BEAM MEASUREMENT BY A WALL GAP MONITOR IN ALPHA*

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Abstract

In this report, we present our electron beam measurements with a wall gap monitor (WGM) in ALPHA injection and extraction beam lines. The WGM is first bench mark tested, and then installed in the ALPHA injection line to measure both the macro and micro pulse of the injected beam and calibrate the beam current. By scanning the bending magnet before the WGM, and applying a demodulation signal processing scheme, we measured the tomography of the longitudinal phase space of the injected beam. We moved the WGM to extraction beam line and measured the properties of the extracted beam. By comparing the frequency spectrum of injected and extracted beam, we have confirmed the debunching performance of ALPHA.

INTRODUCTION

The Advanced Electron-Photon Facility (ALPHA) [1] is an electron accelerator we are building at Indiana University Center for the Exploration of Energy and Matter (CEEM). The mission of this machine is to provide high power electron beams for radiation effect experiments and high brightness inverse Compton X-Rays source for the IU community.

The electron beam is injected from a S-band LINAC, with the characteristic 2.86 GHz micropulse structure. In the transient mode of ALPHA operation, the injected beam passes through the ring for one turn then extracts out. After this one turn, we expect to debunch the micropulse structure and significantly reduce the 2.856 GHz beam signal. A Wall Gap Monitor (WGM) is installed on the beam line to confirm the beam debunching. We also measured other beam properties, including beam current and longitudinal phase space, by this WGM.

THE WALL GAP MONITOR AND ITS BENCH TEST

The wall gap monitor (WGM) was used on Cooler Injector Synchrotron [2]. Figure 1 shows the picture of the WGM designed and constructed in Fermilab [3].

In the bench test, a thin metallic wire is stretched across the WGM and driven by a function generator to simulate the beam signal. Our bench test results can be summarized as follows:

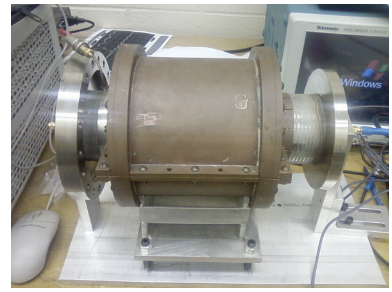

Figure 1: The WGM on the test bench. A thin metallic wire passes through the WGM, with one end connected to the function generator and the other end terminated by a 50 Ω terminator. The output signal is measured by an oscilloscope.

1. The low frequency cut-off of the WGM is about 4 KHz, agree with the earlier estimate.
2. The effective impedance of the WGM is 2.1 Ω, thus we can use the WGM to calibrate the beam current as:

$$\text{Beam Current (I)} = \frac{\text{Detected voltage signal (V)}}{2.1\Omega}$$

3. The signal magnitude is insensitive to either the position or the direction of the beam in the WGM.

THE WGM MEASUREMENT IN THE INJECTION LINE

Figure 2 shows the schematic layout of the ALPHA injection beam line from the LINAC to the WGM location. Two 45° dipoles, made up a double bend achromat, are located between the LINAC and WGM, The dipole field and the slit can be used to select the energy of the beam.

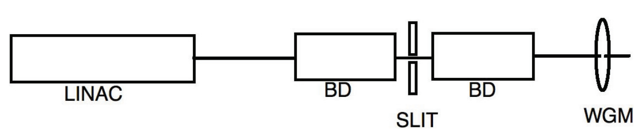

Figure 2: The part of ALPHA injection line layout. After being injected from the LINAC, the beam passes through two 45° bending dipoles before arrive at WGM. There is a slit between the bending dipoles to filter out the electrons out of the acceptance of the storage ring.

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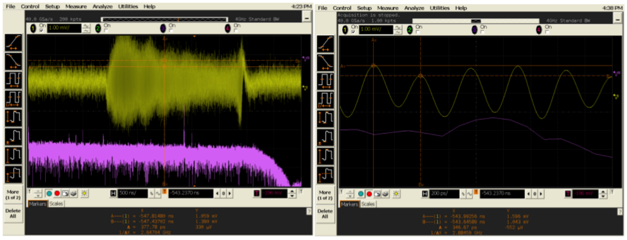

(a) Macropulse signal (b) Micropulse signal

Figure 3: The WGM signal of the injected beam.

