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NewFEB: SBE to the SEB Line using FKGlO

M. Tanaka

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Collider Accelerator Department

Brookhaven National Laboratory

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Accelerator Division
Alternating Gradient Synchrotron Department
BROOKHAVEN NATIONAL LABORATORY
Upton, New York 11973

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Technical Note

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M. (Sanki) Tanaka

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ABSTRACT

This note describes the results from a feasibility study of performing SBE to the SEB line using the new fast kicker FKG10 system for NewFEB instead of the old E05 SBE system. Without hardware modifications, it is only feasible

- at momentum p = 22-24.5 GeV/c,
- at the maximum strength of the SEB septum magnets[SMF05 and SMF10],
- at the machine tune Q_h = ~8.6,
- with a distorted extraction bump[BLWG09].

Furthermore, if the AGS accelerates high intensity protons on h =8 and its bunch length before debunching stays greater than ~100 ns, then the designed FKG10's half-sine pulse width (base) should be increased from 360 ns to 500 ns.

1. Introduction

The AGS new fast extraction [NewFEB] system is designed to perform single bunch multiple extraction [SBME] at 25-50 ms intervals up to 12 times per AGS cycle for the muon g-2 experiment (E821) and for RHIC injection. The NewFEB system, described fully in the conceptual design report and conference papers[1], is under construction and will consist of a new fast multi-pulsing kicker with a limited aperture at straight section G10 [FKG10] and a new ejector septum magnet at straight section H10 [SMH10], together with localized extraction orbit bumps generated by powering backleg windings on the selected main magnets [BLWG09 and BLWH11]. Since the old FEB and SBE systems[2] are no longer available, retaining the capability of doing standard FEB (one-turn extraction) to the U-line and SBE to the SEB line is desirable for the AGS physics program.

In FY1994, there are requests for the SBE test beam to the SEB line for a few days from the g-2 experiment and also from the neutrino experiment (E841/E889)[3]. The muonium-to-antimuonium conversion ($M \rightarrow \overline{M}$) experiment (E849) was originally scheduled to run a two-week experiment in the D-2 line that required a single bunch proton beam to the D-target station. If it was successful, E849 would run in the D-line with SBE in FY1995 or later[4]. E849's run plan is currently unknown. This note is an updated and extended version of the previous report[5] and describes the results from a feasibility study of performing SBE to the SEB line using FKG10 instead of FKE05.

2. The Old E05 SBE System

The old SBE system consists of a fast kicker at E05 [FKE05] and a local fast orbit bump [BLWE05] coupled with the SEB extraction system (thin septum magnet [SMF05] and thick septum magnet [SMF10] with a 3/2 λ bump [BLWF07]) [2]. This system became operational in 1983 for Experiment 745 on the QCD test in the D-line, which required a single bunch of ~35 ns long at p=22 GeV/c to produce a short pulse of muons. The E05 SBE system was also recently used to deliver the SBE test beam for the detector test of the g-2 experiment. FKE05 gave ~0.9 mrad kick to one of twelve circulating bunches without disturbing the remaining eleven bunches. SMF05 and SMF10 provided an additional ~1.2 and ~15 mrad deflection, respectively, to extract the bunch from the ring to the SEB extraction channel. It should be noted that in the original CBA and RHIC designs, the SBE and FEB systems were assumed to be used for CBA/RHIC injection. However, this system is no longer available due to the AIP program.

