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IMAGE INTENSIFIER CAMERA FOR STREAMER CHAMBER PHOTOGRAPHY

H. Gentsch, E. Gygi, M. Hanney and F. Schneider

G E N E V A

1974

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SUMMARY

A three-stage image intensifier camera is described which makes it possible to record on film tracks of an isotropic streamer chamber; the precision of reconstruction of a distorted image is given.

CONTENTS

	<u>Page</u>
1. INTRODUCTION	1
2. HARDWARE	1
3. SOFTWARE	2
4. CONCLUSION	4
Table of results	5
Figures	6

1. INTRODUCTION

If a streamer chamber is utilized such that the quality of the tracks is independent of their directions with respect to the electric field¹⁾, the light output is very weak. The individual plasma streaks will have an average length of 3 mm, radiating about 2×10^8 photons per streak. It is impossible to record such streaks directly onto a photographic film if the depth of field is 50 cm or more. Therefore, to obtain a reasonable density on a sensitive film it is necessary to have an amplification of 5×10^3 (this figure comes from a demagnification of 40, a depth of field of 60 cm, and a film sensitivity of 4×10^9 photons/cm²).

Magnetically focused tubes, electrostatic tubes, and proximity tubes with and without channel plate amplification are commercially available. The first kind requires high stability for electric and magnetic focusing fields (better than 10^{-3}) in order to guarantee an image point stability of 10 μ m. The last kind still suffers from imperfections such as lifetime and inhomogeneous amplification. The electrostatic tube does not need a very good stability for the electric field (less than 10^{-2}), and in addition there exists a version with a 38 mm $\varnothing$ screen which is relatively cheap. A camera constructed with such a tube is less cumbersome than one with a magnetic tube.

2. HARDWARE

The image intensifier (I.I.) is composed of three single electrostatic image intensifier diodes, RCA 8505/V1 and 8505/V2. The tubes have fibre optic face plates and they are glued together with an optical cement. Between the second and the third stage an additional 15 mm thick fibre plate is inserted in order to prevent electrical breakdown through the face plates during pulse operation. The position and the shape of an image on the output window is very sensitive to magnetic stray fields. For this reason the tube is shielded against fields of the order of several gauss by a μ -metal cylinder (a field of ≈ 0.1 G perpendicular to the optical axis gives rise to a displacement of an image point of ≈ 50 μ m). If the intensifier is installed in an environment where fields of several kilogauss are present, then provision must be made for additional shielding.

As can be seen from the sketch of Fig. 1, the I.I. can be operated in either a continuous or a pulsed mode, where the voltage per stage can be as high as 15 kV. The continuous mode is extremely useful for alignment purposes; whereas for the normal use (recording of faint and short events) the tube has to be pulsed for the following reason: a sensitive photographic film, applied directly onto the output window, will be darkened by the internal noise of the tube within one second. In order to keep the recorded noise level below the threshold of the film, the pulse time has to be ≤ 1 msec. The most appropriate pulsing method is the application of the pulse onto the cathode of the third stage. (In order to prevent a corona discharge, or even a breakdown between film and output window, the latter, which from the electrical point of view is the anode, has to be on ground. In addition, it is easier to produce a stable negative 15 kV pulse than a positive one.) Furthermore, triggering the last stage has the following advantage: the duration of the light flash, emitted by a streamer, is ≈ 100 nsec. Owing to the persistence of the phosphors, the build-up time for the maximum of the intensity on the output of the second stage is several μ sec

and the storage time of the image several 100 μsec . This means that without a measurable loss of light the last stage can be triggered with a delay of several μsec . One can even afford a time delay of $\approx 100 \mu\text{sec}$, which results in a loss of $\approx 30\%$ only. This time delay could be used for deciding whether or not it is interesting to record the image.

The circuit diagram of the 15 kV pulse generator can be seen from Fig. 2 and its realization in form of a plug-in unit from Fig. 3. The pulse as it appears at the cathode of the last stage of the I.I. is shown in Fig. 4a. The light intensity of a streamer on the output window of the I.I. for different delays of the gate pulse is represented in Fig. 4b.

