BEAM INSTABILITY AND CORRECTION FOR "DRAGON-I"

Wenwei Zhang Zhiyong Dai Hong Li Wei Jiang Kaizhi Zhang Jin Li Jianjun Deng Linwen Zhang and Jinshui Shi
Institute of Fluid Physics, CAEP
P.O.Box 919-106, Mianyang China 621900

Abstract

"Dragon-I" is a high current pulsed electron linear induction accelerator designed and constructed in IFP/CAEP. It generates a 20MeV, 2.5kA, 60ns pulsed electron beam. The whole facility has three parts: injector; accelerator and beam focus system. The accelerator consists of 72 induction cells and 18 connection cells. A solenoid was installed inside each cell forming the beam transport system. During the initial beam test both high frequency and low frequency beam centroid oscillation were found. A lot of simulation and experiment investigations were done to obtain the transverse impedance of the cells and to reduce the corkscrew motion of the electron beam. Details of both the simulation and the experimental methods to control the instability are presented.

INTRODUCTION

"Dragon-I" is a high current linear induction accelerator to produce high quality pulsed electron beams[1], which now is operating in Institute of Fluid Physics. The main body of the accelerator consists of 72 induction cells. Inside each cell there is a solenoid focus magnet and a pair of X, Y dipole steering magnets. The cells are assembled in blocks of four followed by a resistance BPM and a connection cell with ports for beam diagnostic and vacuum pump. Inside the connection cell there are solenoid and steering magnets too. Following the accelerator several solenoids form a drift space and two thin lenses are used to focus the beam. The electron beam source is a 2.5kA pulsed diode injector[2]. To transport and accelerate the pulsed electron beams to the end of the machine, beam instabilities such as Beam Break Up and Corkscrew are concerned. In the design stage of the induction accelerator cell, attention was paid to the shape of the induction gap to optimize the microwave character of the cell. In accelerator assembling stage, four induction cells and one connection cell were installed on a mount to form a block first. The magnets inside the connection cell bridge the magnetic field between adjacent blocks. The magnetic axis of the blocks was measured and aligned by pulsed taut wire method. Then under the monitoring of a laser tracker the blocks are located and aligned along the mechanical axis of the accelerator system. .

During the initial beam test the beam centroid oscillation was observed obviously. To reduce high frequency centroid oscillation a metal wire netting is put into the connection cell; and the pair of dipole steering magnets in each cell is used to reduce the corkscrew of the beam centroid.

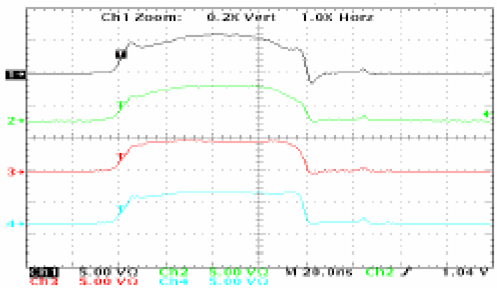
HIGH FREQUENCY BEAM CENTROID OSCILLATION

A 60ns pulsed electron beam around 3.5MeV, 2.6kA is provided by Dragon-I injector [2]. Along the whole beam line there are totally 21BPMs to detect the current and the position of the beam. The first BPM located at the exit of the injector, the 20^{th} at the exit of the drift space and the last one at the beam exit of the facility.

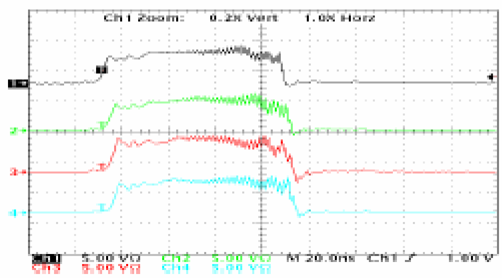
In the initial beam tests, a high frequency oscillation around 550MHz was found on the waveform detected by BPMs. It indicates a kind of beam centroid oscillation. The oscillation appeared on the 9^{th} BPM first, and then got strong gradually on the following BPMs. Waveforms from BPM1, BPM9 and BPM21 are shown in Fig 1. BPM1, BPM9 and BPM21 are located at the beam exit of the injector, in the middle of the accelerator and at the beam exit of the facility correspondingly. The phenomenon means that the frequency of the beam centroid transverse oscillation was around 550MHz.