3. SBE to the SEB line using FKG10

3.1 Basic scheme

To perform SBE for the SEB line without the E05 SBE system implies that we have to use the FKG10 system for NewFEB as a substitute. One of the twelve circulating bunches has to be kicked by FKG10 and make almost a full turn around the ring, then jump a thin septum of SMF05 without scraping the limited aperture in the beam pipe. In the following figures, we show the location of required elements of SBE operation to the SEB line; (1) BLWG09 (1 λ bump) to produce a local orbit bump which brings the circulating beam into the aperture of FKG10, (2) FKG10, (3) SEB System: BLWF07, SMF05 together with the layout of the old E05 SBE extraction system:

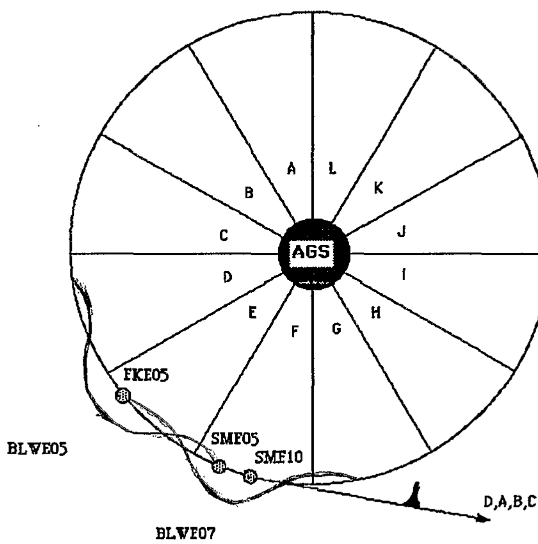

Fig. 1a. E05 SBE system.

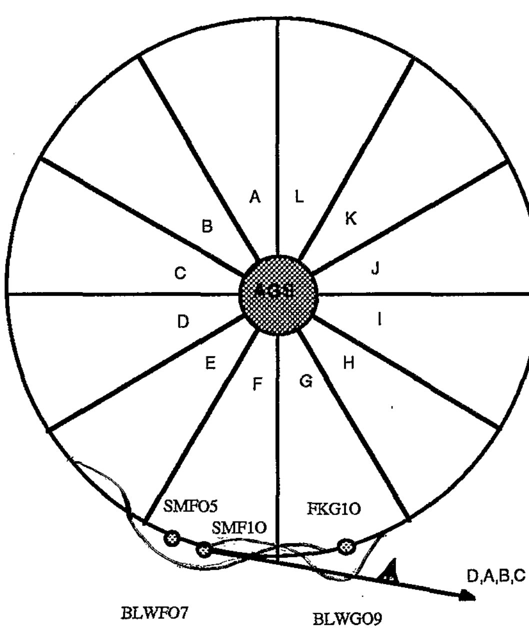

Fig. 1b. G10 SBE system.

3.2 FKG10 requirement

If $\Delta x(F05)$ is the displacement needed between the circulating bunches and the kicked bunch at SMF05, then the required kick by FKG10 can be estimated by

$$\theta(FKG10) = \Delta x(F05)/\{\sqrt{\beta(F05)\beta(G10)}\cdot\sin(\delta\mu)\}$$

where $\delta\mu$ is the betatron phase advance from FKG10 to SMF05, and β 's are beta functions. Assuming that

- $\varepsilon^*_h(95\%) \leq 50\ \pi$ mm-mrad ! horizontal normalized beam emittance
- $(\Delta p/p)_{full} \leq \pm 0.2$ % ! full beam momentum spread
- $p = \sim 24.5$ GeV/c ! typical SEB proton momentum
- $Q_h = \sim 8.7$! horizontal machine tune
- $w_s = \sim 8$ mm ! septum thickness of SMF05

and ~2 mm clearance at both sides of the septum, we have

$$\begin{aligned}\Delta x(F05) &= \text{beam full width} + \text{septum thickness} + \text{clearance}\\ &= 18\ (99\%) + 0.8 + 4\\ &= 23\ \text{mm}\end{aligned}$$

and

$$\begin{aligned}\theta_k &= 23./\{18.5\cdot(-0.964)\}\\ &= -1.3\ \text{mrad}\end{aligned}$$

