PROPOSED POSITION MONITOR SYSTEM USING DRIFT CHAMBER AND LASER

N. Ishihara[1]

KEK, National Laboratory for High Energy Physics
Tsukuba, Ibaraki, 305, Japan

1. Introduction

In order to realize the high luminosity in a future linear collider, it will be essential to squeeze the beam size up to an order of nm at the collision point. Since the alignment error of the linear accelerator components seriously affects the size and position of the beam, the precision alignment and monitor techniques become more and more important. The continuous and simultaneous alignment-monitor is desirable for the accelerator components, especially in the transverse directions to the beam. A beam based alignment is a way to simultaneously measure the relative positions, but not useful under the normal operation.

When we mount small drift chambers on the accelerator components, and measure relative positions of the chambers with reference to beams of pulsed-UVL (Ultra-Violet Laser), this technique will be useful for the continuous and simultaneous monitor of the transverse positions for the several components aligned in a straight line. If the relative position is well known between the drift chamber and the component, this system will also be useful for the initial alignment. In the present paper, a concept of this method is described, and some problems concerning the position accuracy is discussed.

2. Concept of the position monitor using drift chambers and UVL

A UVL beam can ionize the gas molecules by a multi-photon ionization process, if the energy density is sufficiently high, as briefly described in the next section. On the other hand, once the ionized electrons are produced in the chamber gas, those production points are determined in two dimensional projected-plane by the drift chamber with an accuracy of around 13 μm as described in section 4.

Though a UVL beam usually has a divergence angle of an order of mrad, the suitable arrangement of optical lenses will make the UVL beam narrow enough for the ionization

[1]e-mail: isiharan@kekvax.kek.jp

process in the drift chambers. Thus, the combination of the pulsed UVL and the drift chambers is useful for the continuous and simultaneous position-monitor in three dimensions as shown in the conceptual drawing of Fig.1. In the figure, the UVL beam is in z-direction, the beam position in x-z plane is determined by the chamber part called x-chamber and the one in y-z plane is done by the y-chamber. Both x and y-chambers are accommodated in a box. If the drift chambers are accurately mounted on the accelerator components, the initial alignment will be possible for the components with reference to the UVL beam.

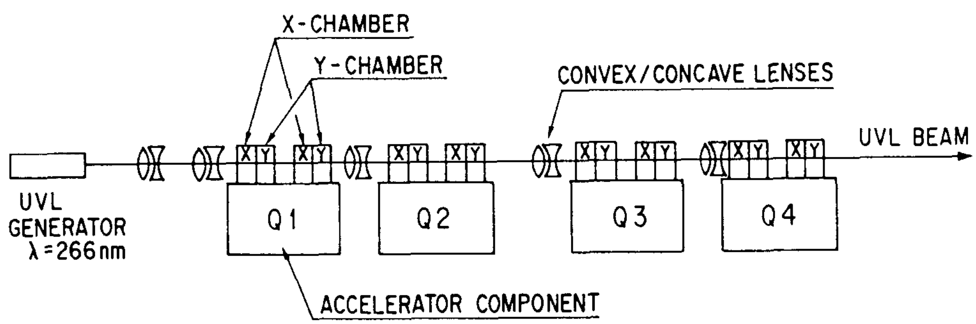

Fig.1 Conceptual drawing of the position monitor system using drift chambers and pulsed UVL beams.

3. Ultra-violet laser (UVL)

Since the quantum energy of UVL is much lower than the ionization energies of gas molecules, two or more laser photons are required to ionize the gas molecule in the chamber. For example, in the case of CO_2 gas, the ionization potential is 13.81 eV and the average energy required to produce an ion-pair by an electron beam is 32.8 eV [1]. On the other hand, N_2 gas laser of λ = 337 nm wavelength and Nd-YAG laser of λ = 266 nm (the fourth harmonic wave) correspond to the quantum energies of 3.67 eV and 4.65 eV, respectively. Therefore, the UVL demands the high power density in order to produce enough number of ionization electrons in the drift chamber.

