NUCLEAR INSTRUMENTS AND METHODS 143 (1977) 513-517 ; © NORTH-HOLLAND PUBLISHING CO.

TECHNIQUE FOR PAINTING LIGHT INTEGRATION BOXES

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Received 10 February 1977

We describe a method for the application of a highly reflectant, diffuse coating to the interior of light integration boxes. Simple box design considerations are presented in addition to techniques for dealing with a variety of problems which we have experienced. An analysis of the performance of a light integration box of 4 m^2 surface area is given. The overall box reflectivity is found to be 96.7% and that of the paint is found to be 97.3% at a wavelength of 425 nm.

1. Introduction

Scintillation and Cherenkov counters have been used in a variety of configurations. For some applications, it is desirable that a detector have a high degree of spatial uniformity of response. In such cases it is most advantageous to house the light emitting substance in a large box, the walls of which are coated with a diffusely reflecting substance. The interior of the box is viewed by photomultiplier tubes and if the fractional area covered by photocathode material is small enough, the emitted light is sufficiently randomized by the time it is collected to enable one to achieve a degree of uniformity of response which is difficult to attain in a light piping configuration.

In order to achieve this uniformity without incurring severe light losses it is important that the reflectivity of the diffuse substance be quite high. Pure $BaSO_4$ powder possesses one of the smallest absorptivity coefficients of known materials, particularly in the part of the spectrum whic is most visible to photomultiplier tubes (at 400 nm the reflectivity is 99.7%). With grain sizes of the order of microns, $BaSO_4$ powder is an ideal choice for the diffuse reflection surface for the interior of light integration boxes. A prepared paint is commercially available from Eastman Kodak Company[1]). However, this paint has a polyvinyl alcohol base which degrades the performance in the near ultraviolet region. A paint which utilizes an inorganic binding material to overcome this limitation has been developed at the Goddard Space Flight Center[2]). Since this was developed to optimize reflectivity rather than ease of application, it is somewhat difficult to coat the interior of light integration boxes with this paint, particularly if large surfaces are involved. In this paper we describe a procedure for application of the Goddard paint which we have found to be quite successful with regard both to mechanical integrity and reflectivity.

2. Preparation of the primer

In ref. 2 it is pointed out that the Goddard paint has an acidic pH. In order to avoid adverse chemical reactions with the metal substrate from taking place it is necessary to first apply a prime coat which has a basic pH to the surface. This prime coat also results in improved bonding of the paint. A suitable priming coating, with maximum reflectance in the ultraviolet region, was developed at Goddard. This primer consists of a mixture of 113 ml of potassium silicate solution [electronic grade PS7, obtainable from Sylvania, Inc.[3])] plus 661 ml of distilled water plus 453.6 g (a one pound bottle) of reagent grade Al_2O_3. To obtain a homogeneous primer which is suitable for application with a spray gun it is necessary to mill this mixture for roughly one hour. One will thence obtain a milled slurry with a volume of about 850 ml. The primer separates rapidly (with a time scale of 10 min) so it should be milled immediately before it is applied. The ratio of wet primer volume to dry primer volume is about 2:1.

3. Preparation of the paint

The appropriate paint mixture is 750 ml of distilled water plus 7.04 g of reagent grade K_2SO_4 plus 500 g (one full bottle) of Eastman White Reflectance Standard[1]) (this is ultra pure $BaSO_4$). The water and potassium sulfate are added to a blender and mixed for about 10 s until the potassium sulfate is dissolved. The $BaSO_4$ is then added and the mixture is blended for 10 min. This makes roughly 800 ml of paint. The paint also separates rapidly so it should be made just before it is applied. The ratio of wet paint volume to dry paint volume is about 3.5:1.

4. Light integration box design considerations

If one is designing a detector which will utilize a light integration box, he should do so bearing in mind the problems concomitant with the painting procedure. The interior of the box should have no curved surfaces and the number of seams where one piece of metal is screwed to another should be minimized. The best box is one which is folded up out of one piece of metal and welded at the edges. Aluminum is the best material to use. It is soft enough so it can be easily sandblasted to provide a good surface for primer adhesion and it can be machined with very little quantities of lubricants which should be avoided as contaminants to the paint and primer. One must not use any blue dye for laying out work. It is impossible to get rid of all of this with the use of common solvents and even if no trace is visible to the eye, it will cause the paint to turn blue if it is coated. If one plans to use a solid scintillator or Cherenkov radiator in the light box, it should be placed in a well to conceal the edges from the inside of the box. This will minimize the amount of self absorption by the radiator and will result in an improved efficiency for light collection[4]).