According to the results of transverse impedance calculation for the accelerator cell and the connection cell, a TM11 mode of 580MHz was found, which produced by the connection cell. Some experiments were

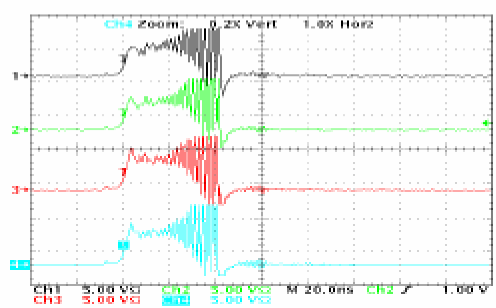
1-4244-0917-9/07/$25.00



a. Signals from the first BPM



b.signals from the 9th BPM



c. signals from the last BPM

Fig 1 Beam current signal obtained in initial beam test

down to measure η parameter and determine the transverse impedance of the connection cell. A peak of 558MHz was found on the measured η curve. According to the equation $Z_{\perp} = 377\frac{W}{\pi b^2}\eta$, the calculated transverse impedance for the 580MHz TM11 mode is $Z_{\perp} = 3765\Omega/m$. Where W is the width of the induction gap and b is the radius of the beam pipe[3],. When a metal wire netting was insert to the cell the 558MHz peak on the measured η curve reduced significantly. Fig 2 shows the measured η curve. The blue fine line is the measured curve of the connection cell without the metal wire netting, and the bold pink line is the measured curve when the wire netting is placed into the connection cell. The wire netting was employed to every connection cell finally and the high frequency beam centroid oscillation disappeared.

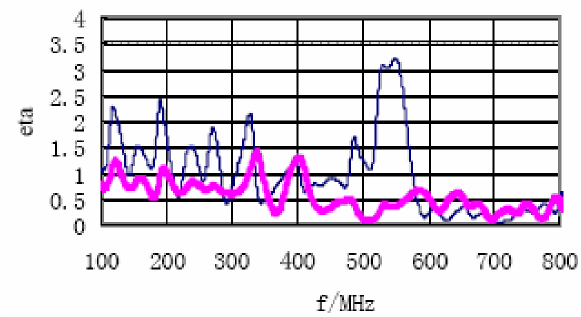


Fig 2 measured η of the connection cell

CORKSCREW

Beam centroid offset are measured along the beam line by 21 resistance BPMs, when the electron beam goes through one BPM four waveforms are recorded by a digital oscilloscope, which represent the horizontal and vertical beam centroid transverse motion during the pulse. Doing calculation with the four waveforms according to some equations the beam centroid motion is derived. After the 550MHz centroid oscillation mentioned before was eliminated, corkscrew motion was observed obviously. It forms downstream near the exit of the beam line, and the peak value was more than 4mm. Fig 3 shows one pair of waveform measured on the last BPM.

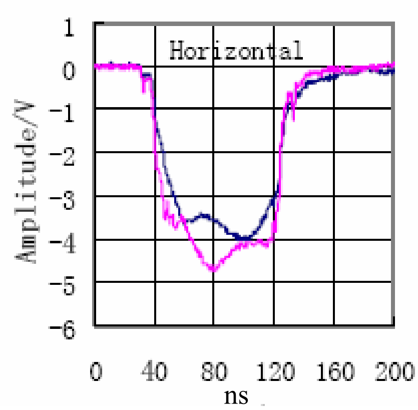


Fig 3 Waveform measured on the last BPM

One of the main methods to reduce corkscrew motion is using the steering coils to tune the beam centroid trajectory. It is usually conducted under the guidance of simulation. A simple model is used in the calculation to trace beam centroid motion along the beam line and the peak value of corkscrew at the accelerator exit. The beam centroid motion is traced by matrix formalism. The electron beam is modeled as a string of rigid disks; as a result all the beam disks are transported together. We consider particle coordinates x, x', y and y', where x and y are the transverse spatial coordinates, x' and y' the dimensionless transverse velocities[4]. The solenoid magnetic field are approximated as a series of small solenoids with hard edge and different magnetic field intensity, the vertical and horizontal steering coils are considered as two thin lengths between two adjacent small solenoids.