The Injected Beam

Our LINAC has a limited beam current, and there is a strong noise from the LINAC klystron located near by the WGM. Thus we have to amplify the beam signal and shield the noise from klystron in order to get a clear WGM signal.

The injected beam has a strong 2.856 GHz signal from the S-band LINAC modulation. On the other hand, the frequencies of klystron noise are mainly under 100 MHz. So we use a bandpass amplifier to amplify the signal around 2.856 GHz. To shield the external noise, we use Helix cable for all the signal connections and the amplifier driving power. After all these efforts, we get a clean beam signal shown in Fig. 3:

Because we have used the bandpass amplifier to get the signal, it is not straight forward to measure the DC part in the frequency spectrum to calculate the beam charge Q. To recover the DC information from the signal, we use a demodulation signal processing scheme described as follows:

1. Import the measured data to Matlab and do FFT. Apply a bandpass filter from 2.6 GHz to 3 GHz.

2. Shift the frequency data by moving the 2.856 GHz to 0 Hz.

3. Do inverse FFT to recover the demodulated signal in time domain.

The effectiveness of this scheme has been tested in Matlab with a pseudo WGM signal. When the micropulses of the linac beam is non-overlapping, within several tens of pico seconds, the frequency spectrum has the magnitudes including DC and 2.856 GHz. Their strengths are almost the same. The demodulation method can recover the DC component. However, when the micropulses begin overlap with each other, the 2.856 GHz amplitude decreaases. The demodulation method cannot be used to recover the DC current anymore.

Longitudinal Phase Space Scan of the Macropulse

As we have shown before, the slit between the two bending dipole selects the electrons with a particular energy. By changing the dipole magnet strength, we can select different energy part of the beam and obtain a longitudinal tomography with the WGM. Thus we can get the information of the beam energy spectrum and longitudinal phase space.

This idea is first tested in the G4Beamline[4] simulation, as shown in Fig. 4. We summarize our simulation results as follows:

1. This method can recover the energy spectrum of the injected beam quite well.

2. Due to the finite size of the beam and the slit, as well as the beam transverse momentum, some electrons in the right energy range still can be lost. We cannot recover the absolute strength of the beam.

3. The finite size of the slit, which is about 4mm now, will give an energy resolution of about 0.13 MeV.

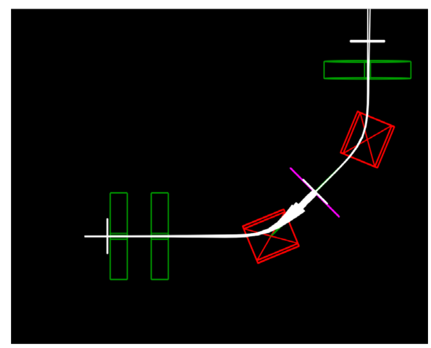

Figure 4: The G4Beamline simulation of the energy scan by bending dipole. A beam with gaussian energy distribution is injected from the particle source. After passing through the dipoles and slit, the survived beam is measured by a detector at the WGM position.

For each bending magnet strength, we measure the corresponding beam longitudinal profile by the WGM and process the signal with the demodulation scheme described above. Combining the results for all the energy, we can obtain the tomography of the longitudinal phase space of the macro pulse, shown in Fig. 5.

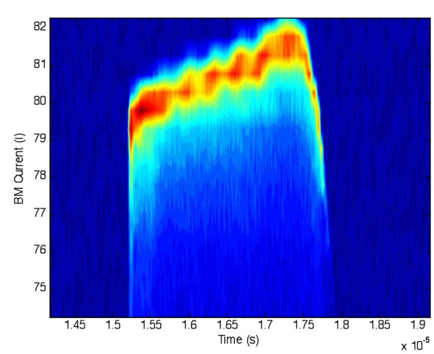

Figure 5: The longitudinal phase space of the injected macropulse. The dipole current strength corresponds to the beam energy, and the time represents the beam length.

By integrating the current over the time to calculate the total charge for the beam of each energy value, we can derive the energy distribution of the injected beam, shown in Fig. 6.

