

Trimming Longitudinal Emittance of Au⁷⁷⁺ in the AGS

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October 1993

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U.S. Department of Energy

USDOE Office of Science (SC)

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AGS Complex Machine Studies

(AGS Studies Report No. 311)

Trimming Longitudinal Emittance of Au^{77+} in the AGS

Study Date: October 15, 1993.

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Reported by: D. -P. Deng

Machine: AGS

Beam: Gold 77+ Ions

Tools: LeCroy 7200A scope, LeCroy 9040 scope F20 wall current monitor.

1 Introduction

In FY93 gold run for SEB in AGS, the injected bunched beam from Booster was debunched into a ribbon beam and then adiabatically captured into 12 bunches.

In this report, we studied a method—bucket squeezing—to trim the longitudinal emittance during the acceleration cycle in at the expense of reduced beam intensity.

Longitudinal emittance is usually defined by the **macroscopic** area occupied by 95% of the particles in the longitudinal space. One pair of commonly used canonical variables in the longitudinal space are the rf phase ϕ and $W = (E - E_s)/\omega_{rf}$ the energy difference from the synchronous energy divided by the angular rf frequency. Thus the longitudinal emittance takes the unit of the product of energy (electron volts) and time (seconds) or eVs . For heavy ions, a convenient unit is electron-volt-second per nucleon or eVs/u , the total emittance divided by the total number of nucleons. The longitudinal emittance is a conserved quantity under adiabatic and no beam loss conditions. Any non-adiabatic changes, such as transition crossing, can only increase the emittance.

In this report, we use the bunch size, bunch area and longitudinal emittance interchangeably.

2 A bunch in a bucket

A bunch is accelerated in a bucket provided by the rf system. The size of the bucket at certain energy is solely depended on the total rf voltage V_{rf} and the rate of change in the magnetic field \dot{B} .

$$\frac{1}{2} A W^2 = -B (\cos \phi - \cos (\pi - \phi_s) + (\phi - \pi + \phi_s) \sin \phi_s) \quad (1)$$

$$V_{rf} \sin \phi_s = 2\pi R_0 \rho \dot{B} \quad (2)$$

where

ϕ_s : the synchronous phase,

$A = \eta \omega_{rf}^2 / E_s \beta^2$,

$B = e V_{rf} / 2\pi h$,

$\eta = 1/\gamma_{tr}^2 - 1/\gamma^2$,

E_s : synchronous energy,

$\beta = v/c$: ratio of the speed of synchronous particle to that of light,

e : charge state of the particle,

V_{rf} : rf volts,

h : harmonic number, the ratio of the rf frequency to the revolution frequency of the synchronous particle,

R_0 : the average radius of the orbit,

\dot{B} : rate of change in the magnetic field in the orbit,

ρ : the magnet bending radius.

These equations determine the shape of the bucket, see Figure 1. The size of the bucket critically depends on the synchronous phase ϕ_s , if $\phi_s = \pi/2$, the size of the bucket goes to zero. Usually the \dot{B} is programmed a priori, then the gap volts is the only handle to change the size of the bucket.

It is obvious that the bucket has to be bigger than the bunch, otherwise beam is lost. This is also the basis to trim the longitudinal emittance by decreasing the size of the bucket below the size of the bunch non-adiabatically, see Figure 2. As long as the magnetic field is rising the beam outside the bucket will be driven to the beam catcher.

3 Experimental results

The experimental technique is very simple. When rf voltage is suddenly dropped down to sufficiently low, the bucket size will shrink below the size of the bunch. All the particles outside the smaller bucket are gone very quickly. The beam longitudinal emittance is essentially the area of the smaller bucket. As the rf voltage is adiabatically raised, the beam maintains its latter longitudinal emittance.

