MICROWAVE INSTABILITIES IN BOOSTER AND AGS*

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Microwave instabilities is evaluated for the Booster and AGS for the preparation of the relativistic heavy ion collider. We found that the Booster may require feedback system for the transverse instability at the high intensity proton operation. The coherent instability is not important for the nominal RHIC operational intensity.

Introduction

The construction of the Booster at Brookhaven National Laboratory has to meet several important issues: (1) acceleration of heavy ion to the highest energy available for the stripping of charge states; (2) acceleration of the highest intensity proton beam with high repetition rate for the strange particle productions; (3) accumulation of the polarized proton from the pulses of LINAC to obtain good intensity for the experiment and for possible polarized proton operation in RHIC. To meet these aims, we shall evaluate the constraint on the booster design and required upgrade in the AGS from the point of view of the coherent instabilities.

Table 1 lists the design parameters for the Booster relevant to the coherent instability.

Booster Parameters In The Coherent Effect

part.species	P	S	Au
A	1	32	197
<Q>	1	14	33
$N(10^9)$	5000	6.7	2.2
β_{iNj}	0.5662	0.1002	0.0463
γ_{iNj}	1.2131	1.0050	1.0010
ε(π mm-mrad)	50	50	50
ε_N(π mm-mrad)	34.35	5.04	2.32
η	-0.64	-0.95	-0.95
$\Delta\upsilon_{sc}$	0.77	0.35	0.50
τ_{REV}(μs)	1.19	6.72	14.54
V (kV)	90000	610	1600
ϕ_S	0.0462	0.6822	0.2601
h	3	3	3
area(evs/amu)	1.6636	0.0675	0.0673
ω_{SYN}	45895.	2952.7	3322.1
$\Delta p/p(10^{-9})$	4.1939	1.0911	2.4943
σ_L(m)	9.8651	10.507	9.9472
I(peak)(amp)	5.4982	0.0171	0.0064
I(av.)(amp)	2.0214	0.0067	0.0024

Estimate of the Impedance of the Booster

The interaction between the beam and its environment can be described by two frequency dependence terms, the transverse impedance $Z_\perp(\omega)$ and the longitudinal impedance $Z_\parallel(\omega)$. There are serveral sources of the impedance in the accelerators

(1) Resistive wall of the vacuum chamber:

The vacuum chamber of the booster is made of stainless steel. The conductivity of the stainless steel is $\sigma = 7.7 \times 10^5$ mho/m. The impedance is then estimated to be $Z_\parallel/n$ = (1-i) .33/sqrt(n) Ohm and $Z_\perp$ = (1-i) 1.2/sqrt(n) MOhm/m.

(2) Space charge contribution

$$Z_\parallel/n = i\,\frac{Z_0 g_0}{2\beta\gamma^2} = i\ 27.5\ \text{Ohm}$$

$$Z_\perp = i\,\frac{RZ_0}{\beta^2\gamma^2}\left(\frac{1}{a^2}-\frac{1}{b^2}\right) = \begin{cases} i\ 9.2\ \text{MOhm/m -- proton} \\ i\ 2018\ \text{MOhm/m -- Au} \end{cases}$$

(3) Bellow contribution

The impedance of bellows is similar to that of the cavity. At low frequency, the contribution of these resonances is purely capacitive. They can be estimated to be $\mathrm{Im}(Z_\parallel/n) = 2.0/\beta$ Ohm and $\mathrm{Im}(Z_\perp)$ = .066 MOhm/m which are much smaller than the impedance due to the space charge. At the resonance frequency, for the geometry of cylindrical configuration with length 1.5 m and radius 7.6 cm, the fundamental frequency would be around 1.5 GHz. Using TBCI code the Q value is estimated to be around 7000. Because of the length, the resonances are densely populated. The revolution frequency of the particle is smaller than 1.48 MHz. Thus the n value of the collective mode is about 1500. The estimated effective impedance of the bellow are (ref. 2) $Z_\parallel/n$ = 3.3 Ohm and $Z_\perp$ = .02 MOhm/m.

(4) Beam position monitors

There are 48 PUE's of 30 cm each in the booster. Using stripline configuration approximation, the impedances are estimated to be $Z_\parallel/n = .049n - i\,5.3\beta$ Ohm and $Z_\perp = .005n - i.058b$ MOhm/m.

Adding up all the contributions estimated above, we obtain that the impedance besides the space charge contribution are $Z_\parallel/n$ = 7.9 Ohm and $Z_\perp$ = 0.143 MOhm/m.

The Stability Limit for the Single Bunch Collective Effect

We assumed that the bunch has Gaussian distribution with RMS distribution $\Delta p/p$ and σ_L given in the table 1.

(a) The microwave instability, with growth rate much faster than the synchrotron oscillation frequencies, are given by[1]

$$|Z_\parallel/n| \le \frac{2\pi|\eta|EA}{qeI_p}(\Delta p/p)^2 \qquad (1)$$

$$|Z_\perp| \le \frac{4\sqrt{2\pi}|\eta|EA}{qeI_p\langle\beta\rangle}(\Delta p/p) \qquad (2)$$

Table 2 lists the limiting impedance for the microwave instability for the booster.

