TIME-RESOLVED BEAM EMITTANCE MEASUREMENT OF DRAGON-I LINEAR INDUCTION ACCELERATOR

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Abstract

Two beam emittance diagnostic systems of the intense pulsed electron beam (18MeV, 2.6kA, 80ns) of Dragon-I linear induction accelerator is developed. One is based on optical transition radiation, the other is based on three gradient method. Streak camera and gated CCD camera is used to get time-resolved result. The measured emittance is about $2100\pi.mm.mrad$.

INTRODUCTION

Emittance is a very importance parameter of an accelerator. At the same time, it is very difficult to measure it. To measure the emittance of Dragon-I linear induction accelerator, two systems are developed. One is based on optical transition radiation, the other is based on three gradient method.

Optical transition radiation(OTR) has many fine properties[1]. The angular distributin is peaked at $1/\gamma$ direction, and it is radial polarized. It is possible to extract the energy and divergence of several kinds of beam using the angular distribution property. OTR is also suitable for beam profile measurement.

At the beam waist, emittance can be write as follows.

$$\varepsilon = 4\beta\gamma\tilde{x}\tilde{x}' \qquad (1)$$

Where β, γ are relativistic factors, $\tilde{x}$, $\tilde{x}'$ are root-means-square radius and root-means-square divergence respectively.

With OTR, the beam radius and divergence both can be measured, so emittance can be calculated.

At early works, we have measured the emittance using OTR. Recently, a gated CCD camera is used to measure the time-resolved emittance.

Three gradient method is widely used in other types of accelerator. Typical three gradient method measure the downstream beam radius of a quadrupole lens and use the sigma-matrix and transport matrix to calculate the emittance. The space-charge effect cannot be included. The method we used is based on the root-means-square envelope equation and It makes possible measurement of the emittance of space charge dominated beams.

Root-means-square envelope equation can be writed as follows[2].

$$\tilde{r}'' + k^2\tilde{r} - \frac{K}{2\tilde{r}} - \frac{\tilde{\varepsilon}_r^2}{\beta^2\gamma^2\tilde{r}^3} = 0 \qquad (2)$$

Where $k = ecB_z/2\beta\gamma m_0 c$, B_z is the magnetic field at the beam axis, k is associated with magnetic focus

strength. $K = 2I_b/I_\alpha\beta^3\gamma^3$, I_b is the beam intensity, and I_α is the Alfen current, its value is 17.045kA. $\tilde{\varepsilon}_r$ is the root-means-square emittance. The K is related to beam intensity I_b, so the space charge effect is included.

The process of measurement is showed in figure 1[3].

A focusing solenoid is placed before the analysis plane. Beam profiles are measured with different focusing current. With many times of experiment, we can draw a curve of beam radius vs focusing current. The beam emittence can be fitted based on rms envelope equation. We call this method modified three gradient method(MTGM).
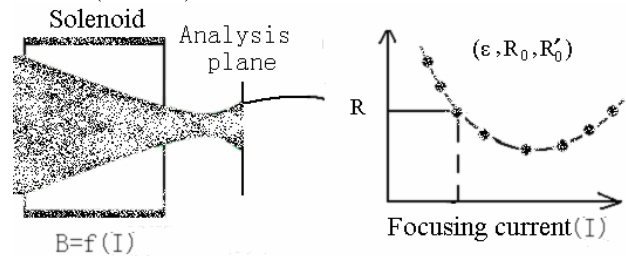

Figure 1: Modified three gradient method

EXPRIMENTAL SET-UP

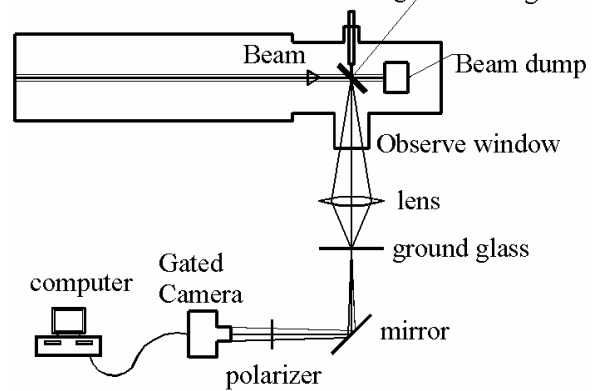Figure 2 shows the schematic set-up of the OTR system.

Figure 2: schematic set-up of OTR

An 80-mm-diam, 0.5-mm-thick thin quartz foil held at 45° to the beam axis is used. The foil is aluminized to generate optical transition radiation. Graphite is used as beam dump to absorb electrons. Optical light is detected normal to the beam axis.

When the beam divergence is measured, a lens with 400mm focus length is used. A ground glass is placed at the focal plane of the lens. The ground glass can change the OTR pattern at the focal plane to a real image. A gated camera is used to record the image at the ground

glass. A polarizer is placed in front of the camera to get polarized OTR pattern.

When the beam profile is measured, the camera record the image at the quartz foil directly.

In present work, we use only one gated camera, so two times of measurement is needed to measure the beam profile and beam divergence. Further work will measure the two parameter synchronously use two gated camera.