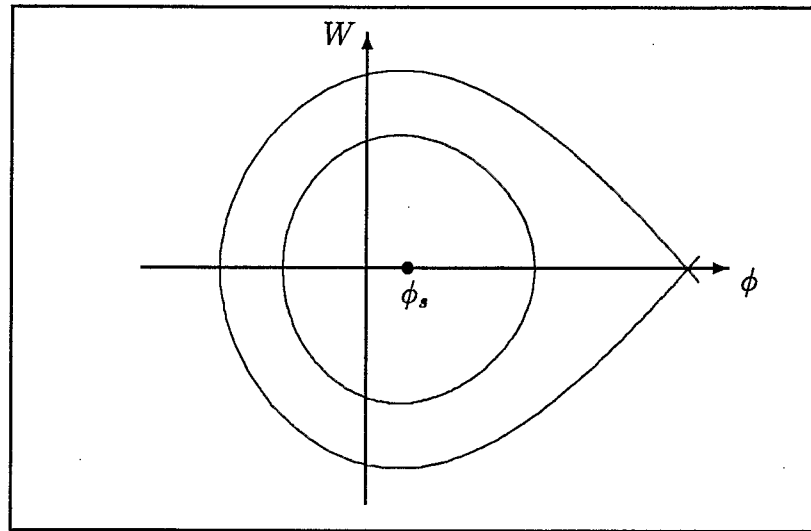


Figure 1: A bunch is inside a bucket

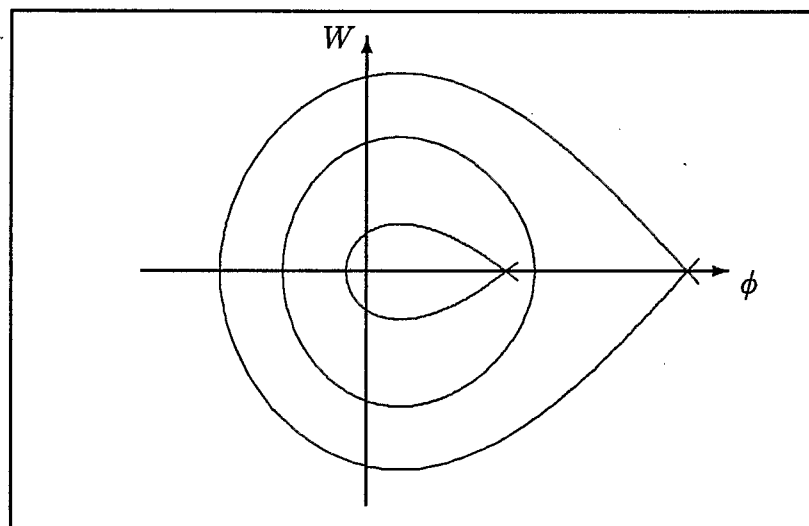


Figure 2: Bucket squeezing. The large bucket is suddenly shrunk to the small bucket.

3.1 Voltage program 1

The normal rf voltage during acceleration is kept constant at 200 kV . In our studies, we have designed two rf programs. In program 1, the rf voltage is dropped in the middle of acceleration from 200 kV down to 100 kV instantaneously and then gradually raised to 200 kV in 150 ms . Figure 3 shows

1. Voltage program.
2. F15 current transformer signal (beam intensity)
3. The rate of change of magnetic field \dot{B} .
4. F20 wall current monitor signal (bunch shape).

Figure 4 shows the bunch shape in the normal rf program, Figure 5 shows the bunch shape in the program 1. The bunch length has reduced from 55 ns long to 29 ns long. The measurement is made 478 ms after T_0 .

3.2 Voltage program 2

In program 2, the rf voltage is dropped from 200 kV down to 100 kV instantly, remained in there for 130 ms and then gradually raised to 200 kV in 100 ms .

Figure 7 shows the bunch shape in the normal rf program, Figure 8 shows the bunch shape in the program 2. The bunch length has reduced from 29 ns long to 18 ns long. The measurement is made 608 ms after T_0 .

