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Area and extraction field analysis of the analogue saturation of 40 mm microchannel plate photomultiplier tubes

J. S. Milnes,[1,a)] T. M. Conneely,[1] C. J. Horsfield,[2] and J. Lapington[3]
[1]*Photek Ltd., 26 Castleham Road, St Leonards on Sea, East Sussex TN38 9NS, United Kingdom*
[2]*AWE Aldermaston, Reading, Berkshire RG7 4PR, United Kingdom*
[3]*University of Leicester, University Road, Leicester LE1 7RH, United Kingdom*

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Microchannel plate (MCP) photomultiplier tubes (PMTs) are a well-established instrument for the inertial confinement fusion (ICF) community, with several detectors installed at NIF, Omega (LLE Rochester), and Orion (AWE). The analog signals produced at these major ICF facilities cover many orders of magnitude and often need multiple detectors operating at different levels of electron gain. As such, understanding the upper saturation limit of MCP-PMTs to large, low rate signals takes on a high importance. A previous study looked at the saturation limit of double and single MCP-PMTs over their full working area with pulse widths between 4 ns and 100 ns. This follow-on analysis will look at the effect of how the illuminated area affects the saturation limit and at the impact of the MCP to anode extraction field on the impulse response and the level of saturation. *Published by AIP Publishing.* https://doi.org/10.1063/1.5036635

I. INTRODUCTION

Microchannel plate (MCP) photomultiplier tubes (PMTs) are a well-established instrument for the inertial confinement fusion (ICF) community, with the market being served by Photek,[1] Hamamatsu,[2] and Photonis[3] and several detectors installed at NIF, Omega (LLE Rochester), and Orion (AWE). Recent measurements of MCP-PMTs have shown the shortest response time recorded by devices of this type with a 10 mm single MCP PMT having a FWHM of ~85 ps,[4] and significant improvements have been made to their gating ability.[5] The two main diagnostics where these detectors are used are gamma detection[6] (in combination with a Cherenkov radiator) and neutron time of flight[7] (in combination with a scintillator). Both of these diagnostics produce multi-photon pulsed signals that cover many orders of magnitude and often need multiple detectors operating at different levels of electron gain. As such, understanding the upper saturation limit of MCP-PMTs takes on a high importance as it is key to know the limitations of the whole diagnostic.

We previously measured the pulsed saturation curves of a single and a double 10 mm Photek MCP-PMT over their respective working gain ranges and over a range of pulse widths between 4 ns and 100 ns.[8] This study showed that the total saturation level of ~1.2 nC (1.5 nC/cm^2 for a 10 mm diameter) depends only on the integrated charge of the pulse and is independent of pulse width and gain over this range. The level of charge available in deep saturation was proportional to the operating gain; however, this did not extend the linear region of either device. Here we analyze the effect of the illumination area on the saturation curves in a larger 40 mm diameter single MCP-PMT (Photek PMT140) over the range of 30 ns–100 ns. We also look at the impact of the MCP to anode extraction field on the saturation of a 40 mm double MCP-PMT (PMT240) and on the impulse response of a PMT140.

II. EXPERIMENT

We reproduced the setup from the previous study[7] where the input optical pulse was monitored at each setting by a separate photodetector known to be linear over this range, as shown on Fig. 1. In this case, we had to add extra diffusion to ensure a flat field over the larger area, and from the subsequent loss of light, we no longer needed the set of ND filters. The photodiode was a 10 mm diameter Photek PD010 whose linearity was confirmed by measuring the integrated pulse output up to the maximum value used at the limits of the pulse width and then making the same measurement but with 10% of the light simply by adding an ND of 1.0. Graphing the 10% range against the 100% range at both pulse widths produced good linear relationships.

At each data point, the oscilloscope averaged the signal for 100 times to remove the natural signal variation caused by the limited number of photons per pulse and then integrated the pulses to produce a charge value: Each data point thus consisted of the integrated charge of the signal pulse from the photodiode and the same from the PMT being analyzed. The pulse width and amplitude of the laser diode pulses were controlled by a software script that also read out the charge values from the oscilloscope.