This value corresponds to -0.11 T-m and is well below the design maximum strength of -0.20 T-m for FKG10 as mentioned in ref.[5] (See also table A.1). However, a MAD[6] simulation result shows that at a reasonable working point $\{Q_h, Q_v\}=\{8.78, 8.72\}$, the required kick of SMF05 will be ~3.0 mrad (or 5 kA), which is *well above* its operational maximum limit of ~1.22 mrad (2.1 A). There are two reasons for that:

- The orbit displacement Δx at SMF10_us per the fixed FKG10 kick strongly depends on Q_h. *e.g.* for $\theta(FKG10)=-1.1$ mrad, Δx (SMF10_us) changes +15 mm at $Q_h=8.56$ to -7 mm at $Q_h=8.80$ as seen in fig.2.

- The interference between BLWF07 and BLWG09 reduces the extraction bump amplitude at SMF10_us by $\Delta x= \sim 7$ mm and $\Delta x' = \sim 1.2$ mrad, which in turn requires an additional kick from SMF05 to compensate for it.

Therefore, we seek a workable solution without any modification of the existing devices by:

1) setting $\{Q_h, Q_v\}=\{8.61, 8.75\}$ at p=24.5 GeV/c where $IQ_h= -230$ A & $IQ_v= 115$ A,

2) minimizing the interference between BLWF07 and BLWG09 at SMF10_us by distorting the 1 λ BLWG09, which would have at least two independent power supplies (XBLWG09a and XBLWG09b).

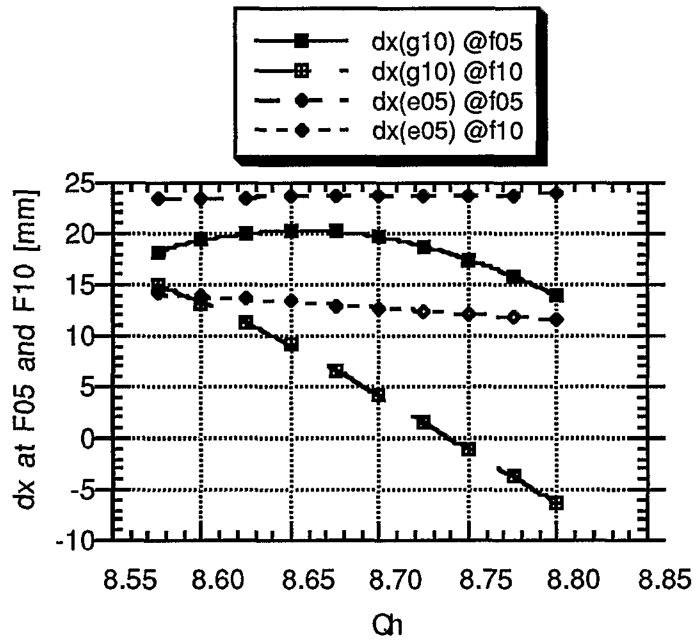

Fig.2. The displacement Δx at SMF05 and SMF10_us by FKG10 (and FKE05) as a function of Q_h.

4. MAD Simulation

4.1 Results

A series of MAD simulations was performed with a model of AGS that includes quadrupolar and sextupolar components of the main combined function magnets, the extraction components and high field tune control quadrulpoles to find a workable solution. First, MAD was run to obtain the desired closed orbit at FKG10 and SMF05 with BLWF07 and BLWG09a(F8/F9, G2/G3) and BLWG09b(G16/G17) while keeping the machine tune at $Q_h = 8.61$ as shown in fig.3 with numerical values from the MAD output. Then, the bunch with initial conditions at the beginning of ssG10 is traced through the lattice and receives appropriate kicks by FKG10, SMF05 and SMF10, assuming that the extracted bunch must be about 44 cm from the reference orbit at straight section F13_md. The bunch kicked by FKG10 has to make almost a full turn and jump the septum of SMF05 with large orbit perturbations of ± 30 mm outside the extraction bumps as seen in fig.4.