4 Conclusions

We have successfully demonstrated the validity of bucket squeezing technique to trim longitudinal emittance. And in principle, this technique can produce beam with arbitrary value of longitudinal emittance, of course, provided that the intensity is not a big concern.

In the particular programs used the beam loss is roughly 50%. In the AGS Studies Report No. 310, the measurement of longitudinal emittance is illustrated. To extend the results there further, the emittance scales approximately as the square of the bunch length. So in program 1, the emittance reduction is $1 - (29/55)^2$ or 72%; in program 2, the emittance reduction is $1 - (18/29)^2$ or 60%.

"1-knob-Long-emittance"

15-Oct-93
3:27:21

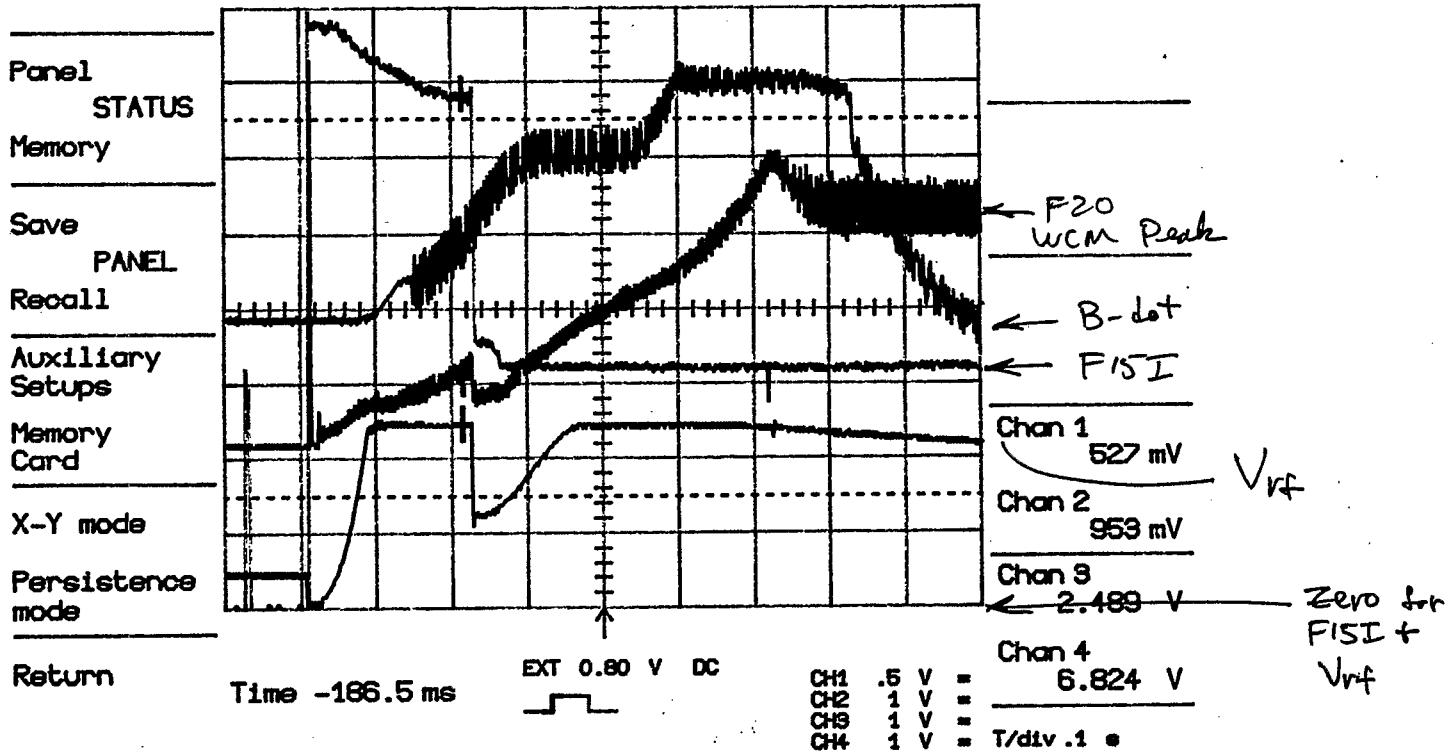


Figure 3: Voltage program 1. F15 current transformer signal (beam intensity). The rate of change of magnetic field \dot{B} . F20 wall current monitor signal (bunch shape).