For all the saturation curves shown in this study, the integrated charge from the photodiode reference pulse used on the x-axis is purely arbitrary as it only represents a fixed ratio of

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a)Author to whom correspondence should be addressed: james.milnes@photek.co.uk

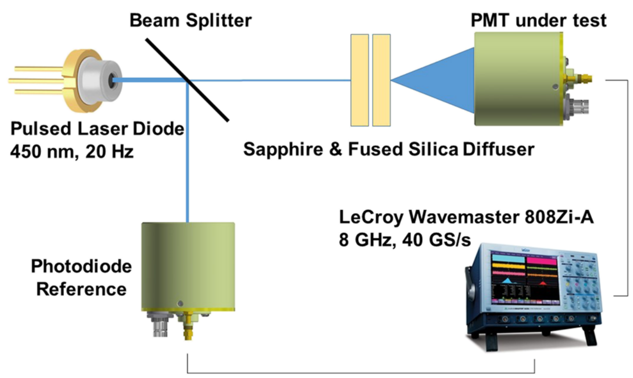

FIG. 1. Experimental layout for the PMT saturation study.

the light arriving at the photodiode and PMT, respectively. The x-axis only serves to have a linear reference to compare to, and the key parameter to take from each graph is the shape of the curve and the amount of charge produced by the PMT where the curve begins to show a non-linear relationship.

III. AREA ILLUMINATION

The study looked at four different areas of a 40 mm diameter single MCP-PMT; the full 40 mm diameter, a nominal 25 mm and 13 mm inner diameter, both located centrally, and finally an inverse 25 mm mask where the central area is blocked, while an annular region between an inner 25 mm diameter and the outer 40 mm perimeter is exposed; see Fig. 2.

To confirm that the PMT active area was receiving a flat field illumination, and to accurately measure the various mask sizes, we began by substituting the MCP-PMT with a Photek 40 mm image intensifier (MCP140). This device has the same size and shape of a fused silica input window as the MCP-PMT, so it would show any issue with illumination uniformity as well as any reflections within the window. Each mask design was applied to the MCP140 which was then illuminated using the same experimental set, as shown in Fig. 1, and images were captured using a CMOS camera observing the output phosphor screen. The resulting line profiles from the taken images confirm the flat field and are shown in Fig. 3. The resulting accurate mask area measurements were used in all calculations rather than their nominal values and are shown in Fig. 2. The full area was assumed to be 40 mm diameter, and all other masks were scaled to this value.

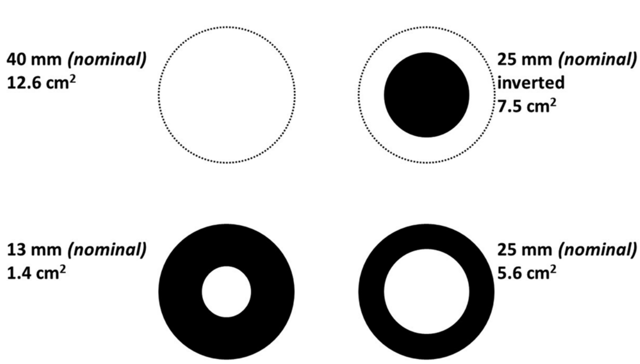

FIG. 2. Mask sizes with nominal diameters and accurate area measurements.

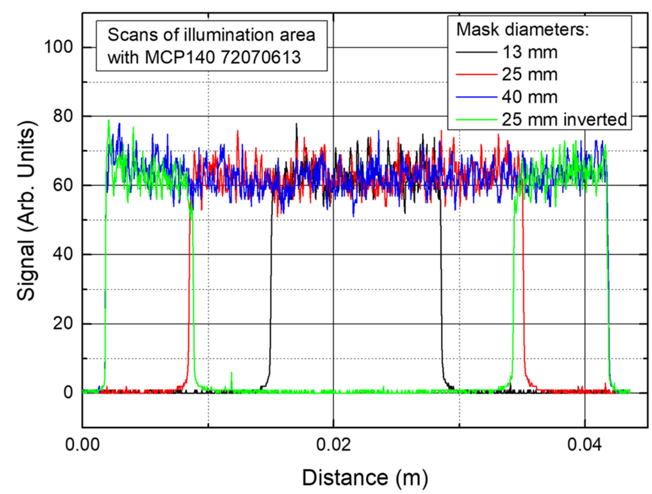

FIG. 3. Line profile scans of the masks used in the area saturation study which confirms the flat field illumination.

IV. AREA SATURATION STUDY

Each masked zone had the saturation curve measured over a pulse width range from 30 ns to 100 ns at a fixed gain of 2350. We restricted ourselves to a limited pulse width range and a fixed gain as their saturation relationships had been previously established.[7] As expected, the saturation was independent of pulse width and an example is shown in Fig. 4 for the 25 mm mask size.

To analyze the effect of illumination area, each zone has its area factored into the result by dividing by the area to give a saturation level in nC/cm^2. As we have established the independence of the pulse width, we combined the data from all the widths to show the full saturation curves and the results are shown in Fig. 5. In the linear region (up to 1.5 nC/cm^2, as established by the previous study[7]), all four curves appear to be within the measurement error, so we can conclude that the PMT saturates linearly with area.

