Ageing of Vacuum Phototriodes under intense illumination.

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The Measurements

In order to investigate possible ageing effects, tubes have been operated with a high photocathode current for an extended period, both in the absence of a magnetic field and in an axial field of 1.8 T. Three devices have been tested, two from Electron Tubes (D821/1000UVB: ET #25, ET #27), and one from Hamamatsu (XA0553). These are all 1″ diameter devices with faceplates of UV glass. The tubes were operated (as they will be in CMS) with the photocathode at ground potential, to avoid the possibility of photocathode damage arising from leakage currents flowing in the glass faceplate. The tube envelopes were covered with a conductive envelope maintained at photocathode potential. The bias potentials were: V_D = +600 V, V_A = +800 V.

The standing current in the tube was generated by illuminating the photocathode with an LED (5 mm 'Ultrabright', λ_{Peak} = 470 nm), excited by a steady current. The illumination was increased as the response of the photocathode deteriorated, in order to maintain the photocathode current, I_k, at 1 μA. The response of the tube was monitored concurrently with the dc illumination, using a pulsed LED of the same type. Both LEDs were arranged to give uniform illumination of the photocathode. The data were recorded with a digital oscilloscope. The temperature within the magnet gap was monitored with a platinum resistance thermometer.

The results

Figure 1 shows the relative anode response of the tubes as a function of time over a period of 9 days. In the case of the Hamamatsu tube, the first exposure to the dc LED was made at 1.8 T. A rapid decrease in response is evident during the first few hours, stabilising at 80% of the initial value, with little change over the subsequent three days. After 4.5 days, the magnetic field was reduced to zero and the illumination was continued. A second sharp fall in response, by a further 11% of the original value, is observed. Note that the measurements at 0 T have been renormalised so that the first point at this setting matches the last measurement at 1.8 T. Finally, the magnetic field was returned to 1.8 T and operation at I_k = 1 μA continued for a further day. The points are plotted with the same normalisation as the first set of data at 1.8 T. The overall decrease in response after 8 days is 31%.

The high current ageing of ET #25 was also started at a field of 1.8T, followed by exposure at zero field, with a final run at 1.8 T. The effect on the tube is similar to that observed with the Hamamatsu device, although the overall degradation is somewhat larger, amounting to 40%. In the case of ET #27 the exposure was first made at zero field. A much bigger initial decrease in response is observed in this case. The tube was then operated for a day with both the dc LED and the magnet turned off, inducing a slight recovery. The 1.8 T magnetic field was then turned on for the first time causing a further gradual decline in the response. After 8 days, the overall degradation is also 40%.

The zero field exposure lasted for one day for ET #27 and two days for ET #25 and XA0553. There is some suggestion that the anode response is continuing to fall at the end of the exposure in all cases.

In addition to the behaviour discussed above, an instantaneous decrease in the signal from the pulsed LED was observed when the dc LED was first turned on. In the case of the Hamamatsu device, the effect was only 1%, but for ET#25 and ET#27, the falls were 10% and 7% respectively. These instantaneous changes are not included in the figures. As discussed below, they may be a spurious consequence of running at a very high photocurrent.

Figure 2 shows the dc gain, measured as the ratio of the anode and cathode standing currents. For XA0553, the gain **rises** by about 6% during initial operation at 1.8 T, before stabilising at a value of 7.0. In the subsequent run at zero field it remains constant with a value close to 9.0. For ET#25, the gain **falls** by about 15% at first, stabilising at 4.2 at 1.8 T. During the run at zero magnetic field, it falls by 5% to 6.7. In the final run at 1.8 T, the gain remains constant at a value of 4.0.