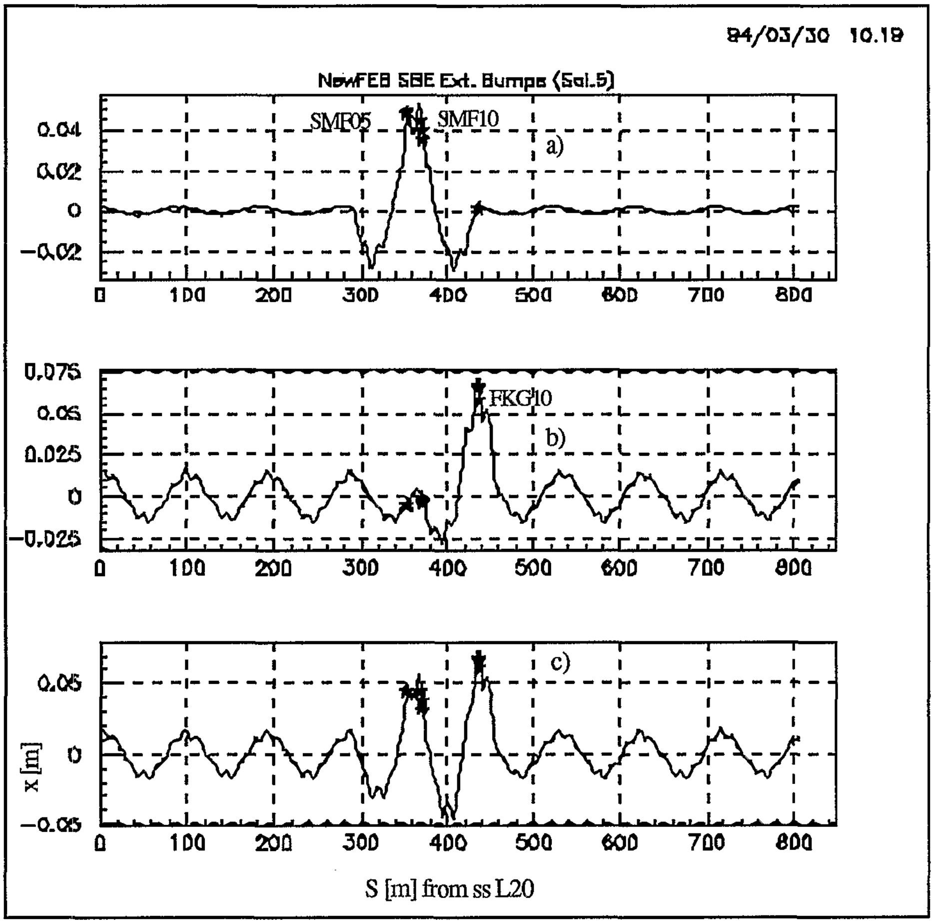

Fig.3 a) BLWF07: the standard 3/2 λ extraction bump for DMF05 and SMF10,
b) BLWG09: the distorted 1 λ extraction bump for FKG10 to force x =~0 at SMF10 (XBLWG09a = 4.1%, b = 2.6% x 2), c) BLWF07+BLWG09.