The beam centroid trajectory tuning processes begin with simulation. First varying the current fed into the pair of steering coil trace the beam centroid at each BPM downstream. Curves of the steering current versus the beam centroid offset at the location of each downstream BPM are derived, typically shown in Fig 4. The nearer the location of the steering coil to the injector, the more curves relating to it are obtained. Consulting with those

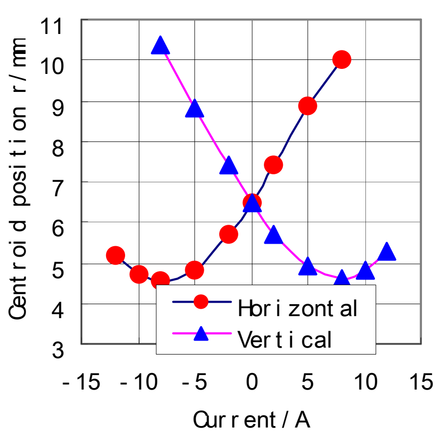


Fig 4 Centroid offset at the location of one BPM versus correct current of one coil

curves of the first pair of coils choose steering current for them, do the same calculation on the second pair of coil to derive the related curves and decide the steering current for them, and then do the same on the next pair of coil, until the steering current for the total five pair coils (coils of one block) are chosen. It is a kind of closed loop simulation, the results as a reference for beam trajectory tuning experiment. The experiments conducted from upstream to downstream one block by another. The initial parameters of the steering current fed into dipole coils of one block comes from simulation, and modified according to the experimental results. The criterion to judge whether the modifications are successful or not are both the peak value of the transverse beam centroid motion detected by the last BPM and the beam centroid trajectory along the beam line. Fig 5 shows the beam centroid motion measured on the last BPM during the pulsed beam goes through. The upper line was measured before the beam trajectory tuning experiments, and the lower line was measured after the experiments. The effect of the beam trajectory tuning is that the peak value of centroid transverse motion reduced to less than 2mm.

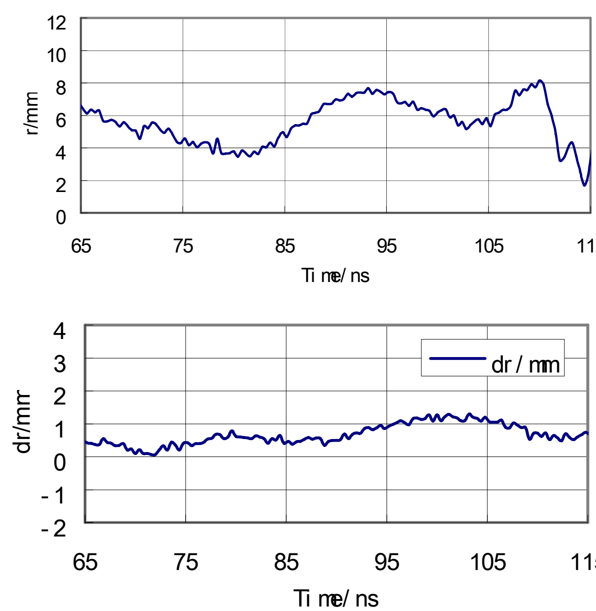


Fig 5 centroid motion during the beam pulse

REFERENCE

[1] Deng Jian-jun, Ding Bo-nan, Wang Huan-cen, et al., "Physical design of the Dragon-I linear induction accelerator". High Power Laser and Particle Beams, 2003.
[2] Zhang K Z, Wen L, Li H, et al., "3.5MeV Injector for an induction Linac". Proceeding of Linac 2002 Conference.
[3] Paul Allison, et al, "Beam-breakup calculation for the DARHT accelerator" Proceeding of PAC 1991
[4] Wenwei Zhang, Kaizhi Zhang, Chengjun Liu, "Beam Centroid Motion Estimate for a High Current LIA". High Power Laser and Particle Beams, 2003

1-4244-0917-9/07/$25.00 ©2007 IEEE