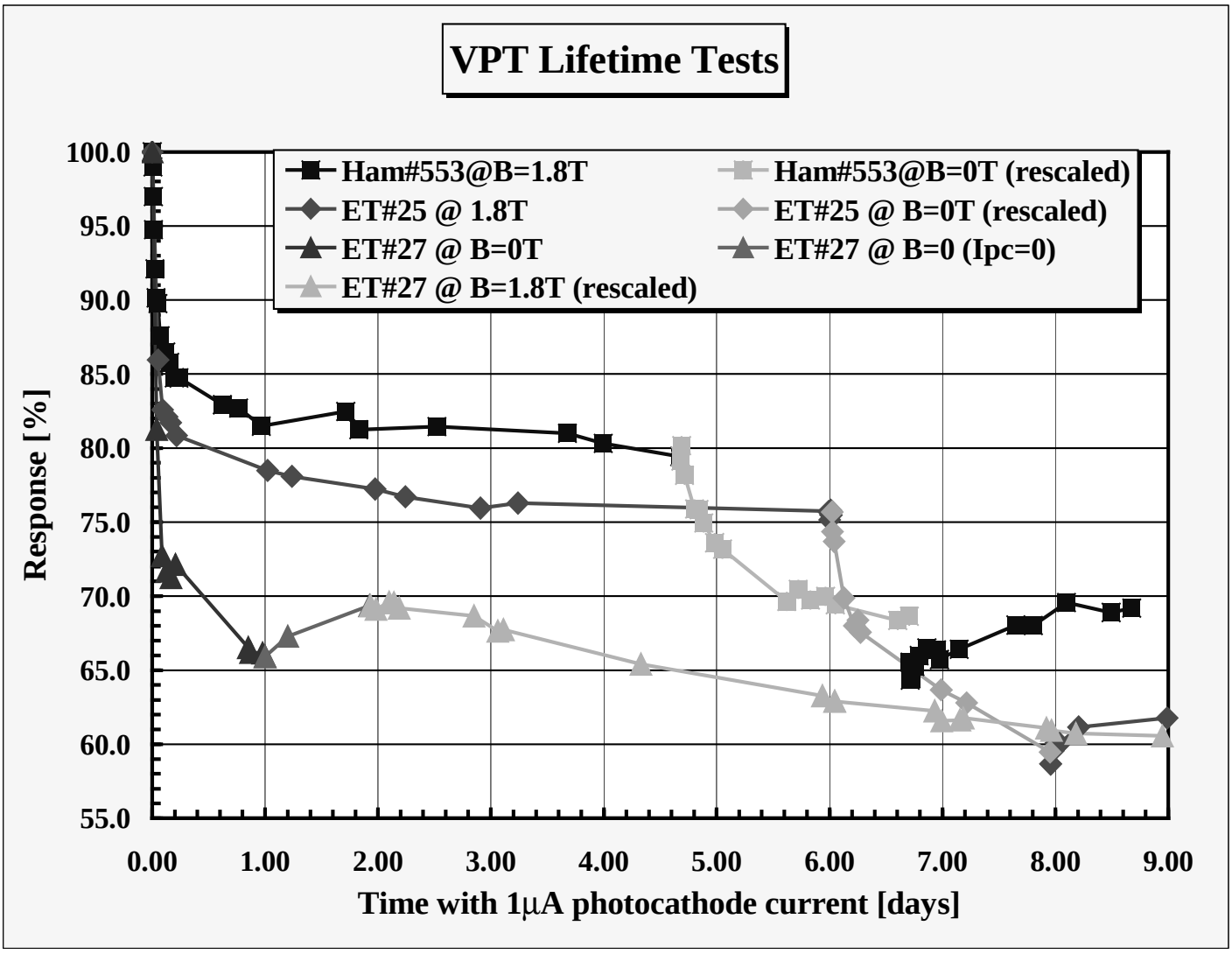

Figure 1 Anode response as a function of time. The points are normalised to a value of 100 for the first measurement at I_k = 1 μA. The relative normalisation of field-on and field-off data is explained in the text.