The direct application of the film onto the output window saves one stage, as compared to a system which has lens coupling. This means better resolution and less distortion. During the exposure time, the film and the output window must be in close mutual contact, and during transport they should be separated from each other in order to prevent scratches on both the film and the fibre plate. The realization of the film application mechanism is shown on the sketch of Fig. 5. The linear movement of a pneumatic piston is transformed into a rotation of an axis with the help of a "two-lever articulation". This mechanism ensures the approach of a definite angular position of the axis with speed zero without having to adjust the excursion of the piston very precisely. The movement of the application plate, owing to its spring suspension, is such that during its action no displacement of the film can occur. A microswitch interlock prevents transport, whilst the film is pressed against the tube. For further details see Fig. 5.

A commercial electric film magazine from Beattie (Model CS48) is used for film transport.

The entire camera weighs 17 kg; it can be installed very easily and brought into operation within a few minutes. The executed model (Fig. 6) has been in operation for more than two years, and up to now has shown no fault. A cosmic-ray shower in a streamer chamber of $45 \times 20 \times 20 \text{ cm}^3$ taken with a demagnification of ≈ 30 is represented in Fig. 7.

3. SOFTWARE

The I.I. has a photon amplification of $\approx 2 \times 10^4$ in the centre and $\approx 7 \times 10^3$ on a peripheral circle with a diameter of 32 mm (for incident light in the range of 650 nm, for an output light in the range of the P20 phosphor, and for 15 kV/stage). A point-like object produces on the film an image whose diameter is $\approx 40 \mu\text{m}$ in the centre and about $65 \mu\text{m}$ on the periphery. A square picture of $25 \times 25 \text{ mm}^2$ on the entry photocathode has its image on the output window within an area of 32 mm in diameter.

If one images an object with an area $1 \times 1 \text{ m}^2$ with an objective having an aperture f/8 (for which a depth of field of 70 cm can be covered without serious loss of resolution), the fraction of solid angle subtended by the lens is 5×10^{-7} . Streamers of dimensions $4 \times 1 \text{ mm}^2$ (side view), each radiating $\approx 3 \times 10^8$ photons, give, under these conditions, a photon density on the output of the I.I. of about 3×10^{10} for the centre and $\approx 7 \times 10^9$ photons/cm² for the periphery. With a sensitive film, such as Kodak 2484, one obtains a density of ≈ 1.5 and ≈ 0.7 .

Image handling by electrostatic lenses is always accompanied by serious distortions. Furthermore, because the image has to traverse seven fibre-glass plates, which suffer from

imperfections in their fibre structure, one has to reckon with irregular displacements of image points on the output window of the tube. Both kinds of distortions can be seen in the image of a regular test pattern (correction grid) from Fig. 8.

A reconstruction makes sense only if the distorted image is sufficiently stable. The stability of the tube has been tested by measuring the distance d between two points, approximately 20 mm apart. The variation, due to a change of the H.T. of the first two stages, is $\Delta d \approx -6.6 \mu\text{m/kV}$; i.e. with an H.T. stability of 10^{-2} one must expect: $\Delta d \approx 2 \mu\text{m}$, which is smaller than the setting error of a point. Measurements from 20 pictures, taken within a time interval of 1 hour, show a standard deviation: $\langle \Delta d \rangle \approx 3 \mu\text{m}$ (which was about the setting error of the microscanning table used). The average distances of such series, taken on different films on different days show: $\langle \Delta \bar{d} \rangle \approx 1.7 \mu\text{m}$. One can conclude that the stability of the tube (in absence of a magnetic field) is such that one single correction of the distortion is sufficiently good for a period of at least several hours.

A program has been written for the reconstruction of points of a plane, based on the known positions of the crossing points of the correction grid; i.e. a smooth correction has been envisaged, which ignores the spontaneous jumps due to the imperfections of the fibre plates.

In a first step the deformed coordinate system (x_1, y_1) (represented by the crossing points of the correction grid) has been pre-stretched (x_2, y_2) with a third-order polynomial:

$$x_2 = \sum_{j=0}^3 \sum_{i=0}^{i=j} a_{ij} x_1^{j-i} \cdot y_1^i$$

$$y_2 = \sum_{j=0}^3 \sum_{i=0}^{i=j} b_{ij} x_1^{j-i} \cdot y_1^i .$$

The coefficients a_{ij} and b_{ij} have been worked out (by taking into account all crossing points of the grid) with the help of the least squares method, i.e.

$$\frac{\delta}{\delta a_{ij}} \sum_k^n (x_{0k} - x_{2k})^2 = 0 ; \quad \frac{\delta}{\delta b_{ij}} \sum_k^n (y_{0k} - y_{2k})^2 = 0 ,$$

where x_{0k}, y_{0k} are the coordinates of crossing points in the object plane and n is the number of crossing points.

