for calibration data of Bubbler 021

give relative flow rates so that changes can be observed in the gas line. The error in fact lies mostly in the Dwyer RMA-151-SSV flow meters attached to the gas distribution box; the oscilloscope readings are reasonably precise, but the fluctuation of the flow meter reading is large (on the order of  $\pm 5$  cc/min at times). It is pointless to try for precise measurements with the Dwyer flow meters; in our evaluation, we intended only to qualitatively confirm that a rough linear fit still exists at these flow rates.

The issue of the changing spike amplitudes is something of a mystery. We currently surmise that it is related to the change in bubble size at different flow rates; when the flow rate increases, the pressure on the tubing outlet would increase, and a slightly larger bubble would form. This larger bubble could deform and become more like an ellipsoid, with the major axis oriented vertically. This way, the refraction at the top of the bubble remains relatively the same, but the rest of the bubble surface is more perpendicular to the LED beam than a sphere's surface, and would thus refract much less. This is pure conjecture at

this point, and further studies may investigate this phenomenon in the future.

The issue of baseline fluctuations does not appear to be a direct result of our installation of oil traps; rather, we believe that baseline spikes may be caused by dust particles that at some point during production were trapped in the bubbler system. These dust particles could conceivably get caught in the photogate apparatus and cause less refraction than the oil-gas film of a bubble, but still enough to register small spikes along the baseline when a bubble is not present. Eventually, the gas flow itself should push this dust particle out of the photogate, thus explaining the temporary nature of the baseline fluctuations. An alternative theory is that a small gas bubble may attach itself to the side of the photogate, and similarly cause smaller but noticeable refraction when a full bubble is not present. Neither of these theories has been confirmed, but as the baseline spikes are a temporary but recurring problem, further experimentation is planned to study this issue.

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