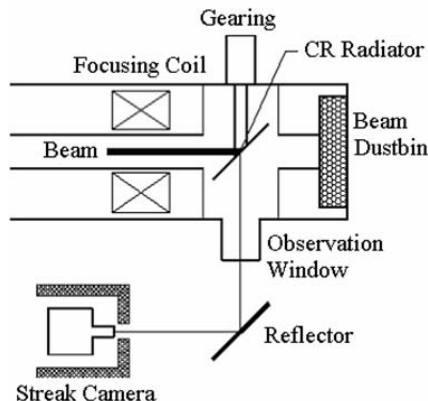Figure 3 shows the schematic set-up of the MTGM system.

Figure 3: schematic set-up of MTGM

The radiation chamber is located at a definite distance downstream from the focusing solenoid. An thin quartz foil similar to OTR system is used to generator Cerenkov radiation, while this foil is not aluminized. We utilize the CR light within the visible spectrum to measure the beam radius. A streak camera is used to record the image at the quartz foil. Time-resolved beam profile can be measured with this system.

Several C++ Codes are developed to deal with the experimental data. one code process the experimental image and get corresponding data, one code calculate the ideal OTR pattern, one code calculate the ideal radius vs focusing current curve of MTGM, and the last fit the calculated and experimental data.

EXPERIMENTAL RESULTS

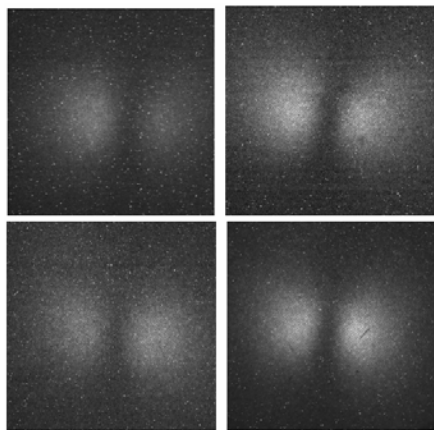Figure 4 show the time-resolved OTR pattern in the experiment.

Figure 4: Time-resolved OTR pattern

When the experiment is carried out, some upstream focusing solenoid is tuned to get a beam waist at the quartz foil.

Figure 5 is the data extract from one of the measured pattern and its fitted curve. We can get the beam divergence is 6.8mrad and beam energy is 18.3MeV from the data fitting.

The unique angular distribution of optical transition radiation is used in the data fitting.[4] The beam divergence will change the angular distribution of OTR slightly, which makes the measurement of beam divergence possible.
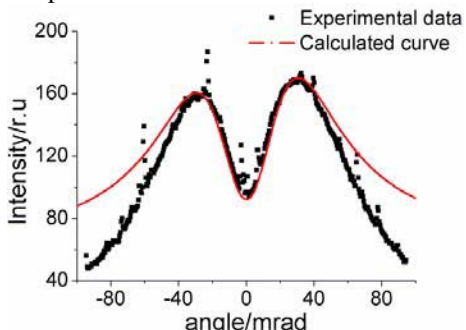

Figure 5: Measured and fitted
OTR characteristic curve

Time-resolved beam profile measurement is also performed. Thus the time-resolved beam emittance calculated is about 2300π.mm.mrad. In the calculation, equation 1 is used.

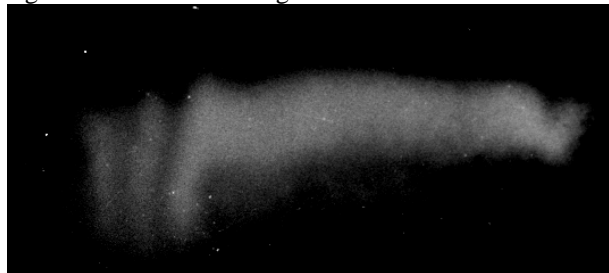Figure 6 is one of the images in the MTGM measurement.

Figure 6: Time-resolve beam profile in MTGM

The measurements have performed several times by changing the focusing current of the solenoid. Figure 7 show the measured and calculated curve of beam radius vs solenoid current. The data fitting is based on root-means-square envelope equation.
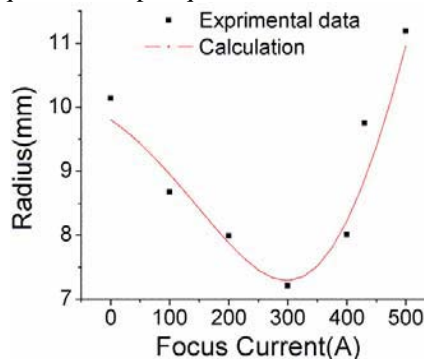

Figure 7: Data fitting of MTGM

From the data fitting, we can get the beam emittance is 2060π.mm.mrad.

CONCLUSION

We have developed two emittance diagnostic systems of intense pulsed electron based on optical transition radiation method, and modified three gradient method. With both method, Time-resolved result of beam emittance is obtained. The result with OTR method is about 2300π.mm.mrad, while MTGM is about 2100π.mm.mrad. The two result accord with each other, despite the first result is a little greater than the second.

REFERENCES

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