Discussion

For the three tubes tested, operation at high cathode current causes an initial rapid decrease in the anode response, followed by relatively stable operation at the lower value. For the Hamamatsu tube, the degradation appears to be dominated by a loss in photocathode efficiency, indeed there is some evidence that the effective gain **increases**, although this might be an artefact caused by non-uniform damage of the photocathode. In the case of ET#25, there is a loss in gain which is sufficient to account for more than half of the decrease in overall response.

On the basis of this rather restricted evidence, it appears that the presence of a magnetic field limits the damage caused by operation at high current, either in terms of the region of the photocathode affected, or the intensity of the damage within a given region. High current operation at zero magnetic field causes additional damage, the effect of which persists when the magnetic field is (re-)established

A more detailed interpretation of the results in figure 1 is limited by uncertainties associated with variations in temperature during the course of the measurements, which may have caused the output of the pulsed LED to change. The effect is particularly noticeable when the magnetic field is re-

established following a zero field measurement. Changes of up to 3^{O}C have been observed as the magnet warms up, which might explain, at least in part, the apparent recovery of ET#25 and XA0553 during operation under strong illumination at 1.8 T, following exposure at zero field. This point will be investigated further.

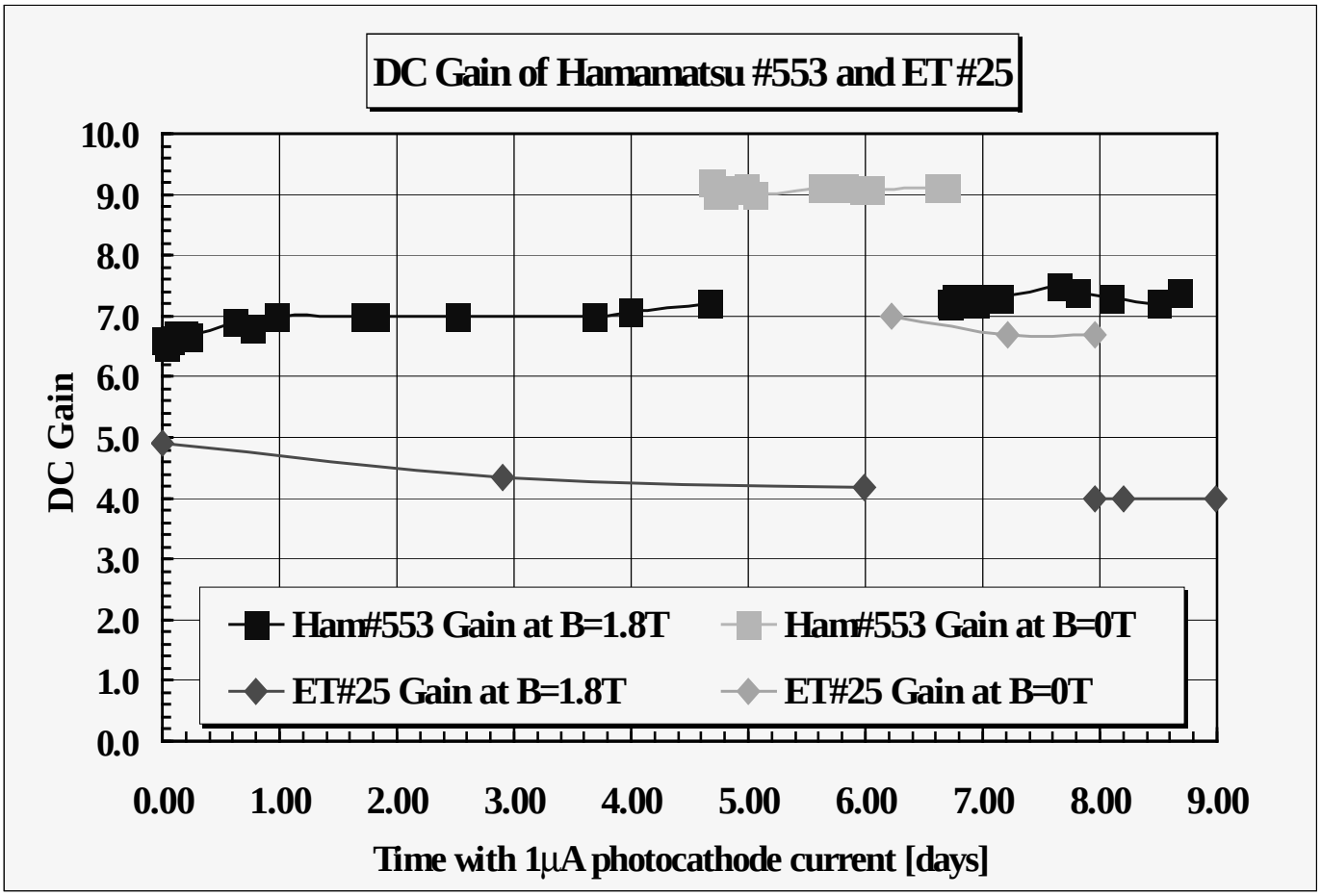

Figure 2 Effective gain, defined as the ratio of the anode current to the cathode current, as a function of time.