ELEMENT SEQUENCE				HORIZONTAL								VERTICAL		
POS. NO.	ELEMENT NAME	OC NO.	DIST [M]	BETAX [M]	ALFAX [1]	MUX [2PI]	X(CO) [MM]	PX(CO) [.001]	DX [M]	DPX [1]		BETAY [M]	ALFAY [1]	MUY [2PI]
BEGIN	AGS	1	0.000	16.612	-1.441	0.000	14.117	1.478	0.830	0.078		14.998	1.285	0.000
278	SMF05us	1	352.766	21.793	0.072	3.761	43.656	1.919	0.745	-0.045		10.431	0.025	3.816
279	SMF05ds	1	353.426	21.718	0.042	3.766	44.923	1.919	0.714	-0.045		10.439	-0.038	3.826
294	SMF10us	1	368.895	18.628	1.414	3.932	44.345	-6.317	0.586	0.005		11.962	-1.000	4.002
295	SMF10md	1	369.910	15.924	1.251	3.941	37.933	-6.317	0.597	0.005		14.164	-1.170	4.015
296	SMF10ds	1	370.925	13.551	1.087	3.952	31.521	-6.317	0.609	0.005		16.711	-1.340	4.025
360	FKG10us	1	435.966	20.689	1.590	4.647	67.191	-5.449	1.173	-0.139		11.717	-0.980	4.726
361	FKG10md	1	437.166	17.117	1.386	4.657	60.653	-5.449	1.013	-0.139		14.308	-1.180	4.740
362	FKG10ds	1	438.366	14.037	1.181	4.670	54.115	-5.449	0.853	-0.139		17.382	-1.381	4.753
END	AGS	1	807.076	16.611	-1.441	8.606	14.117	1.478	0.830	0.078		14.999	1.285	8.740

TOTAL LENGTH = 807.075641 QX = 8.606079 QY = 8.740115
DELTA(S) = 7.645617 mm QX' = -24.876638 QY' = 5.570914
ALFA = 0.140275E-01 BETAX(MAX) = 24.809541 BETAY(MAX) = 24.435147
GAMMA(TR) = 8.443267 DX(MAX) = 3.916755 XCO(MAX) = 72.967216 XCO(R.M.S.) = 18.837486

