Instabilities and Collective Effects

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1. AGS injection parameter

Beam power, Linac exit	0.06	MW
Kinetic energy	1.5	GeV
Repetition rate	2.5	Hz
Pulse length	1.05	ms
Injection turns	360	
Chopping rate	0.65	
Linac peak current	25	mA
Momentum spread	$\pm$ 0.2	%
Norm. 95% emittance	12	$\pi\mu m$

Table 1. Superconducting Linac parameter

RF voltage	100	KV
Bunch length	316	ns
Longitudinal emittance	5.1	eVs
Momentum spread	$\pm$ 0.47	%
Norm. 95% emittance	100	$\pi\mu m$

Table 2. AGS injection parameter

2. AGS injection consideration

- **To reduce the space charge effect, bunch needs to be long, and transverse emittance needs to be large.**
- **To reduce the dispersion induced beam loss at the transition, beam longitudinal emittance needs to be small.**

Fig.1. AGS injection with double RF

3. AGS transition loss

- With large gamma jump, the AGS transition loss is dominated by the momentum aperture limit. Small beam momentum spread helps to reduce this loss.
- RF voltage drop at the gamma jump is used in AGS operations to make the bunch long, and hence the momentum spread small.
- With small longitudinal emittance defined at the injection, same approach can be used to reduce the beam loss at the transition.

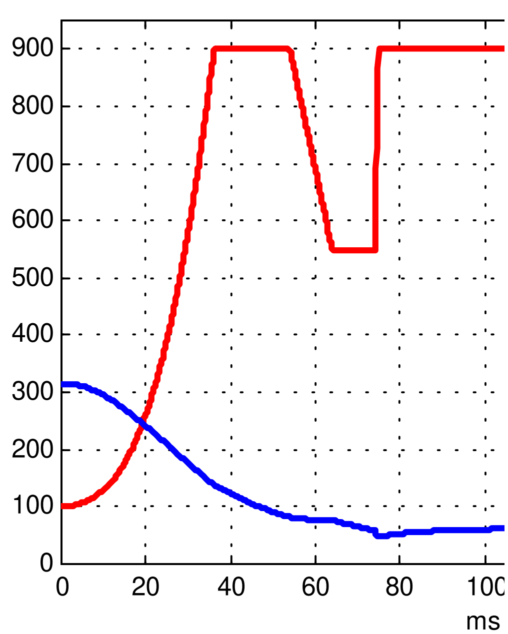

Fig.2. RF voltage for AGS operation

4. AGS beam instabilities

- **Resistive wall instability is cured by damper.**
- **Longitudinal microwave instability is not a problem, with the exception that immediate above transition.**
- **This is cured by the fast RF voltage rise and VHF cavity dilution, which enlarges the beam longitudinal emittance.**
- **AGS is transversely unstable at high energy, above transition. This is normally cured by using VHF cavity dilution.**
- **Beam longitudinal emittance is enlarged to 10 eVs at the extraction.**

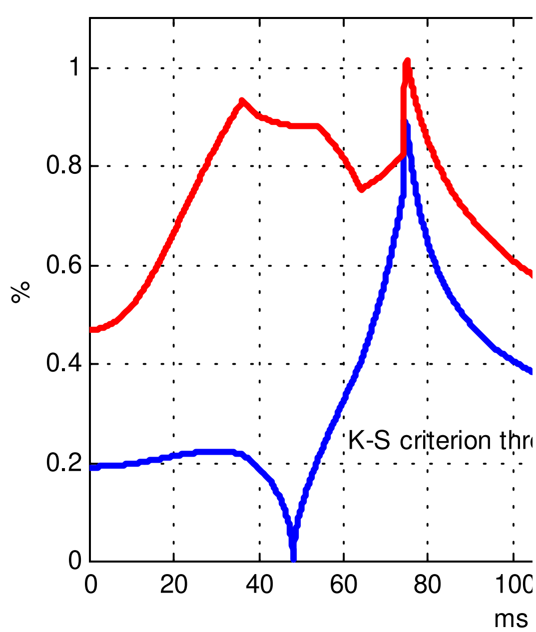

Fig.3. Beam momentum spread and K-S criterion

5. Compressor ring parameter

Circumference	200	m
Bending field	4.15	Tesla
Kinetic energy	24	GeV
Transition gamma	38.4	
eta	-0.00074	
Betatron tune, x/y	14.8/9.2	
Maximum beta function, x/y	12.9/19.8	m
Dispersion function	0.12	m
Chamber radius	25	mm
Maximum beam radius, x/y	7.0/8.6	mm
Acceptance, x/y	48.5/31.6	$\pi\mu m$
Beam emittance, x/y	3.8/3.8	$\pi\mu m$
Accp./emit. ratio, x/y	12.8/8.3	
Natural chromaticity, x/y	-2.5/-1.7	(norm)