The value of 1 μA was chosen for the photocathode standing current so that the effect of one year of high luminosity running at LHC, for a detector in the middle of the Endcap, could be reproduced in a day. However, bialkali photocathodes are very resistive at room temperature and a photocurrent of 1 μA might generate a sufficient potential gradient across the photocathode to distort the electric field between the electrodes of the tube and modify the response. Both the RCA and Philips catalogues indicate that the surface resistivity ($R_{\square}$) of a SbKCs photocathode is close to 10^{10} Ω at 20^{O} C. (The ET catalogue does not give a value, but the recommended maximum photocathode current for a 2″ photomultiplier tube is 2.5 nA, to be compared with 10 nA recommended by Philips, indicating a similar or even higher photocathode resistivity.) At a low photocathode current, I_k, the voltage drop between the circumference and the centre of the photocathode, under uniform illumination, is:

$$\Delta V = I_k R_{\square}/4\pi$$

For I_k = 1 μA and $R_{\square} = 10^{10}$ Ω, then ΔV = 800 V, thus the 'low current' condition does not apply, and the operation of the tube should be strongly modified.

However, for the Hamamatsu device, the fact that the anode response, measured with the pulsed LED, falls by only 1% during the first two minutes after the 1 μA standing current is introduced, indicates

that the above effect is not important. Furthermore, figure 3 shows that the anode and dynode currents vary linearly with the cathode current over a wide range, demonstrating that the gain remains constant and indicating that the electric field is not suffering a significant distortion up to I_k = 1μA.

