Time Integrated Phosphor Behavior in Gated Image Intensifier Tubes

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ABSTRACT

New flow analysis applications of MCP image intensifier tubes require faster image repetition rates. When coupled to CCD readout chips their time-integrated behavior determines the overall system's response concerning the intensity of unwanted

Previously published experimental data as well as manufacturer's literature provide only time resolved response information. New data for the widely used high-efficiency, slow-decay P20 and P43 phosphors are determined as functions of both exposure (excitation) time and interframe time.

Previously reported dependency of decay time being determined solely by the preceding exposure time is not supported by new data. Data herein show an increase of decay time by more than a factor of 100, especially for short excitation times. This is caused by intensity integration on the CCD chip. The P20 shows a very long non-exponential decay. Though being faster during the initial 200 to 500 µs, the P20's decay extends over a substantially longer time as compared to the P43 phosphor. This is in clear contradiction to earlier results, which could lead to the expectation of the P20 being more than an order of magnitude faster than P43 for very short exposure times.

Keywords: image intensifier, phosphor decay, flow analysis, P20 phosphor, P43 phosphor

1. INTRODUCTION

Intensified CCD cameras are now featuring more flexible timing modes with numerous new uses arising. One feature of special interest is the ability to provide high repetition rate (i.e. > 50/60 Hz) double exposures. This is particularly true for applications like Particle Imaging Velocimetry (PIV), Molecular Tagging Velocimetry (MTV), and Fluorescence Analysis. They require repetition rates even down to the submicroseconds time scale. For such methods the time behavior of the image intensifier's output phosphor is of critical importance. Lack of reliable data on the time behavior triggered the work described in this paper.

Presently, there are mainly two classes of phosphors in use. The first class is represented by the somewhat higher efficiency P20 and P43 phosphors, which have the disadvantage of a long decay time. The P46 and P47 phosphors are widely-used members of the second class, that is the "fast" or "very fast" phosphors. This class of phosphors lacks a factor of 2 to 3 in output brightness for the same level of electronic excitation. This paper deals with the experimental setup and the results for the slow phosphors.

2. EXPERIMENTAL SETUP

All measurements were performed with our 4 Quik E camera and real time video spectroscopy package 4 Spec. The camera is a system that has all timing and power supply units for control of the intensifier included. The internal lens coupling of the intensifier to the CCD allows for a fast exchange of the intensifiers, keeping all other components identical. The camera's internal timing generator is flexible enough to perform all measurements without the need of an external timing control unit.

The P20 data were obtained with two intensifiers from Proxitronic. For the P43 measurements one intensifier was manufactured by Proxitronic, the other one came from DEP. A yellow super bright LED provided constant illumination. It was focused directly onto the camera's photocathode for a spot size of one-half the diameter of the intensifier. With this setup very short photocathode gate times could be used, thus having a quasi-instantaneous excitation of the phosphor under investigation. This setup has the advantage of replicating a very typical application case of such cameras. A schematic diagram of the experimental setup is shown in Figure 1.

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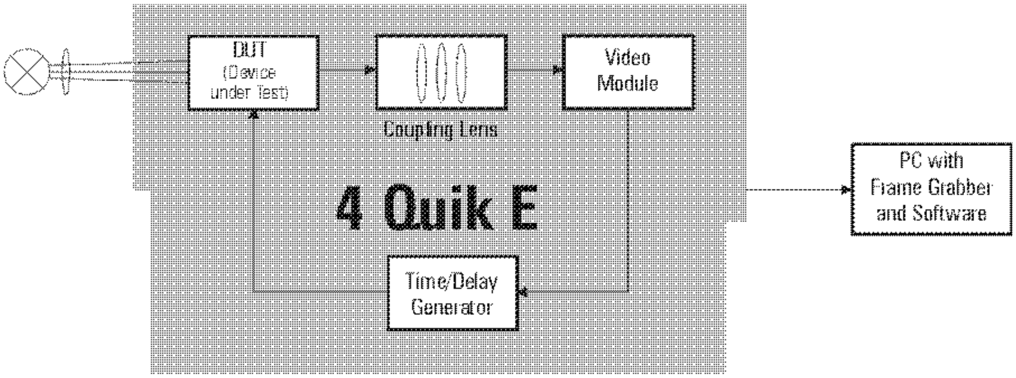

Figure 1: Experimental Setup

For readout of the phosphor intensity, a video unit with an interline transfer CCD chip is integrated. This type of CCD architecture uses optically sensitive columns to accumulate electrons induced by light during an integration period that is determined by the time in between consecutive readout pulses. In less than 100 ns this resulting charge is shifted from the open integration section to the opaque readout transfer registers. To determine the total brightness of unwanted ghost images the camera's exposure and frame grabber's digitizing were synchronized in such way that an increasing time was inserted in between turn-on of the photocathode and the chip readout.

