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Conceptual design for an optoelectronic delay line

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Résumé. — Nous décrivons le principe de fonctionnement de base d'un tube intensificateur d'image baptisé "Vacuum Image Pipeline" (VIP). Ce tube est capable de retarder de façon contrôlée un flux continu d'images optiques, et de sélectionner et d'amplifier une petite partie d'entre elles.

Abstract. — We describe the basic operation principle of a Vacuum Image Pipeline (VIP) able to delay in a controlled way a continuous flow of optical images and to select and process a small fraction of them.

Introduction.

A fast tracking detector for future hadron colliders is being developed within the framework of the LAA Project [1]. It involves small diameter ($\sim 50 \mu\text{m}$) plastic scintillating fibres which display track images of ionizing particles at very low light levels and at a rate of 10^8 s^{-1} . This detector will be operated in a very high ($\sim 5 \text{ T}$) and uniform magnetic induction. Most of these images ($\sim 99.9\%$) are uninteresting for physics and must be discarded. Only a small fraction of them should be amplified and transmitted to subsequent optoelectronic devices for further processing. This small fraction is selected by trigger signals which, due to their generation and transmission, arrive with delays of $\sim \mu\text{s}$. Therefore, we must delay the track images accordingly, reject the vast majority and transmit and amplify only the small triggered fraction ($\sim 0.1\%$) of them. This letter describes the VIP which we have designed for this purpose.

Envisaged solutions.

The first solution considered, a pure optical delay line, would ask for 200 m long bundles of coherent and small diameter optical fibres. In order not to

lose any information and because of the intrinsic attenuation associated with this form of image delay, the solution requires preamplification by an image tube having contradictory features: a very high gain and an extremely fast phosphor screen (decay time $< 10 \text{ ns}$). For this reason this solution is not feasible.

In a second approach it was also envisaged to use a gas filled image tube, taking advantage of the local magnetic field to focus the electronic images. This solution was also discarded due to difficulties in implementation.

The currently preferred solution applies a vacuum tube consisting of a photocathode, a delay section where the photoelectrons travel at low velocities, a gating system (controlled by the trigger) and, finally, an amplification stage where only the selected images are amplified. The focusing of the image is ensured by the high magnetic field, parallel to the photoelectron trajectories. In order to avoid overlapping of the generated (10^8 Hz) optoelectronic images, our design requires an excellent time resolution within the delay section. Unfortunately, this requirement is counter balanced by the velocity spectrum of the

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electrons emitted by the photocathode, which provokes an intolerable mixing of the track images.

Principle of VIP operation.

Our design is based on the reflex klystron principle [2] and an idea proposed by Smith [3]. The combination of both principles allows the construction of an image pipeline giving excellent time resolution. The following paragraphs briefly describe these principles, the VIP tube itself and its two running modes, which we call elimination and selection modes.

In a reflex klystron, electrons generated by a cathode are accelerated and passed through a resonator where they are velocity-modulated. A reflector electrode, operated below cathode potential is located so that electrons are reversed in a direction after their passage through the resonator and made to return through the same resonator. The velocity modulation and transit

time effects then cause the electrons to form in bunches by the time they pass through the resonator cavity. The bunch impacts convert the kinetic energy of the electrons into electromagnetic energy.

In studying transient light phenomena, Smith showed that it was possible to store photoelectrons for a few hundreds of nanoseconds by letting them drift back and forth, at constant low (~ 100 eV) velocities in a long (~ 500 mm) magnetically focussed image intensifier. The electrons were then sampled by gating grids and amplified by a cascade intensifying section. At the output screen an image resolution of 20 lp/mm was achieved with a 500 G magnetic field. The time resolution of the device (ensured by a transit time effect similar to the bunching effect explained before) allowed sampling rates as high as 100 MHz.

The VIP is made of a long (~ 600 mm), evacuated, cylindrical envelope (Fig. 1), closed at one end by

Fig. 1.— VIP scheme.

fibre optic input window bearing a photocathode and at the other end by a phosphor screen and the associated fibre optic output window. The tube contains four grids (labelled G1 to G4), confining five sections (named acceleration, selection, zero field, reflection and amplification sections).

The elimination mode represents the normal running of our VIP device and corresponds to a non-active trigger. Consequently, all track images projected onto the input window during this period must be finally discarded. The image elimination mode works as follows: photoelectrons produced (with various velocities) by the grounded photocathode are accelerated by a low voltage at grid G1 and drift at constant velocity, through G2 up to G3, in the zero electric field section (G2 and G3 being at equal potential with G1). The electrons then reach the reflection section where they are repelled by grid G4 which is at negative potential. Finally, the electrons cross backwards successively the zero field, selection and acceleration sections. They finally strike the photocathode, where they are absorbed. In this elimination mode, the (DC) potentials at grids G1, G2, G3, G4 are at 4 V, 4 V, 4 V, -2 V respectively; the (DC) potential of the phosphor is at 15 kV.

The trigger signal activates at randomly distributed

time intervals the selection mode, where a single interesting image is selected for further processing. In the description of the selection mode, it is worth mentioning that the above electrical potentials (along with the section lengths) have been chosen so that, after a travel time some 35 ns longer than the required delay, the images are re-bunched in the selection section enclosed by the two grids G1 and G2. This bunching property is the essential feature which allows image selection. Indeed, once the selected image is confined between G1 and G2, a negative electrical pulse is applied at G1. It strongly repels the photoelectrons belonging to the selected image into the forward direction through G2, G3 and G4. After grid G4, the electrons are accelerated by the phosphor high voltage, before they are finally converted into optical images at the phosphor screen. In order to avoid the selection of incoming photoelectrons, the emission from the photocathode must be blocked by a positive voltage before gating G1. This is the reason why the image travel time is longer than the trigger delay time. For this selection mode, the gating sequence induced by the trigger signal is displayed in figure 2.

This scheme is relatively simple, because during the

Fig. 2.— Sequence of electrical pulses applied to the VIP.

elimination mode, the VIP tube is operated by DC voltage only. For the selection mode, comparatively low voltage pulses are applied to gate the photocathode and G1 whereas all other potentials remain constant.

VIP simulation.

In order to check the scheme for VIP operation, extended computer simulations have been performed. These simulations suggest that we should expect a $1 \mu\text{s}$ delay using a 600 mm long device. Assuming the incoming optical images are adjacent to one another and that each has a 10 ns time spread, the time dispersion after delay should be less than 7 ns, resulting in an average electronic image overlap of less than 25%. This last figure is estimated for the worst case, where the intensity of each incoming image is constant throughout its duration. We believe that the overlap will be less than a few percent for real images.

Conclusions.

We propose a device which, according to computer simulations, should meet the required specifications. A still unsolved question is the absorption efficiency of photoelectrons (from the not-triggered images) at the photocathode of the VIP tube. This forms the object of measurements which are currently in progress. We are sub-contracting the manufacture of prototypes and we expect to be able to test the viability of this design concept within the coming months.

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