Thus the coordinates of points of a line (ξ_1, η_1) can be transformed into coordinates (ξ_2, η_2) of the pre-stretched frame.

In a second step a local correction has been applied to a point (ξ_2, η_2) . With the help of six grid crossing points P_{2k} of the pre-stretched plane (as indicated in Fig. 9), the 12 coefficients $(\alpha_{ij}, \beta_{ij})$ of a transform have been calculated, taking into account second-order terms, i.e. from the set of the 12 equations:

$$x_{0k} = \sum_{j=0}^2 \sum_{i=0}^{j-1} \alpha_{ij} x_{2k}^{j-i} \cdot y_{2k}^i$$

$$y_{0k} = \sum_{j=0}^2 \sum_{i=0}^{j-1} \beta_{ij} x_{2k}^{j-i} \cdot y_{2k}^i \quad .$$

The finally corrected coordinates (ξ_3, η_3) of an arbitrary point are then given simply by

$$\xi_3 = \alpha_{00} + \alpha_{10}\xi_2 + \alpha_{01}\eta_2 + \alpha_{20}\xi_2^2 + \alpha_{11}\xi_2\eta_2 + \alpha_{02}\eta_2^2 ; \quad \eta_3 = \beta_{00} + \beta_{10}\xi_2 + \dots \quad .$$

A correction grid with an edge length of 36 cm and composed of 13×13 lines has been de-magnified to a square of $25 \times 25 \text{ mm}^2$ onto the photocathode. The parameters of three representative straight lines (Fig. 8) have been calculated by taking into account about 60 points for each line. The setting error for a point turned out to be $\approx 7 \text{ } \mu\text{m}$ on the film (from a CERN hand-operated image-plane digitizer, magnification 16). When fitted to a straight line one obtains A_0 (parallel displacement) and A_1 (inclination); and from the parabola fit R (virtual radius of the line).

Each one of three pictures has been scanned by two persons. The table opposite gives the results, standardized to a square of $1 \times 1 \text{ m}^2$. $\bar{A}_0$ and $\overline{\sigma(A_0)}$ are the averaged values from the six measurements of the parallel displacements and their errors (maximum likelihood method); $\sigma_1(A_0)$ is the standard deviation of a single measurement (out of the six samples), and $\sigma_2(\bar{A}_0)$ is the error of $\bar{A}_0$ (the same notation holds for the A_1 's); A_{00} and A_{11} are the true values of the parameters. The disagreement between the different errors could be due either to the irregular displacements of points in the fibre plates, which could not be taken into account, or to an imperfection in the reconstruction method, or to both.

4. CONCLUSION

If the image intensifier camera, as described above, is used for the record of streamer chamber tracks of about 1 m long, one can expect, for the projected view, a precision of position of about 0.2 mm and of inclination of about 0.35 mrad. In a field of 15 kG the momentum measurement will be limited to about 100 GeV/c.

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* * *

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Table of reconstruction results

Track Parameter	I	II	III	
A_{00}	42.696	-295.308	293.644	mm
$\bar{A}_0$	42.669	-295.260	293.474	mm
$\overline{\sigma(A_0)}$	0.063	0.049	0.048	mm
$\sigma_1(A_0)$	0.208	0.107	0.169	mm
$\sigma_2(\bar{A}_0)$	0.085	0.043	0.069	mm
$\bar{A}_0 - A_{00}$	-0.027	0.048	-0.170	mm
A_{11}	1.00060	-0.32475	-0.05263	tg α
$\bar{A}_1$	1.00007	-0.32495	-0.05260	tg α
$\overline{\sigma(A_1)}$	0.110	0.154	0.165	mrاد
$\sigma_1(A_1)$	0.241	0.369	0.275	mrاد
$\sigma_2(\bar{A}_1)$	0.098	0.151	0.112	mrاد
$\bar{A}_1 - A_{11}$	-0.267	-0.180	0.026	mrاد
$\bar{R}$	675.4	402.4	402.7	m

Fig. 1 Image intensifier camera

Fig. 2 Circuit diagram of pulse generator

Fig. 3 Pulse generator, plug-in unit

Fig. 4a H.T. pulse shape

Fig. 4b Light intensity at the output window

Fig. 5 Film pressure mechanism

Fig. 6 View of the camera

Fig. 7 Cosmic ray shower in a streamer chamber $45 \times 20 \times 20 \text{ cm}^3$

Fig. 8 Correction grid

Fig. 9 Local correction