5. Preparation of the surface to be painted

Optimal results are obtained when the surface to be painted is a flat horizontal piece of aluminum. There should be no trace of grease or oil on the metal. It should be sandblasted lightly and uniformly and any free sand embedded by this process should be removed with fine sandpaper. Finally, the surface should be cleaned thoroughly with methyl ethyl ketone or ethanol (190 proof ethyl alchohol).

6. Description of painting equipment and facilities

It is virtually impossible to apply the primer or the paint to a large surface by any technique other than spraying. Any high quality spray gun should be adequate for this purpose. We found the Binks Model 62 spray gun to perform very nicely. The primer mixture is relatively thin so that the common siphon cup arrangement can be used for its application. A medium sized nozzle and needle can also be used (we used a 66SD nozzle and 365 needle for primer). The paint, on the other hand, is quite thick. In order to apply it one needs a pressure pot arrangement, whereby the air pressure is applied to the paint in the can and forces it through the gun. One should also use a larger nozzle and needle than for the primer. We found a Binks 67PB nozzle and 367 needle to perform very well.

The people at the Lawrence Berkeley Laboratory, Austin Paul in particular, were very kind in allowing us to use the facilities of the LBL paint shop. These facilities included a sandblasting room and an enclosed, "clean", painting hood. The air supply was triple filtered to eliminate the oil in the lines.

7. Application of the primer

The optimal amount of primer to be applied is a dry thickness of 0.2 mm or a wet thickness of 0.4 mm. When one first starts to paint he should use premeasured quantities of primer, taking into account spraying losses. After a while one is able to tell by visual inspection when an adequate quantity has been applied. The primer is applied to the box one side at a time. We have found that an air pressure of 20 lb/in.^{2} provides a nice spray. The side to be primed is placed horizontally and the premeasured amount of primer is applied by spraying in one application (a useful rule of thumb

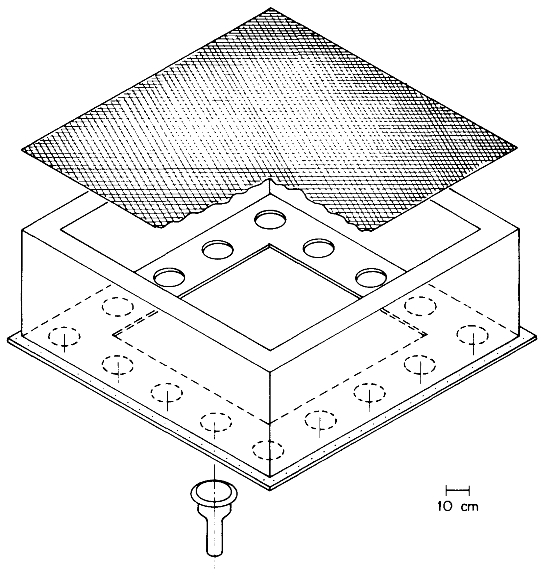

Fig. 1. Schematic of Cherenkov light integration box. Outside dimensions are 102 cm × 102 cm × 38 cm. The 1.27 cm thick Pilot 425 radiator fits in the 65 cm × 65 cm well at the bottom of the box. The top is a 1 mm sheet of aluminum and the sides are 3.2 mm aluminum. The walls and top are coated with $BaSO_4$ paint. Two layers of Millipore paper are placed beneath the radiator, which is supported by a low porosity aluminum plate of precise thickness.

for both the paint and primer is that when the material stops beading on the surface and flows together an adequate amount has been applied). A wait of between 1 and $1\frac{1}{2}$ h is required for the primer to dry sufficiently so that the primed surface can be moved without having the primer flow off (this time depends on the size of the surface and the ambient conditions such as relative humidity and temperature). After this time is up, the box is placed in a new position so that another side can be primed. The process is repeated until the entire box is completed. The box should then be set aside in a clean place for at least 24 h before the paint coat is applied. After this drying period the coated surface should be brushed lightly with a clean paper towel and the dust should be blown away.

It is absolutely essential that the paint spray equipment be thoroughly cleaned with ethanol and distilled water immediately following each application. This prevents clogging by the thick paint and primer and in the case of the primer minimizes the amount of corrosion of the needle by the potassium silicate solution.

8. Application of paint

A pressure of 25 lb/in.^{2} at the needle and 10 lb/in.^{2} on the pressure pot give good results for the application of the paint. A dry thickness of 0.2 mm or a wet thickness of 0.7 mm provide optimal reflectivity. The paint is sprayed on the box in exactly the same way that the primer is sprayed on the box. Again, about a one hour wait is required between coats. The completed box should be left alone for several days to let the paint dry thoroughly.