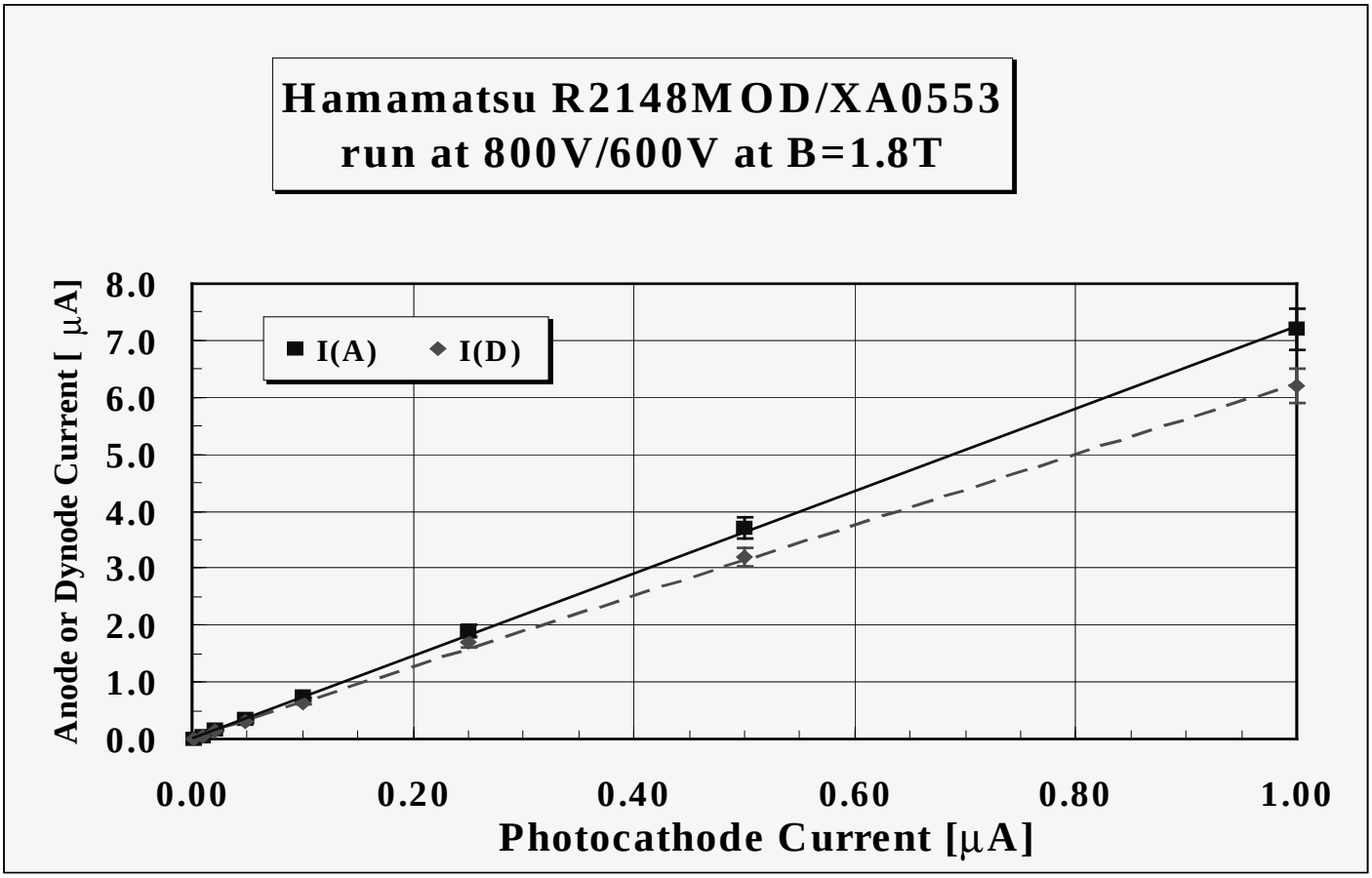

Figure 3 Anode current and dynode current as a function of cathode current for XA0553. The relationships are linear, indicating that the gain is constant.

In the case of the ET tubes, the fall in anode response by of order 10% as soon as the strong illumination is started, suggests that photocathode resistance may be causing some effect. In view of this, and since accelerating the ageing studies by using very high photocurrents may in any case not give a true indication of the behaviour to be expected at LHC, further investigations will be made by running for longer periods at lower currents.

Conclusions

- All three tubes show significant damage under high current operation.
- In a field of 1.8 T, the loss in response saturates at 20% for Hamamatsu XA0553 and at 24% for ET#25. Losses at these levels, over 10 years of LHC operation, would probably be acceptable, although it should be noted that most of the degradation occurs early on.
- If a tube is operated at high current in zero magnetic field, a further loss in response of up to 15% occurs. Operation of the final detector under these conditions must therefore be avoided.
- The damage caused by high current operation at 1.8 T is less than that produced in the absence of a magnetic field, strongly indicating that there is no catastrophic ‘Penning’ effect.
- Further studies should be made in which the tube delivers a similar total charge at much lower current.