The camera is set up and programmed to operate fully synchronous with the video cycle. The gate timing is thus firmly integrated into the video timing sequence. The internal time/delay generator is programmed for a delay/exposure sequence that results in a 120 ms time in between two consecutive phosphor excitations. After this time there is no residual intensity left from the previous event. The frame grabber is always triggered in the 5th field of the sequence, thus digitizing only the field images transferred with the 6th and 7th/1st readout pulse.

As long as the excitation pulse (EP) occurs fully after the 5th readout pulse (RP), all light is integrated during the 1st field. With the EP taking place immediately before the 5th RP, we get only decayed intensity into the field that is transferred with the 6th RP.

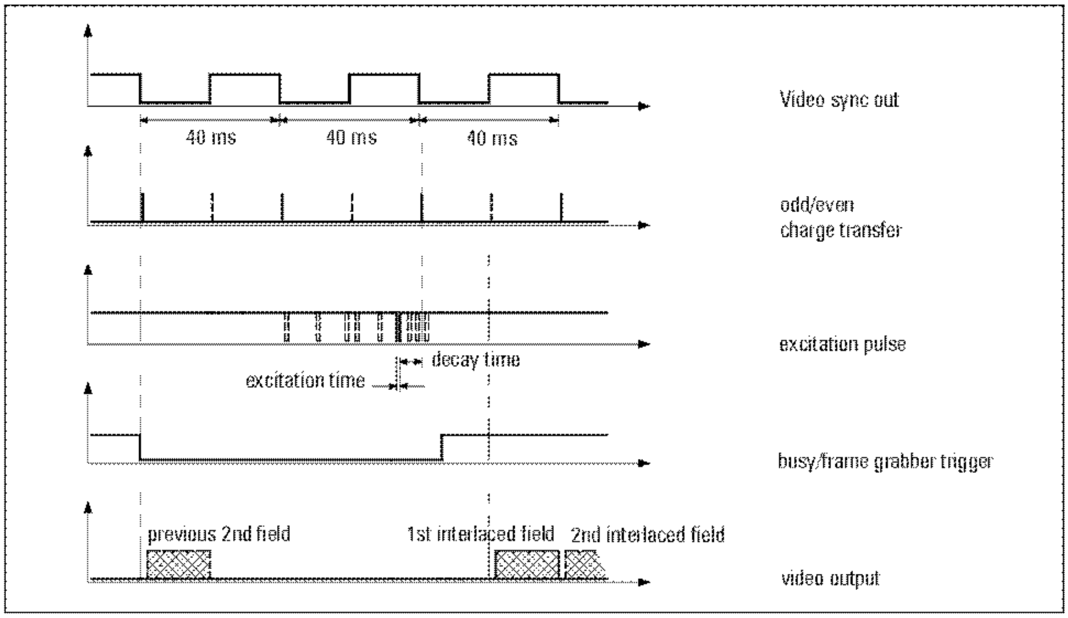

Figure 2: Timing diagram

Continuously shifting the excitation pulse to earlier times results in the integrated decay time behavior of the phosphor under test (DUT). This video signal is then digitized and is summed in real time into one exposure for 100 video frames. A spot of 10 lines in height by 50 pixels width is then binned into one relative intensity value for a given delay time. With this method one gets the sum of 50,000 single measurements for any single data point. This results in a S/N improvement of roughly a factor of 200.

In order to have a longer integration time available (40 ms) we used a CCIR video camera instead of the EIA with its 33.3 ms interframe time. The charge readout occurs every 20 ms, alternately on all odd and all even lines of the video image. This results in a total of 40 ms integration time for the subsequent odd and even fields. All light falling onto the chip during that 40 ms is integrated. In this way we measure the time integrated intensity of the phosphor screen. It is the actual output of all such cameras and also the cause of the so called “ghost images”. These ghost images are “missing” in the intensity of the digitized output of the “original image”. The output image is lowered by the same amount if the integration time is too short. The literature of the intensifier’s manufacturers gives the output intensity as an instantaneous function of time. This results from the intensity being measured with a PIN diode or photomultiplier. This is much harder to interpret for a long decay time on low magnitude. It also has a higher noise due to the short integration time of these sensors. It finally results in seemingly too-fast decay times.