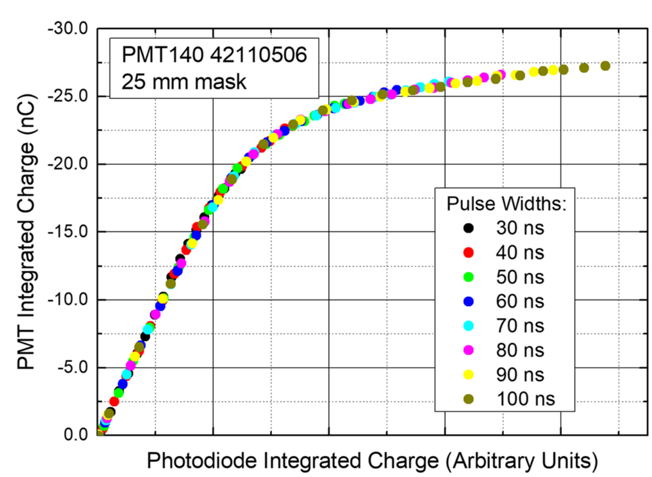

FIG. 4. Typical saturation curves at a range of optical pulse widths for a PMT140 with the 25 mm mask.

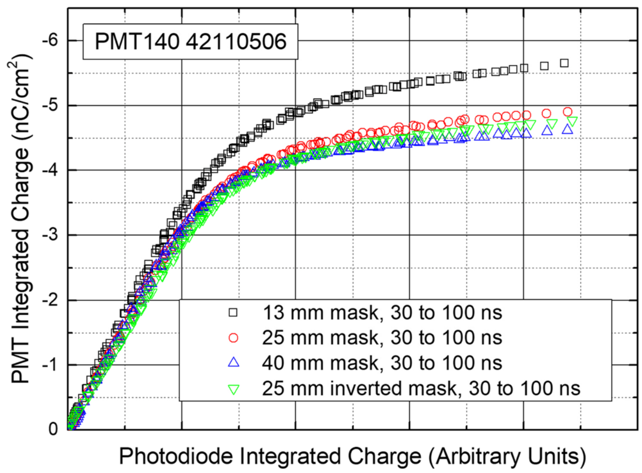

FIG. 5. Saturation curves for a range of mask sizes and pulse widths on a PMT140, now measured as C/cm^2.

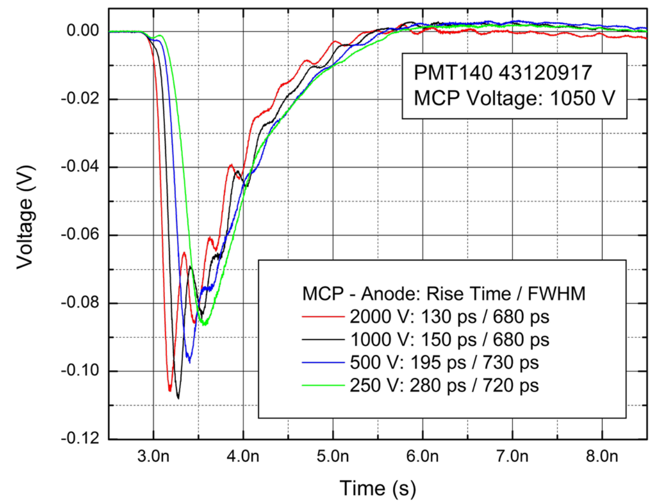

FIG. 6. The impact of the MCP to anode extraction field on the impulse response pulse shape of a PMT140.

Once the PMT reaches deep saturation, the smallest (13 mm) inner mask area shows the highest settling output in deep saturation once the area has been accounted for. One possible explanation for this is the extra stored charge from the unused outer portion of the MCP. In the previous study,[7] we attributed the higher settling level in deep saturation of the higher gain settings to the extra charge stored within the MCP capacitance due to the extra voltage being applied, and this could be a similar effect; the active inner part of the MCP is able to "borrow" charge from the large unused area of MCP around it. While previous studies have dismissed the idea of charge transfer between pores due to the low conductivity of the MCP glass,[9] we speculate that this effect is rather the temporal acquisition of stored charge in the capacitance of the unused MCP area which is formed by the front and rear conducting electrodes. The effect is repeated in the other two masks that did not use the full area, and the amount of deep saturation boost seems to depend (albeit not linearly) on the amount of unused area that the active MCP is able to borrow from. We can conclude that this effect is not simply due to non-uniformity of the active area, if that was the case then the average of the 25 mm and 25 mm (inverted) masks would combine to produce the same data as the 40 mm result, but Fig. 5 shows that the deep saturation level of the 40 mm mask is lower than both. We must therefore conclude that the deep saturation level of any part of the active area is influenced by how the neighbouring area is being used, but regardless of this effect it is not observable in the linear region and would therefore not have an impact on "useful" data.