According to a textbook [1], in a volume V containing a density N of molecules, the ionization rate R is given by the equation

$$R = \phi^n N V \sigma^{(n)}, \tag{1}$$

where ϕ is the photon flux and $\sigma^{(n)}$ an nth-order cross-section equivalent for n-particle collisions in units of $\mathrm{cm}^{2n}\mathrm{s}^{n-1}$. A light pulse with cross-sectional area A and duration T

Table.1 Specifications of the pulsed UVL of λ = 266 nm, the fourth harmonic from Nd:YAG laser [2]

Wavelength	266 nm
Pulse energy	12 mJ
Pulse repetition rate	$< 15Hz$
Pulse duration, FWHM	10 ns
Beam divergency, FWHM	1.5 mrad
Power density (ϕ = 1 mm)	1.5×10^{12} W/m^2

contains *m* photons, if the flux ϕ and the energy *E* are given by

$$\phi = \frac{m}{AT}, \qquad E = mh\nu = \frac{mhc}{\lambda}. \tag{2}$$

Considering a traversed volume $V = AL$, the specific ionization per unit length for the n-photon process is

$$\frac{RT}{L} = \frac{m^n}{(AT)^{n-1}} N\sigma^{(n)} = \left(\frac{E}{AT}\right)^n ATN \left(\frac{\lambda}{hc}\right)^n \sigma^{(n)}, \tag{3}$$

where *(E/AT)* is called the power density of the laser beam.

In the case of two-photon process, the energy levels of the electrons in the molecules are classified into three levels: the ground level (0), the intermediate level (1) and the continuum ionization level, the incident radiation stimulates transitions $0 \rightarrow 1$ and $1 \rightarrow 2$. There is also a spontaneous transition of $1 \rightarrow 0$. Equation (3) is expressed as

$$\frac{RT}{L} = \frac{1}{2}\left(\frac{E}{AT}\right)^2 AT^2 N \left(\frac{\lambda}{hc}\right)^2 \sigma_{01}\sigma_{12}, \tag{4}$$

using the relation

$$\sigma^{(2)} = \frac{1}{2}\sigma_{01}\sigma_{12}T, \tag{5}$$

where σ_{01} and σ_{12} are the cross-sections for the processes of $0 \rightarrow 1$ and $1 \rightarrow 2$, respectively.

The ionization yield increases as the wavelength of UVL decreases. The wavelength dependence resides almost entirely in the factor σ_{01} in eq.(4) [1]. Since it is obvious that the shorter wavelength has an advantage over the longer wavelength from a viewpoint of the ionization yield, we will use the pulsed wave of λ = 266 nm converted from the Nd:YAG laser. The specifications of our pulsed-laser generator is described in table 1.

4. Drift chamber

An example of precision drift chamber is the VENUS vertex detector at TRISTAN [3].

The chamber has a cylindrical shape with 12 sectors, each of which comprises 16 anode (signal) wires. The chamber has performed a good spatial resolution of 37 μm for the tracks of charged particles, using what is called slow gas, a mixture of CO_2(92%) and C_2H_6(8%) pressurized to 3 atm, and a readout electronics system including 100 MHz FADC (Flash Analog to Digital Converter).

When we apply the drift chamber to the detection of the UVL, the following care is required [4].

(1) Since the chamber windows for the UVL beam absorb part of the laser energy, quartz is suitable for the window material.

(2) When the UVL beam hits a wire, many electrons are liberated on a metallic surface. Therefore, it is desirable not to locate wires in the path region of the UVL.

In order to measure the position of the UVL beam in three dimensions, special wire-configurations are contrived as shown in Fig.2. The chamber is separated into two parts: x-chamber for the measurement in an x-z projected plane, and y-chamber for the measurement in a y-z projected plane. Each part has 8 sense wires with the pitch of 6 mm. Potential wires are interlaid between sense wires in order to prevent the so-called cross talk. Main parameters of the present chamber are described in table 2.