3. DISCUSSION OF RESULTS

1. 3.1. P43 Phosphor

The P43 phosphors under test were fairly consistent with the typically reported 90% - 10% decay times of around 1 ms. They were identical for all exposure times and even the same for two samples from two different manufacturers. Figure 3 shows their behavior down to the 0.1% range. In this semilog scale there are two straight lines through the full range of this decay time. P43 phosphor consists of only one material that shows a “power law” characteristic as reported[1] earlier. The decay is determined by two time constants. The fast one dominates the process down to 0.2% within the first 5 ms. Only after that time a slower decay takes over at a very low level. This should not cause measurable influence in most applications.

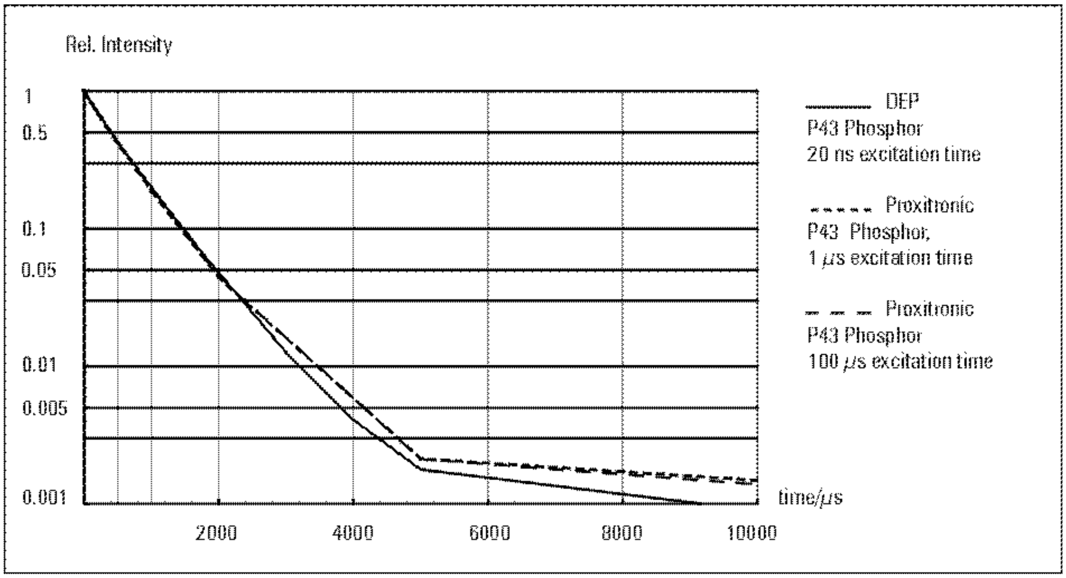

Figure 3: P43 Phosphor decay of two intensifiers after various excitation times

The two decay time constants are totally independent of exposure time and signal amplitude. The ghost image of the first exposure is at 10% if the second exposure is taken 1.5 ms after the first one. After 3.2 ms the remaining ghost is only 1%. This is in good correspondence with the 3 ms given by Bosch[2]. With this decay time information available, the ghost image can be subtracted from the second exposure. Therefore even intra-exposure delay times shorter than 1 ms can be used. If ~32% of the correct values of the first image would be visible in the second image. The intensities of the first one could be corrected to their true values which are obviously a factor of 1.47 (= 1/[1 – 0.32]) higher than the digitized results. The ghost image, which is a factor of 0.47 (= 0.32/[1 – 0.32]) times the first digitized image; can be subtracted from the second one. All above calculations must be applied to every single pixel of the images. This functionality is already included into the 4 Spec software package.

2. 3.2. P20 Phosphor

Our P20 phosphor results do not conform to the simple relationships that might be derived from earlier publications[1,3,4]. Fixed times of 4 ms are reported from Proxitronic for the 90% to 10% decay[3] without any information about excitation time. Other measurements seem to indicate a decay time that is a function of excitation (exposure) time[1]. Both the Flynt[1] and DEP[4] data seem to indicate a decay to 1% in the order of 150 to 200 µs for 1 µs excitation time. Flynt[1] has normalized his decay curves to the beginning of the decay, i.e. the end of the excitation pulse. This may seem reasonable for direct human vision onto the tube, but for integrated instrumental (CCD) view it leads to wrong expectations.

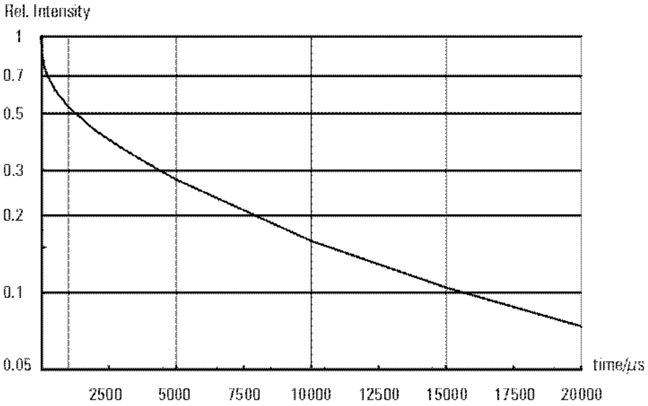

Figure 4: P20 phosphor decay after 100 ns excitation time.