Table 3

- **Operated below transition.**
- **Very small slippage factor, quasi-isochronous ring.**
- **Very small dispersion.**
- **Acceptance/emittance ratio > 8, with the consideration of extremely tight beam loss limit.**
- **Chromaticity needs to be corrected.**

6. RF parameter

RF frequency	5.94	MHz
Harmonic number	4	
RF Voltage	200	KV
Bucket height, in dp/p	±4.2	%
Bucket area	222	eVs
Bunch area	10	eVs
Synchrotron frequency, center	91.5	Hz
Synchrotron frequency, edge	82.6	Hz

Table 4

- **Bunch is injected from the AGS, unmatched. It is extracted immediately after a bunch rotation.**
- **Very low RF voltage required, because of the very small slippage. For the same bucket height, RF voltage in the AGS needs to be 5.3 MV.**
- **Bunch rotation takes a quarter of synchrotron period, i.e. 3 ms, or 4500 turns.**

7. Longitudinal aspect

	Inj.	Ext.	
Particle per bunch	0.17	0.17	10^{14}
Bunch rms length	5/17	0.9/3	m/ns
Peak current	65	363	A
Beam momentum spread	±0.4	±2.24	%
Longitudinal emittance	10.5	10.5	eVs
Broadband impedance	5	5	j Ω
Long. space charge imp.	-1.66	-1.66	j Ω
Keil-Schnell threshold	3.75	25.5	Ω
Effective RF voltage	200	248	KV

Table 5

- **Longitudinal microwave instability threshold is low at the injection, because of the small slippage factor and low dp/p.**
- **Bellows will not be shielded, in order to avoid finger contact arcing, but the chamber steps will be tapered. Broadband impedance of j 5 Ω is reasonable to achieve.**
- **Combination of the broadband and space charge impedance is j3.34 Ω, slightly lower than the K-S threshold. Since it is below the transition, beam instability is not expected.**
- **The overall inductive impedance below the transition has a focusing effect, which is shown as the increase of the effective RF voltage in the bunch rotation.**

8. Transverse aspect

	Inj.	Ext.	
Broadband impedance	0.51	0.51	jMΩ/m
BB imp. induced tune shift	0.0003	0.0017	
Space charge inc. tune spread	0.003	0.016	
Chromatic tune spread, $\xi = 2$	0.22	1.32	
Chromatic frequency, $\xi = 2$	59.4	59.4	GHz

Table 6

- **Transverse impedance is low for compressor ring, $Z_T \propto R$.**
- **Strong focusing also helps for less tune shift.**
- **Comparing to the AGS, the beam is transversely more stable. This is just opposite to the longitudinal instability.**
- **Space charge incoherent tune spread is small.**
- **But if the chromaticity is not corrected, the chromatic tune spread is large.**
- **Chromatic frequency is very large, because of the small slippage factor, the high revolution frequency, and the high tune.**
- **Normalized chromaticity may need to be controlled within the range of 1%.**

9. Conclusion

- **The scheme of 1 MW proton driver is feasible.**
- **AGS beam intensity is modestly higher than the normal high intensity proton operation. Since the proposed beam emittance is larger, the beam instability is not expected to be a problem.**
- **Beam loss limit is tight at the AGS, which may require some upgrade.**
- **Compressor ring design requires very low RF voltage. Also the potential well effect helps for the short bunch production.**
- **Required impedance is reasonable to achieve.**
- **Acceptance/emittance ratio of 8 is much larger than the existing and proposed high intensity proton accelerators. Together with the large momentum aperture, the beam loss can be controlled.**
- **Chromaticity control at the compressor ring is tight, and may need some study.**