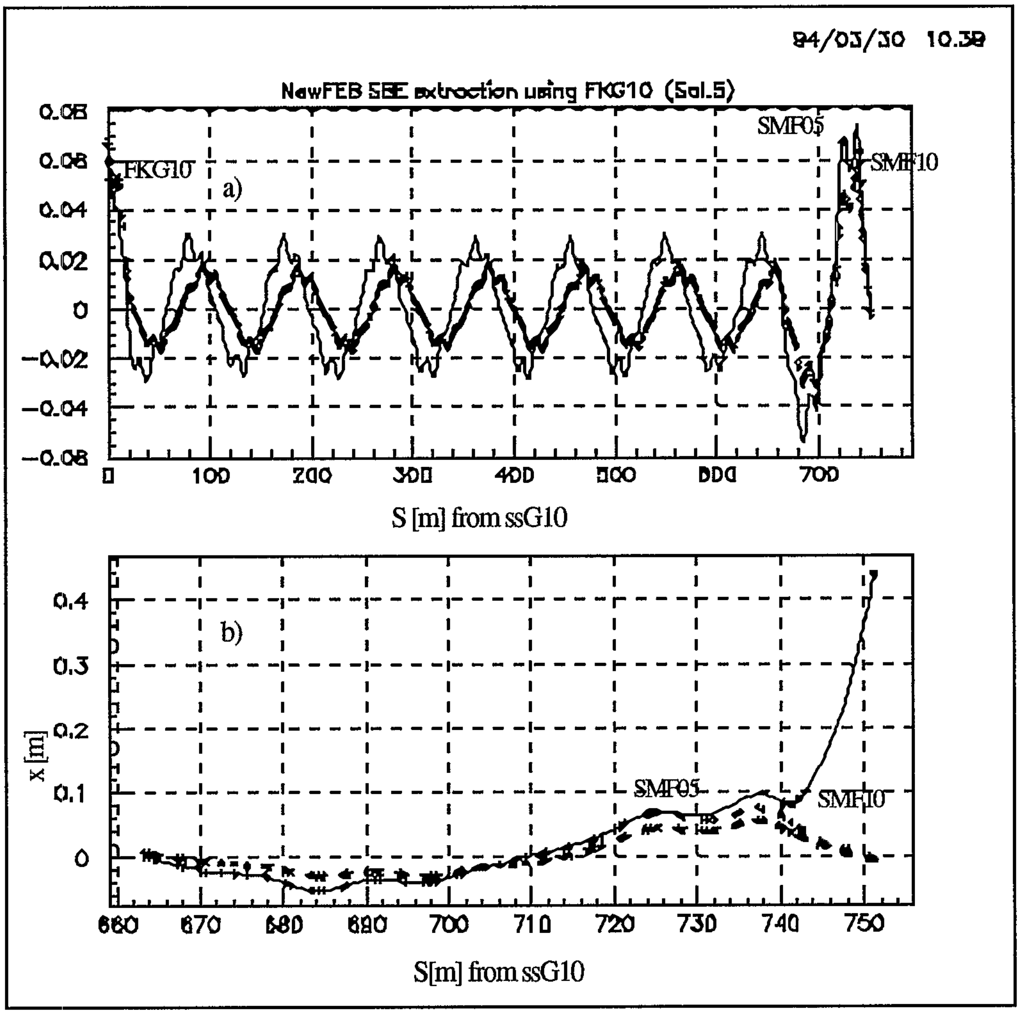

Fig.4. a) Orbit of the circulating bunches on the extraction bumps(◇) and of the bunch kicked by FKG10(-), b) Orbit of the circulating bunch (★), of the kicked bunch by FKG10(◇) and of the extracted bunch by SMF05 and SMF10(-).

ELEMENT SEQUENCE				HORIZONTAL							VERTICAL		
POS. NO.	ELEMENT NAME	OC NO.	DIST [M]	BETAX [M]	ALFAX [1]	MUX [2PI]	X(CO) [MM]	PX(CO) [.001]	DX [M]	DPX [1]	BETAY [M]	ALFAY [1]	MUY [2PI]
BEGIN	SBE	1	0.000	21.737	1.646	0.000	68.956	-5.449	1.216	-0.139	11.100	-0.925	0.000
1	FKG10us	1	0.324	20.689	1.591	0.002	67.191	-5.449	1.173	-0.139	11.717	-0.979	0.005
2	FKG10md	1	1.524	17.117	1.386	0.013	60.284	-6.064	1.013	-0.138	14.307	-1.180	0.019
3	FKG10ds	1	2.724	14.036	1.181	0.025	52.638	-6.679	0.854	-0.138	17.379	-1.380	0.031
600	SMF05us	1	724.199	21.659	0.079	7.723	66.654	2.108	0.007	0.100	9.983	-0.010	7.835
601	SMF05ds	1	724.859	21.574	0.049	7.728	68.474	3.408	0.071	0.099	10.040	-0.076	7.845
616	SMF10us	1	740.328	19.271	1.409	7.893	82.357	-9.321	2.780	-0.048	12.056	-0.991	8.022
617	SMF10md	1	741.343	16.570	1.252	7.902	79.316	3.329	2.734	-0.061	14.237	-1.158	8.034
618	SMF10ds	1	742.358	14.189	1.095	7.912	89.115	15.979	2.662	-0.074	16.757	-1.325	8.044
626	ssF13md	1	751.249	48.151	-6.073	7.996	438.436	64.067	5.928	0.830	3.676	0.868	8.169

TOTAL LENGTH = 752.010670 MUX = 7.998705 MUY = 8.208674
DELTA(S) = 35.274305 mm DMUX = -21.660479 DMUY = 4.881931

We find that

- θ(FKG10) = -1.23 mrad or I = 1.00 kA < I_{max} = 2.00 kA,
- θ(SMF05) = 1.30 mrad or I = 2.11 kA ≈ I_{max} = 2.10 kA,
- θ(SMF10) = 25.3 mrad or I = 5.17 kA ≈ I_{max} = 5.00 kA,

so that at the maximum strength of SMF05 and SMF10, it is *in principle* feasible to perform SBE to the SEB line using FKG10 with a distorted BLWG09 bump at Q_h = ~8.6 though the orbit perturbations outside the extraction bumps after the FKG10 kick are rather large (± 30 mm). The kicked bunch moves deeply inside(x = - 54 mm) at straight section E13 and outside(x = + 97 mm) at MMF09_ds before it is extracted from the ring by SMF10 as seen in fig. 4.