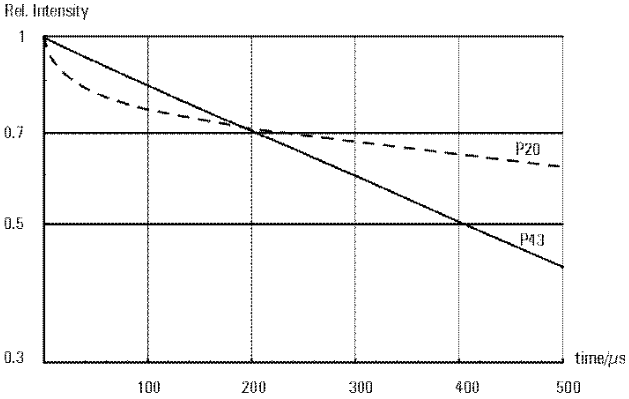

Figure 5: Initial 500 µs of P20 Phosphor decay after 100 ns and P43 Phosphor decay after 20 ns excitation time.

Figure 4 shows the P20 phosphor decay time for a 100 ns exposure time on one intensifier tube of Proxitronic from a new 1999 production. It is faster than the P43 phosphor for the first 200 µs while falling to a 70% level. See Figure 5.

The 10% level is reached only after 15 ms though. For a standard CCIR video (50 Hz repetition rate) the ghost image is 7% after 20 ms. This P20 phosphor displays extremely poor decay characteristics especially for short exposure times. The decay of the P20 phosphor cannot be approximated by any set of straight lines. It is not determined by a “power law” process of a single homogenous material.

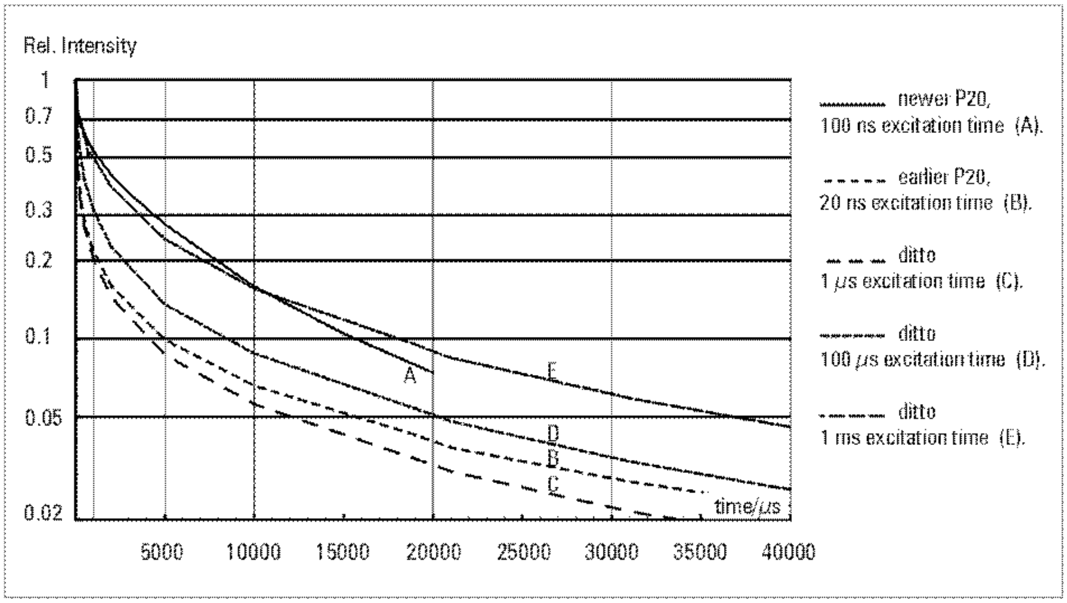

Figure 6: P20 Phosphor decay of two intensifiers for various excitation times.

Figure 6 shows decay times of the older tube for different excitation times. The newer tube is shown for comparison. One can find a decay time that is decreasing for excitation times decreasing from 1 ms to 1 µs. However, at the fastest excitation, the decay time is increasing slightly though. The newer tube shows a much longer decay at short times. There have been no data taken for longer excitation times. The P20 phosphor is made mainly from a mixture of ZnS and CdS. The toxic nature of the latter one may have led to a reduction of the CdS content in the newer tube. This in turn might also have an influence on the decay time. This issue has not been analyzed further, because it lies outside of the scope of this paper.