V. EXTRACTION FIELD STUDY

MCP-PMTs are usually operated by applying a single high voltage, and the internal tube voltages are distributed by an internal resistor network which also contains the gating circuit. The gain of an MCP-PMT is defined by the voltage across the MCP, so if the gain is adjusted by altering the input high voltage, it will also change the MCP to anode extraction field. By request, some PMT models can have the extraction field fixed by Zener diodes to maintain the pulse shape as it is known that reducing the extraction field will broaden the impulse response, albeit in a non-linear fashion; the extraction field must drop considerably before any change is noticed in the response. This is illustrated in Fig. 6 which shows the effect of reducing the extraction field voltage on the impulse response of a different PMT140 and also shows how reducing the field can remove the trailing edge ringing inherent in large area anodes at the expense of leading edge speed.

This analysis sets out to see if this extraction field has any impact on the saturation. We took a double-MCP 40 mm PMT (PMT240) and operated at 3100 gain. A flat field, square, 500 ns input pulse is injected into the PMT, and the amplitude is increased until obvious saturation is observed by the droop toward the end of pulse, as shown in Fig. 7. We varied the extraction field from 2980 V down to 260 V, and only a very small difference was observed, which is better illustrated in the zoomed-in section shown in Fig. 8. As the effect is very minor, it is unlikely to be of interest to a real-world

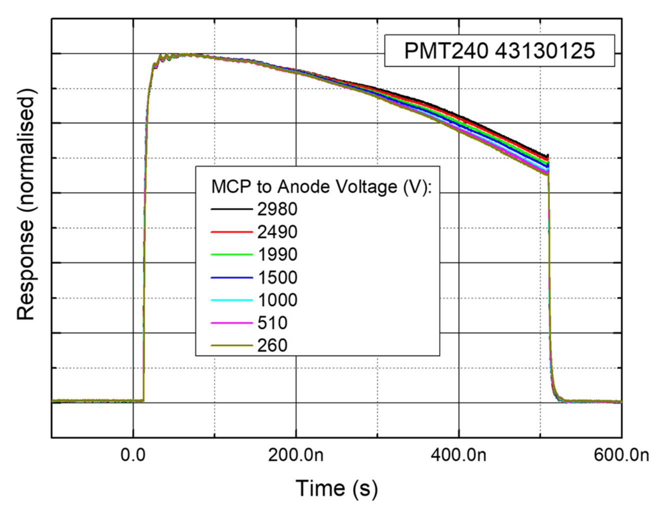

FIG. 7. A PMT240 showing a saturated response for a variety of MCP to anode extraction fields.

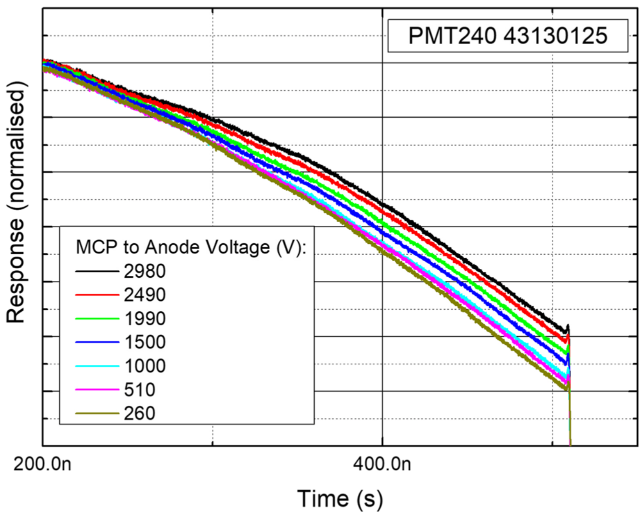

FIG. 8. Zoomed-in section of Fig. 6 showing the relationship between the saturation and the MCP to anode extraction field.

application, and it is too subtle to have been detected by the saturation curve method used in the area study shown earlier. However, it is interesting to note that unlike the pulse shape dependence on extraction field shown in Fig. 6, this minor saturation effect does seem to be approximately linear with the field.

VI. CONCLUSION

We have shown that the analog saturation effect of MCP-PMTs scales linearly with area, but that in deep saturation there is a minor boost in the signal available to parts of the active area if neighboring sections are unused. We have also shown that reducing the MCP to anode extraction field will slow and smooth the impulse response but will only have a very minor impact on the nature of a saturated pulse.

[1] See http://www.photek.co.uk/products/photomultipliers.html for an introduction to the Photek family of MCP-based PMTs.
[2] See https://www.hamamatsu.com/eu/en/product/type/R3809U-50/index.html for the product page for the Hamamatsu MCP-PMT detailing performance characteristics.
[3] See https://www.photonis.com/en/product/mcp-pmt for the product page for the Photonis MCP-PMT detailing performance characteristics.
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