9. Mechanical properties of the surface and touch up procedure

The most important point for the novitiate to realize is that the things that we have referred to as primer and paint are like no other paint he has dealt with before. The coated surfaces are about 10 times as thick as normal painted surfaces and the qualities of adhesion of our paint and primer are minimal to say the least. The structure of the dry paint and primer resembles that of sandstone. The surface has reasonable mechanical strength provided that there are not cracks or bridges. These defects have a tendency to propagate resulting ultimately in large areas of paint flaking off. It is very important, therefore, to repair these defects at a very early stage. As soon as they are detected (they can usually be spotted within hours after the paint or primer has been applied) the paint (or primer) should be cleaned off over the entire impaired area. Fresh paint (or primer) should be added to the area with a small paint brush. After this dries, the patched area can be smoothed by a light brushing action with a clean paper towel.

In order to maximize mechanical strength and reflectivity it is important that the paint or primer be applied to a surface at one time, rather than in many thin coats. In the later case there will be many thin layers of dust which will degrade both of the aforementioned properties.

10. Results regarding mechanical integrity of painted boxes

In the past three years our group has painted nine light integration boxes by the techniques described above. Six of these boxes have survived transportation to South Dakota and back and one balloon flight without any significant loss of paint or reflectivity. Of the other three boxes, one was a prototype, one was used in a Bevalac experiment, and one was painted for another group and will be flown in the Spring of 1977.

11. Measurement of the absolute reflectivity of the painted surface

We have described elsewhere[5]) a high precision Cherenkov counter designed to be used in high altitude cosmic-ray experiments. Refer to fig. 1 for a schematic of this detector. Millipore paper[6]) forms the reflectant surface beneath the Cherenkov radiator and the rest of the surface area of the box is covered with $BaSO_4$ paint with the exception of the view ports of the 16 RCA 4525 photomultiplier tubes. The allocation of surface area is given below:

total interior surface area: $A = 36\,312\ \mathrm{cm}^2$,
$BaSO_4$ coated area: $A_p = 30\,532\ \mathrm{cm}^2$,
Millipore + radiator: $A_M = 4\,225\ \mathrm{cm}^2$,
photocathode area: $A_T = 1\,555\ \mathrm{cm}^2$.

Within two weeks after we had painted this box we had it fully assembled and ready to be tested. At this time there was a smooth Pilot 425 radiator placed in the well (this would later be replaced by a sandblasted radiator). In order to measure the absolute reflectivity of the interior of the box (which is usually quite difficult to do) we took advantage of the unique construction of our box. The photocathode fractional area coverage is small enough so that it is quite a good approximation to assume that any given photon has a probability of hitting a phototube given by $A_T/A \equiv F$. If t is the mean transmittance of a phototube window ($1-t$ is the probability that a photon which hits the tube window is ultimately returned to the interior of the box, suitably averaged over incidence angles) then it can be shown that the probability for a photon to ultimately get through a phototube window is[7]):

$$f = \frac{Ft}{1-(1-Ft)(1-a)}, \tag{1}$$

where a is the mean absorptivity of the light integration box. If each of the 16 tubes has the same overall gain and if one observes a light source with a constant output then the summed phototube output is directly proportional to f:channel $= Kf$. By observing the variation in channel with fractional area covered (F) one can test the validity of eq. (1). If eq. (1) passes the chi-squared test then the best fit value for the parameter a should correctly correspond to the mean absorptivity of the box. The absolute reflectivity of our box was determined in this manner. Our constant output light source was a Pilot F scintillator irradiated by an ^{241}Am alpha particle source. The fluorescence spectrum of the scintillator closely matches that of the Pilot 425 radiator and hence provided information relevant to our detector. This spectrum is peaked at 425 nm with a fwhm of 60 nm.