Table 2 Booster Parameters in the coherent effect

part.species	P	S	Au
$Z_\parallel$/n(Ohm)	14439.	3E+07	6E+09
$Z_\perp$(MOhm/m)	826.30	6E+06	6E+08
V(1/sec)	705	2.9	1.2

(b) For the transverse coherent growth due to the resistive wall impedance is given by the solution of the dispersion integral

$$1 = (U + (1+i)V)\int \frac{f(p)}{\omega-(n-Q)\Omega}\,dp \qquad (3)$$

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where U and V are related to the space charge and resistive wall impedance respectively. f(p) is the momentum distribution of the bunched beam. When the space charge impedance is large at low energy, the solution of eq. (3) has the property, $\mathrm{Im}(\Omega)=V$, which is the resistive wall contribution (see Fig. 1). The last row of table 2 lists the growth factor V for various ion species. Note here that the growth factor is important only for the high intensity proton operation.

Couple-bunch Collective Instability

Booster is operating at h=3 harmonic mode. There are 3 possible coupled bunch modes in the booster. The eigenmode are given by (ref. 1)

$$\Delta\Omega_a = i\,\frac{ge\eta I_o\omega_o^2\hat{\theta}Z_{eff}}{2\pi E\omega_{so}2^2(a-1)!}$$

where $\hat{\theta}$ and I are the rms bunch length and the total average current. The effective impedance is given by

$$Z_{eff} = \sum_{n=-\infty}^{\infty} (nh+s)^{2a-1}Z\left[(nh+s)\omega_o+\Omega\right]\, e^{-.5(nh+s)^2\hat{\theta}^2}$$

where $\Omega \equiv a\omega$ is the mode frequency. Since the synchrotron frequency ω_S is a function of the synchrotron amplitude, the resulting frequency provides Landau damping to the coupled bunch motion. Thus the limiting impedance is given by (see Table 3 for the dipole mode a=1),

$$|Z_{\parallel}| \le \frac{2\pi E2^a a!\ 0.32F_a h^2(2.5\hat{\theta})^2}{16\ qe\eta I_o\omega_o^2\hat{\theta}^{2a-2}}$$

Note here that the limiting impedance is much larger to the impedances estimated in section 2.

Table 3. Limiting impedance for the coupled bunch instability

part.species	P	S	Au
|Z| (Ohm)	1.2E6	7E9	9E10

Microwave instability across the transition energy in the AGS

The particles accelerated through the booster will be accelerated in the AGS to reach B = 100 Tm. These particle will pass through AGS transition energy. Because of the Landau damping at the transition energy becomes rather ineffective, the microwave instability may be important. At the assumed RHIC performance parameters (ref. 5) there is no effective growth for the bunched beam (ref. 4).

However the AGS is also intended to operate at the high intensity mode. At the intensity of 4×10^{13} ppp in the AGS, Fig. 2 shows the total growth vs the real part of the impedance in the AGS for phase space area of 1.06 evsec and 2.00 evsec respectively. Since the total growth scales like N^2/a^3, the increase in the intensity can be accommodated by an increase in the phase space area.

Conclusion

In conclusion, we have estimated the possible effect of the coherent instability in the booster. We identify that the only possible important effect is the transverse instability due to the resistive wall effect for the high intensity proton at the low energy. Feedback system may be needed. The instability becomes less important as the energy of the bunch is increased. Further work on the coupled bunch transverse instability is needed.We have also calculated the effect of the high intensity proton accelerated through the transition energy in the AGS. Larger longitudinal phase area is needed to minimize the microwave instability at the transition energy. For the RHIC operation, the transition energy does not play important role in AGS.

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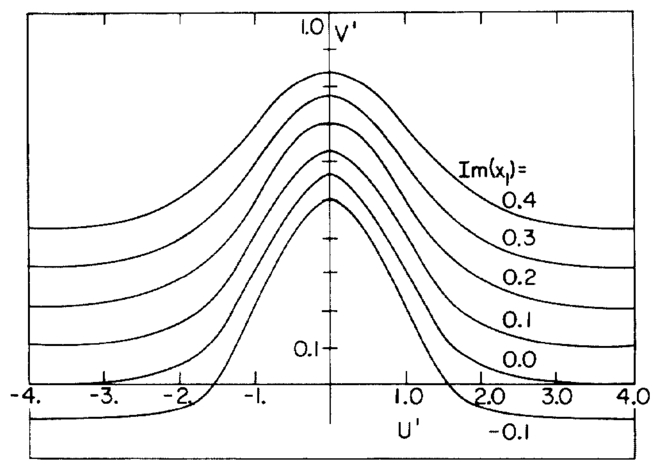

Fig. 1. Stability diagram for the transverse instability due to the resistive wall and space charge impedances with Gaussian distribution.

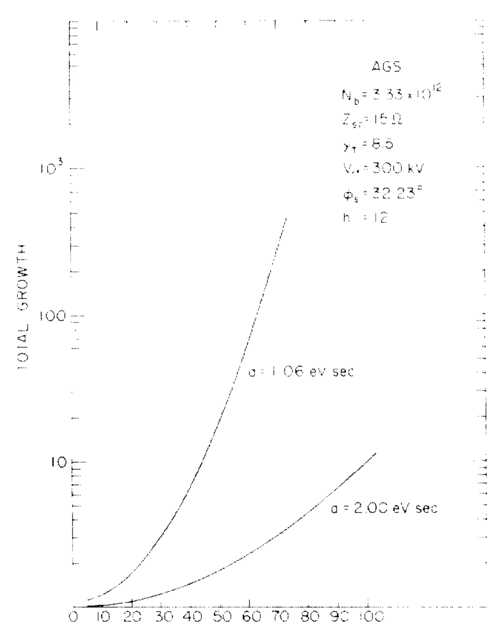

Fig. 2. Total growth due to microwave instability across the transition energy of AGS is shown as a function of the real part of the impedance in AGS. We have assumed $4\cdot10^{13}$ ppp intensity in AGS.