Bunch Shape Monitor for HINS

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Content

- Status of HINS 2.5MeV beam
- Needs of bunch shape measurement
- Basic idea of BSM
- BSM for HINS
Longitudinal distribution of a bunch in linear accelerators is one of the most important beam parameters.

- Can be used for beam dynamics study
- Can be used to tune accelerator
Basic Idea of Bunch Shape Monitor
Basic Idea of Bunch Shape Monitor

Electron

Beam Pipe

RF Deflector

Frequency = h x f_0

Signal Pickup

Pass at zero-phase

Proton Beam

-10 kV
Estimation on Measurement Resolution

Resolution:

\[
\frac{\Delta \sigma_{\phi}}{\sigma_{\phi, \text{full}}} = \frac{w_s}{2dx}
\]

\[
= \frac{w_s}{2L_T \theta_x}
\]

Lorentz Force Law:

\[
\theta_x(\beta, \phi) = \frac{1}{(B \rho) (\beta c)} \int_{L_D} E_x dz
\]

where

\[
B \rho [T \cdot m] = 3.3357 \ p [GeV / c]
\]

is the momentum rigidity
An Estimation on Measurement Resolution

\[ \int E_x \, dz \equiv E_{L_D} \implies \frac{\Delta \sigma_\phi}{\sigma_\phi} \propto \frac{1}{E L_D} \]

**Assume**
- Slit Width, \( w_s = 1 \text{ mm} \)
- Total Distance, \( L_T = 30 \text{ cm} \)

**1% Resolution**

\[ E_{L_D} = 3000 \left[ \text{(V/m)(m)} \right] \]

3.5 cm long deflector

\[ E_x < 100 \text{ kV/m} \]
Reasons for Using Bunch Shape Monitor

1. High Bandwidth Requirement

- High Bandwidth Requirement
- Non-destructive measurement:
- 5% Resolution

\[ \sigma_z = \beta c \sigma_l \]
\[ \beta = 0.073 \text{ at } 2.5 \text{ MeV} \]
\[ \Rightarrow \sigma_{t,full} \approx 300 \text{ ps} \]
\[ \Rightarrow \sigma_{\phi,full} \approx 35^0 \text{ at } 325 \text{ MHz} \]

Bandwidth = 33 GHz
Not easy to achieve

2. Non-Relativistic Proton

\[ \Delta t = \frac{L}{\beta c} = \frac{2R}{\gamma \beta c} \]
\[ R = 2 \text{ cm} \text{ suggests that :} \]
\[ \Delta t \approx 2ns \gg \sigma_{t,full} \]

Wall Current Monitor No Good
It was designed and used for longitudinal beam profile measurement in the 400 MeV Linac some 15 years ago. We will attempt to use it for the HINS Linac front end after some modifications.
RF Deflector
RF Deflector

RF Deflector sits inside the housing
RF Deflector MWS Model

Adjustable Spacing (Major Tuning)

Slug Tuner (Fine Tuning)

Copper Arm

Nylon Support Ring

RF Input

DC Voltage

RF Readback

DC Voltage

Electric Field

λ/2
This RF deflector is designed for Fermilab 400 MeV Linac thus resonates at:

\[ 201.25 \text{ MHz} \times 4 = 805 \text{ MHz} \]

**Question:** Can we use it for HINS?
Tune RF Deflector to HINS Frequency 325MHz

Fermilab Linac 805 MHz

HINS 325*2 = 650 MHz

RF deflector can be used without machining.

Adjust Spacing
Huge Gradient in Endcap Spacing

Assumption: Energy stored in resonator constant

\[ E_{\text{Endcap}} \sim 6 \times E_x \]

Possible problems:
1. Sparking at endcaps
2. Drop in shunt impedance

\[ E_x \sim \text{hundreds of kV/m} \Rightarrow E_{\text{Endcap}} \sim \text{MV/m} \]
Power Dissipation and Quality Factor

Power dissipation drop when move to HINS frequency.

Variation < 10%

Quality factor drop when move to HINS frequency.

$Q_0 = \frac{\omega U}{P_{loss}}$

Variation < 10%
Define Shunt Impedance

\[ R_s \equiv \frac{|EL|^2}{P_{loss}} \]

where \( |EL| \equiv \int_{L_D} |E_x| dz \)

No drop in Shunt Impedance.

Improved by 15%
Quality Factor Measurement

Graph showing the relationship between Quality Factor and Frequency. The graph indicates a peak at a certain frequency, with Quality Factor values ranging from Q0 to QL. The frequency range is from 550 MHz to 850 MHz.
Shunt Impedance Measurement

- Place 2 slightly coupled probes near the deflecting plates
- Apply a known voltage across the plate and the housing by loading down the system
- Scale the transmission coefficient from the probes
- Determine the ratio of voltage to power
HINS needs bunch shape measurement. The introduced bunch shape monitor can possibly provide the service.

Basic idea of the bunch shape monitor is explained. Bunch shape measurement using low energy secondary emission electron can achieve a high resolution (tens of GHz).

A bunch shape monitor designed for Fermilab 400MeV Linac is readily available. Preliminary study on its RF deflector shows that it is possible to use it for the HINS Linac Front End.

More testing will be carried out.
More on Beam Deflection Mechanism
Maximizing Angle of Deflection

The angle of deflection:

\[ \theta_{x,i} = \frac{1}{B \rho} \int_{t_0}^{t_f} E_x(z,t) dt \]

\[ = \frac{1}{B \rho} E_{x0} \int_{t_0}^{t_f} \sin(\omega_{rf} t + \phi_i) dt \]

To keep center of bunch undeflected:

\[ \phi_{center} = 0 \]

\[ t_0 = -L_D / (2 \beta c) \]

\[ t_f = +L_D / (2 \beta c) \]

Also

\[ \phi_{end} = \pm \sigma_{\phi, full} / 2 \]
Optimal Length of Deflector

Electron Energy = 10 keV

$\sigma_{t,\text{full}} = 300 \, \text{ps}$

$\phi = \sigma_{\phi,\text{full}} / 2$

Resolution $\Delta \Phi / \Phi$ [%]

- $E_{x0} = 300 \, \text{kV/m}$
- $E_{x0} = 500 \, \text{kV/m}$
- $E_{x0} = 700 \, \text{kV/m}$
- $E_{x0} = 900 \, \text{kV/m}$

Length of Deflecting Plates [meter]

49.4 mm
Optimal Length of Deflecting Plates vary with electron energy due to transit time factor.

Attention is needed when used with a different electron energy.
### The ProjectX Linac and HINS

#### HINS R&D Program: RT Section + 3 Cryomodules from 0 ~ 60 MeV

<table>
<thead>
<tr>
<th>Ion Source</th>
<th>RFQ</th>
<th>MEBT</th>
<th>RT-CH</th>
<th>SSR1</th>
<th>SSR2</th>
<th>TSR</th>
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<tbody>
<tr>
<td>Eout</td>
<td>50 keV</td>
<td>2.5 MeV</td>
<td>2.5 MeV</td>
<td>10 MeV</td>
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<td>120 MeV</td>
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<td>Zout</td>
<td>0.7 m</td>
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<td>15.8 m</td>
<td>31 m</td>
<td>61 m</td>
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<td>Cavities</td>
<td>2 buncher cavities and fast beam chopper</td>
<td>16 copper CH-spoke cavities</td>
<td>18 single-spoke SC cavities $\beta=0.2$</td>
<td>33 single-spoke SC cavities $\beta=0.4$</td>
<td>66 triple-spoke SC cavities $\beta=0.6$</td>
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**RT Section** + 3 Cryomodules from 0 ~ 60 MeV