In order to reach the same total output energy as e.g. for a 100 µs exposure time, the 10 ns flux must be 10,000 times higher. This seems to excite non radiative intermediate electronic states in the phosphor. They are depopulated (discharged) then only very slowly via the radiative states into the ground state. For low fluxes the non-radiative states are not populated.

3. 3.3. Variation of Normalization

Figure 7 shows the decay of the P20 and the P43 phosphors normalized to the total pulse intensity. The excitation pulse was shifted to start 50 µs after the 5th readout pulse. This assured that all intensity was integrated within the 1st field of the video output. The excitation takes place at the marked 50 µs to 150 µs time span. The newer tube's P20 data for a 100 ns excitation are compared to the P43 decay with 100 µs excitation, as well as the older P20's decay after 100 µs and 20 ns excitation.

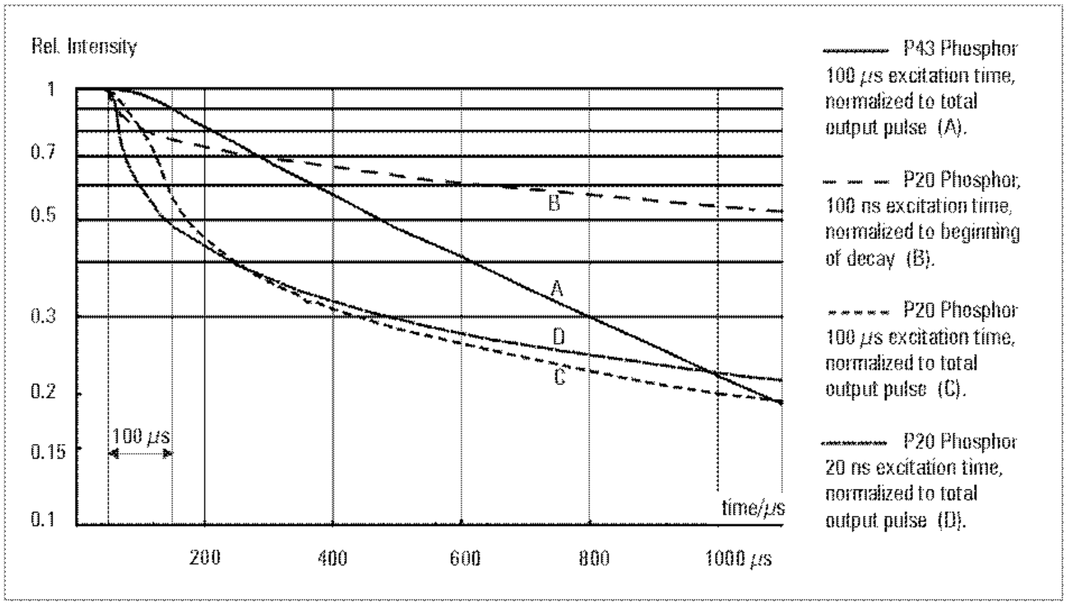

Figure 7: P20 and P43 Phosphor comparison, normalized to total output pulse intensity.

The 20 ns and 100 ns decay curves are unchanged due to the short excitation time. At 100 µs the P43 is 10% lower at the beginning of the decay as compared to the normalized full excitation pulse. The P20 is 45% lower under the same conditions. This may indicate that the P20 decay is not simply a function of exposure time as might be inferred from the data of Figure 6 alone and from earlier publications[1,4]. Instead, it seems to be mostly influenced by the phosphor's composition. Unfortunately, these data are usually not even known by the manufacturers of the intensifiers. The results of the two Proxitronic intensifiers with the P20 phosphor correspond very well with the data published by Bosch[2]. There he gives a 60 ms decay time to 1% for a P20 phosphor. The P20-AF phosphor is listed there as a subtype of P20 with a 220 ms decay to 1%. No dependence on the excitation time is mentioned in that paper, either.

4. CONCLUSION

With its very long decay time, the P20 phosphor is not a usable choice for double (multiple) exposure image series faster than 25 Hz (40 ms). It has a nominal brightness advantage over the P43 phosphor. But this 20% gain is typically of the same order of magnitude as the changes in photocathodes's sensitivity and microchannel plate gain variations. The P43 is well-suited for double frame experiments into the 500 Hz to 1000 Hz range. In typical flow analysis experiments this is satisfactory for liquid flows.

5. REFERENCES

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