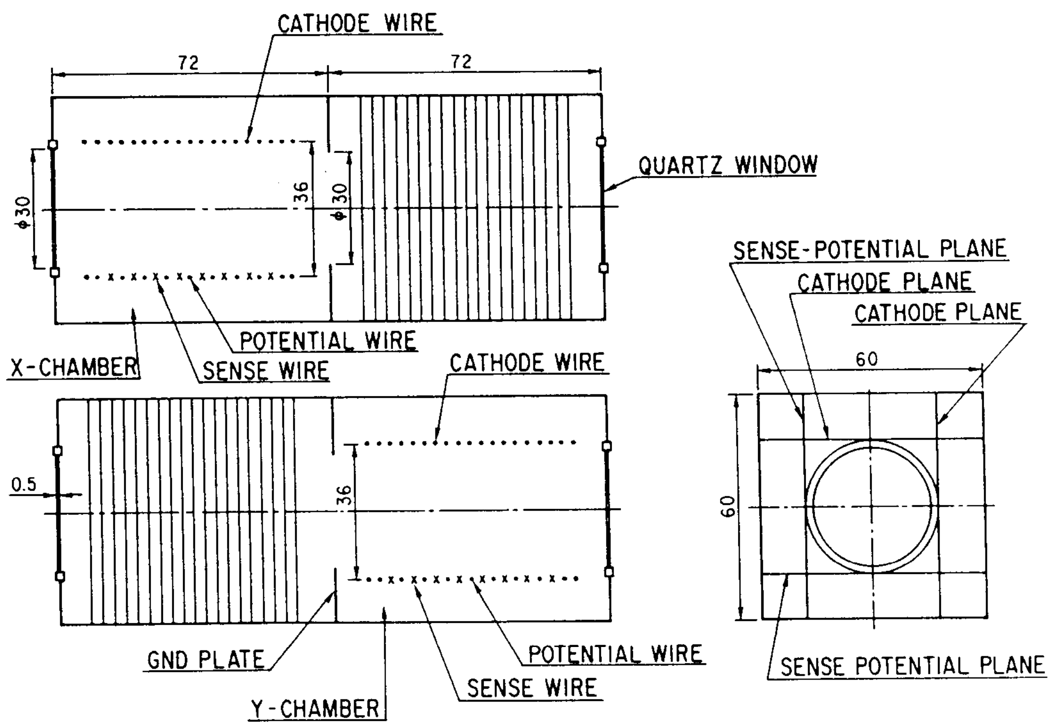

Fig.2 Conceptual drawing of the proposed drift chamber.

Table.2 Main parameters of the drift chamber for the position monitor system

Dimension	60 x 60 x 144 mm^3
	60 x 60 x 72 mm^3 for x-chamber
	60 x 60 x 72 mm^3 for y-chamber
Sensitive volume	r x 12^2 x 48 mm^3/half chamber
Sense wire	8 wires/half chamber
	4 20 μm gold-plated W
Potential wire	9 wires/half chamber
	4 100 μm gold-plated Cu-Be
Cathode wire	19 wires/half chamber
	4 100 μm gold-plated Cu-Be
Edge-anode wire	2 wires/half chamber
	4 100 μm gold-plated Cu-Be
G&S	$CO_2(92\%) + C_2H_6(8\%)$, 1 atm
Window	quartz, ϕ24 mm x 2 / chamber
Readout electronics	pre-amp. + shaping-amp. + FADC

5. Position accuracy

It is well known that the integrated intensity of the laser beams is distributed as the shape illustrated in Fig.3, since a laser beam is always moving due to the instability of the generator.