14-Oct-93
21:14:33

7200A Precision Digital Oscilloscope

LeCroy

Record Traces
On ☐ Off

↓A1
Δ -1.5 mV

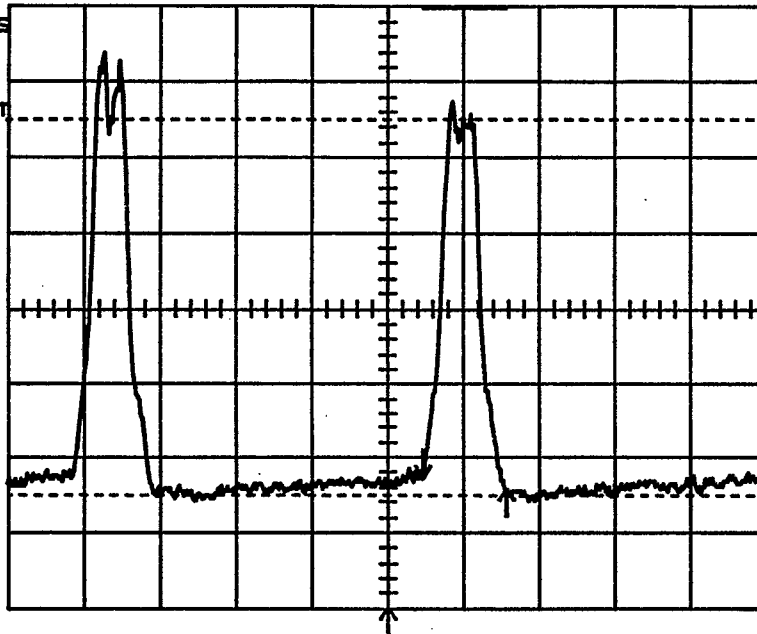
Replay Traces
On ☐ Off

Learn Program
On ☐ Off

EZ Menu
On ☐ Off

Configure
System

Default
Settings



10 mV/DIV.

Turn OFF
Horizontal

At 55.0 ns
1/Δt

18.26 MHz

Select
Cursor

Move ↑



Multi Zoom
On ☐ Off

" 1-knot

Tr
wi

Figure 4: The bunch shape in the normal rf program.

14-Oct-93
21:05:19

7200A Precision Digital Oscilloscope

LeCroy

Record Traces
On ☐ Off

Replay Traces
On ☐ Off

Learn Program
On ☐ Off

EZ Menu
On ☐ Off

Configure
System

Default
Settings

Turn Off
Horizontal

Δt 29.0 ns
 $1/\Delta t$

34.8 MHz

Select
Cursor

Move \uparrow

$\uparrow A1$
 $\Delta 2.1 \text{ mV}$

5 mV/DIV

Multi Zoom
On ☐ Off

"1-kno

b
a

Figure 5: The bunch shape in the trimming program 1, shortened in comparison with previous figure, taken at the same point in the cycle.

without - "2-Knob - long - emittance"