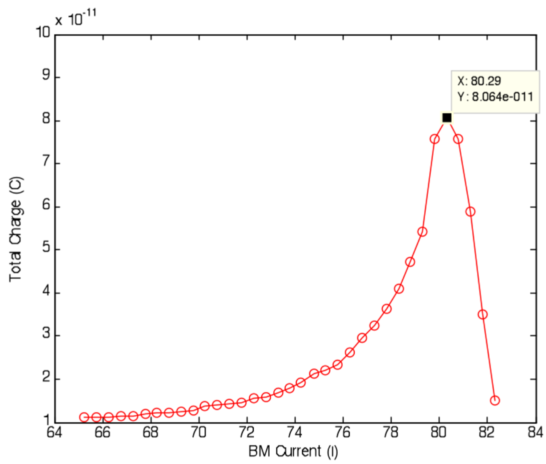

Figure 6: The energy distribution of the injected beam. Thus for this LINAC setting, we should operate the bending magnets at around 80.3 A.

This diagnosis method is used in the LINAC tuning to measure the longitudinal beam quality of the LINAC beam.

THE WGM MEASUREMENT IN THE EXTRACTION LINE

The ALPHA storage ring is designed to have a compaction factor of about 0.5. For the beam with a momentum spread of $\pm 0.5\%$, the 2.856 GHz microbunches will be debunched in a signal pass.

After the measurement of the injected beam, the WGM is moved to the extraction line. From the data of WGM measurement, we can evaluate the debunching effect of the ALPHA storage ring.

Due to the debunching, the domodulation scheme is no longer valid in the extraction line. To preserve the DC part in the spectrum, we use a low pass amplifier instead of the previous band pass amplifier. By comparing the frequency spectrum of injected and extracted beam in Fig. 7 and Fig. 8, we can see the obvious debunching effect.

CONCLUSION

After the bench test, a wide band WGM has been installed in ALPHA to measure beam charge and longitudinal profile in both injection and extraction line. In the injection line, a demodulation signal processing scheme is applied to recover the DC information of the beam. Combined with a bending magnet scanning, the WGM data can be used to paint the longitudinal phase space of the macropulse, as well as the energy spectrum of the LINAC beam. This is used as diagnosis for the LINAC tuning. By comparing the frequency spectrum of the injected and extracted beam, we have confirmed the debunching effect of the ALPHA storage ring.

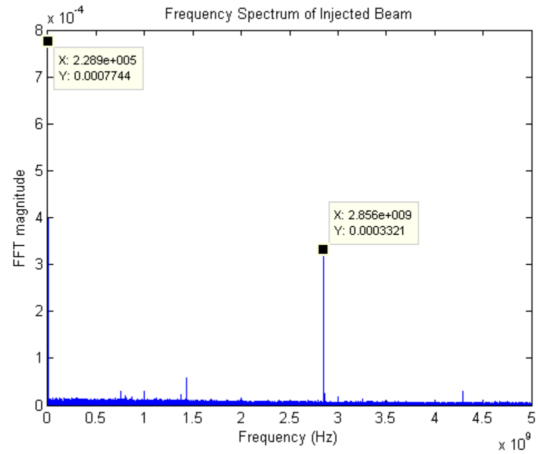

Figure 7: The frequency spectrum of the injected beam.

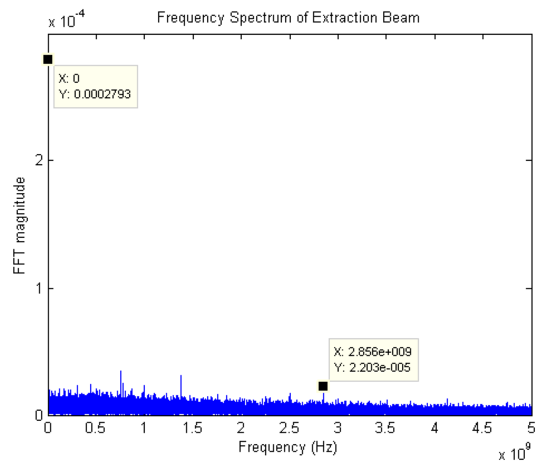

Figure 8: The frequency spectrum of the extracted beam.

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