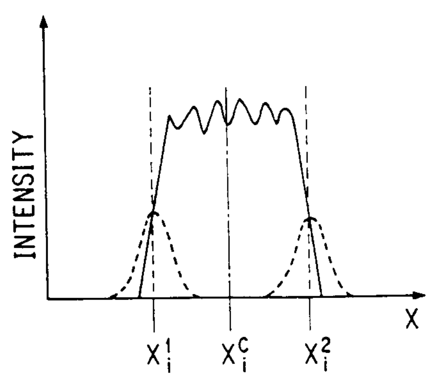

Fig.3 Integrated intensity distribution of the laser beams. Both Gaussian distributions of dashed curves at the profile edges mean the error distributions of the edge measurements.

Therefore, a measurement of the single pulsed-beam position is not enough to determine the relative position of the UVL beam to the drift chambers, and many pulsed-beams are necessary for a mean position measurement. When the mean edge positions of the integrated beam profile are measured to be x_i^1 and x_i^2 (y_i^1 and y_i^2) in the projected x-z plane (y-z plane) at z_i with the detection accuracy of σ_{edg}, the mean center position at z_i

is given as

$$x_i^c = \frac{x_i^1 + x_i^2}{2}, \tag{6}$$

and the accuracy of the measurement is described as

$$\sigma_i = \frac{1}{\sqrt{2}}\sigma_{edg}. \tag{7}$$

Since some studies obtained that the σ_{edg} was less than 50 μm [5] [6], the σ_i is expected to be 35 μm.

Using the present chamber, we can obtain eight data sets, $(x_i^c, z_i)\, i = 1 \sim 8$ (or $(y_i^c, z_i)\, i = 1 \sim 8$). We assume that the error ϵ_i of x_i^c is distributed as Gaussian function around zero, and the error of z_i is negligibly small in comparison with the standard deviation σ_i of the ϵ_i. It is also assumed that every σ_i is same and equal to σ (= 35 μm). The unknown beam-center-position η_i is described as

$$\eta_i = x_i^c - \epsilon_i = \theta_1 + \theta_2 z_i. \tag{8}$$

According to the statistical treatment [7] [8], the least squares estimate of $\tilde{\theta}$ is obtained as

$$\tilde{\theta}_1 = \frac{\sum_{j=1}^{8}(\sum_{i=1}^{8} z_i^2 - z_j \sum_{i=1}^{8} z_i)x_j^c}{8\sum_{i=1}^{8} z_i^2 - (\sum_{i=1}^{8} z_i)^2} \tag{9}$$

and

$$\tilde{\theta}_2 = \frac{\sum_{j=1}^{8}(8z_j - \sum_{i=1}^{8} z_i)x_j^c}{8\sum_{i=1}^{8} z_i^2 - (\sum_{i=1}^{8} z_i)^2}. \tag{10}$$

Therefore, the least squares solutions become

$$\tilde{\eta}_i = \tilde{\theta}_1 + \tilde{\theta}_2 z_i, \qquad i = 1 \sim 8, \tag{11}$$

and the residual error of the $\tilde{\eta}_j$ is given as

$$\delta_j = \left[\frac{\sum_{i=1}^{8} z_i^2 - 2z_j \sum_{i=1}^{8} z_i + 8z_j}{8\sum_{i=1}^{8} z_i^2 - (\sum_{i=1}^{8} z_i)^2}\right]^{1/2} \sigma. \tag{12}$$

Since the pitch between sense wires is 6 mm, the residual error δ_4 which is in the central region of the sensitive volume, for example, is estimated to be factor 0.36 smaller than the σ, and it becomes 13 μm.

6. Concluding remarks

A technique using drift chambers and the UVL has been proposed as a new method of the continuous and simultaneous position monitor system in transverse directions for the accelerator components. If the relative position between the chamber and the component is accurately measured, the method will also be useful for the initial alignment of the components. The position accuracy of the proposed method has been estimated to be about

13 μm. The UVL beam will probably be disturbed by the lenses, the quartz windows and the air turbulence. It remains to be solved how these things affect the position accuracy.

Acknowledgement

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