14-Oct-93
21:53:01

7200A Precision Digital Oscilloscope

LeCroy

Record Traces
On ☐ Off

⊕ A1
Δ 200 μV

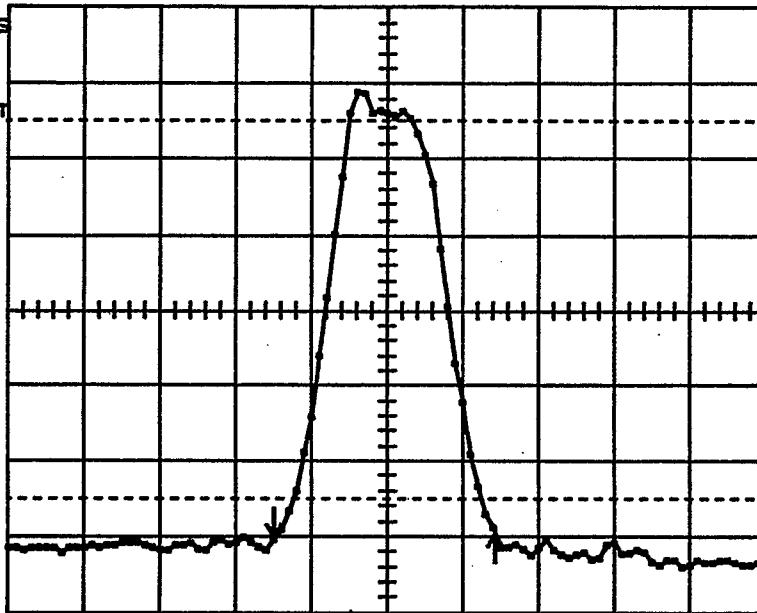
Replay Traces
On ☐ Off

Learn Program
On ☐ Off

EZ Menu
On ☐ Off

Configure
System

Default
Settings



10mV/DIV

Turn Off
Horizontal

At 29.20 ns
1/Δt

34.25 MHz

Select
Cursor

Move ↓



Multi Zoom
On ☐ Off

trig.

Figure 7: The bunch shape in the normal rf program.

14-Oct-93
21:48:17

7200A Precision Digital Oscilloscope

LeCroy

Record Traces
On ☐ Off

⊕ A1
Δ -800 μV

Replay Traces
On ☐ Off

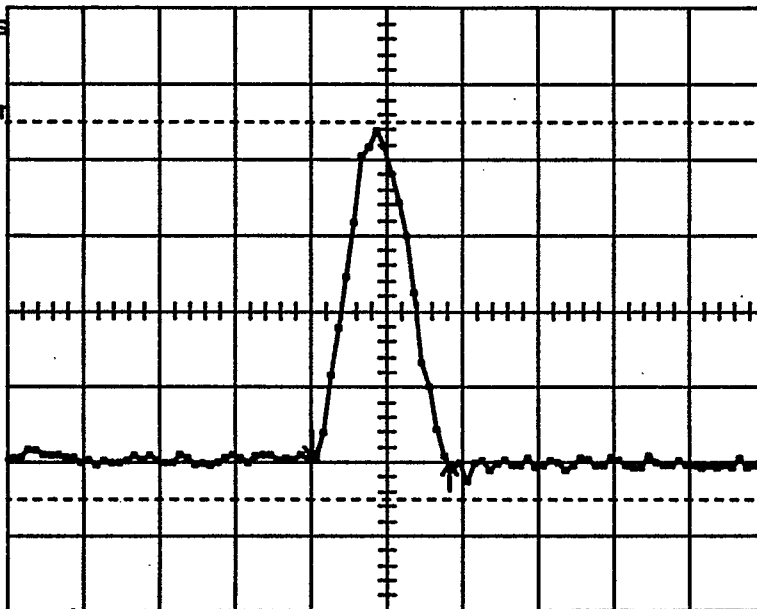
Learn Program
On ☐ Off

EZ Menu
On ☐ Off

Configure
System

Default
Settings

Turn Off
Horizontal



↑
Δt 18.15 ns
1/Δt

55.1 MHz

Select
Cursor

Move ↑



Multi Zoom
On ☐ Off

10mV/DIV

with
"2"
at

Figure 8: The bunch shape in the trimming program 2, shortened in comparison with previous figure, taken at the same point in the cycle.