By placing disks of Millipore paper in front of the faceplates of differing numbers of phototubes we were able to obtain 16 data points measuring response as a function of the fraction of box area covered by phototube faceplates (the charge amplifiers on the tubes were adjusted so that the net gains for the tubes were the same within 2%). The results fit eq. (1) very well. In our case the best fit parameters were: $a = 0.033 \pm 0.002$, $t = 0.69 \pm 0.04$ and $f = 0.476 \pm 0.001$ at $\lambda = 425$ nm. In fig. 2 the fitted function is plotted along with the data points. By assuming the error of each point to be determined by tube gain variations (i.e. $\sigma = 2\%$ for the single tube data point and $\sigma = 2\%/\sqrt{16} = 0.5\%$ for the 16 tube points) and by a 2 channel error in locating the α peak we obtain a χ^2 of 23.5 for 13 degrees of freedom. The 5% critical value of χ^2 is 22.4 and the 2.5% value is 24.7 for this number of degrees of freedom. We conclude that the fit is not significantly bad. Therefore, the mean reflectivity of the box with the smooth Pilot 425 Cherenkov radiator in place is $(96.7 \pm 0.2)\%$. By assuming a Millipore reflectivity of 95%, which is quoted by the manufacturer, and by calculating the effect the presence of the Pilot 425 radiator has (multiple internal reflections and radiator absorption of 425 nm light are considered) a paint reflectivity of 97.3% is obtained. If the Millipore reflectivity is only 93% the paint reflectivity is 97.6%. It seems safe to conclude that the $BaSO_4$ reflectivity is:

$$r = (97.3 \pm 0.3)\ \% \quad \text{at} \quad 425\ \text{nm}.$$

While this value does not compare favorably with that for pure $BaSO_4$ powder (99.7%), it is comparable to the value reported in ref. 2 (98%).

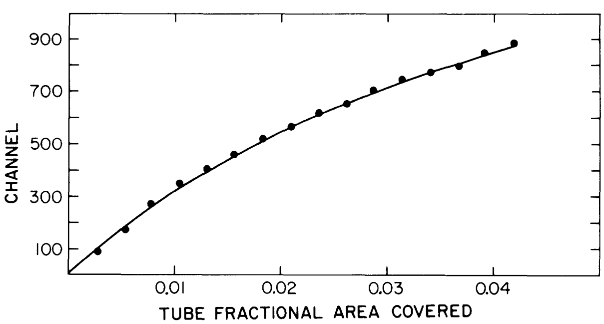

Fig. 2. Plot of the amount of light collected by the Cherenkov light integration box as a function of tube fractional area covered. An ^{241}Am α-particle source irradiated a Pilot F scintillator to provide the light source. The curve is the best fit diffusion box efficiency function to the data.

12. Uniformity of response

In ref. 5 we report results for the calibration of the Cherenkov counter with heavy ion beams at the Lawrence Berkeley Laboratory Bevalac. The spatial uniformity of response is found to be limited by thickness variations in the Chrenkov radiator (these amount to less than 1%).

13. Conclusions

In this paper we have reported on a successful technique for the application of a high reflectance coating to the interior of light integration boxes. Although the absolute reflectivity of the painted surface of a very large integration box compares favorably with that obtained by the Goddard group, we feel that there is room for improvement. Despite our pains to maintain a clean environment for the paint application, we invariably notice numerous dust particles on the surface shortly after application. Most of the particles are not visible in ordinary lighting but can be made so by illumination with an ultraviolet lamp (the dust particles, tiny hairs, etc. fluoresce under UV excitation). Perhaps a specially constructed "clean room" painting facility and antiseptic painting gowns and masks would improve on this aspect.

It has been reported that iron is a very potent contaminant to the $BaSO_4$ paint. The use of stainless steel paint spray equipment is therefore not conducive to chemical purity. It is probably not feasible to develop non-steel paint equipment. However, one can be very thorough in keeping the equipment clean and free from corrosion (it has already been mentioned that potassium silicate is quite bad in this regard). Perhaps frequent replacement of needles and nozzles would be helpful.

Finally, we remark that a very clean air supply is required for best results. We used a triple filtered supply that was designed to eliminate oil from coming through the lines. It is possible that this system is not good enough for our purposes and that the use of pure bottled nitrogen would result in improved reflectivity.

It should be pointed out that for some applications it is not crucial to achieve extremely low absorptivities. This is the case for scintillators where energy loss fluctuations generally dominate photoelectron fluctuations. In such instances the reflectivity we report here (97.3%) should be quite adequate. However, when one is using a high precision Cherenkov counter for very accurate velocity determination it is usually the case that spatial non-uniformities and photoelectron statistics determine the resolution of the counter. For these applications it is essential to collect as much light as possible. By cutting the absorptivity in half, one doubles the light collection. Hence it would be worthwhile to atttempt to improve the performance of the paint by the means indicated above.

We are very much indebted to A. Paul, the Lawrence Berkeley Laboratory painter, for his patience and assistance. He very generously allowed us to use the LBL facilities for a period of several months during which time we developed the technique described here, and painted nine boxes. We also would like to express our appreciation to Prof. P. Buford Price for his support and encouragement, without which this work would not have been possible. This work was supported by NASA Grant NGR 05-003-376.

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