4.2 Reality and Remarks

- With a little bit of luck, the FKG10 system could be ready by the end of the FY1994 HEP/SEB run (July or August?). Then, we might have an opportunity in this fiscal year to test whether this solution would work or not.

- Since even our assumptions on machine/device and beam parameters are right, the solution is quite marginal and the SBE test beam run is expected to run only a few days, we had better setup *a dedicated run for this purpose using low-to-moderate intensity beam.*

- The FKG10 system for NewFEB was designed based on beam parameters obtained from the pre-Booster high intensity AGS performance and also RHIC injection requirements as summarized in tables A.1. and A.2. The actual measured values of ε^*, $\Delta p/p$ and bunch length for the AGS beam were strongly dependent on the machine conditions, especially the beam intensity. Under the normal running conditions (CBM = 1.2-1.8x10^{13} ppp on h = 12) it was generally agreed that $\varepsilon^*_{h,\,v}$ (95%) = (20 - 40) π mm-mrad, and $(\Delta p/p)_{full}$ = ±(0.05 - 0.12)% and bunch length = 25-35 ns. However, *the nominal AGS high intensity (CBM > 2-6 x 10^{13} ppp) beam parameters with the Booster have not yet been established.* During the FY93 HEP/SEB run at CBM = 2.1x10^{13} ppp on h = 12, the bunch length before debunching varied from 55 to 100 ns.

- Furthermore, in this fiscal year the machine rf harmonic numbers were changed from h = 3 to h = 2 in the Booster and h = 12 to h = 8 in the AGS in order to increase the beam intensity without difficulties, by mainly eliminating longitudinal couple-bunch instabilities in the Booster and to reduce possible instability modes to 4 in AGS and likely stay that way thereafter. *As a result, the bunch spacing (peak-to-peak) is 336 ns rather than 224 ns, and the bunch length also increases significantly (from ~40 ns to ~70-120 ns ?) together with a possible increase in $\Delta p/p$.* The FKG10 pulser has been designed to have a half sine wave with its base line width of 360 ns so that its kick will vary ± 4.7 % for the 100 ns long bunch length, compared to ±0.8 % for the 40 ns bunch, which would cause excess beam scrapings. If the bunch length ≥ 100 ns on h = 8, the width should be increased to ~500 ns. (It should be noted that a FKG10 PFN which can provide *fully variable* pulse width including full FEB capability was originally proposed [1]).

5. Conclusions

It is still feasible to perform single bunch extraction[SBE] to the SEB line using the NewFEB fast kicker at G10[FKG10] and its distorted associated bump[BLWG09] at Q_h = ~8.6 at p = 22-24.5 GeV/c. The solution is quite marginal, having large orbit perturbations outside the extraction bumps. Whether it works or not depends on the *actual* AGS performance/parameters(ε^*_h, $\Delta p/p$, bunch length, h, stability etc.).

Acknowledgments

The solution for performing SBE to the SEB line using the FKG10 system described in this note was developed from a series of NewFEB meetings on this subject from October 1993 to March 1994. The regular attendees were L. Ahrens, E. Bleser, E. Forsyth, J. W. Glenn, Y.Y. Lee, A. McNerney, A. Soukas, J. Tuozzolo, T. Roser. I am grateful to all attendees for fruitful discussions and comments I received on this subject during the meetings. I would like to thank Marion Heimerle for reading and imoproving the manuscript.

Appendix

Table A.1. Kicker and septum parameters

	FKG10	SMF05	SMF10	
gap x width	22 x 33	17.5 x 31.75	25.9 x 60.0	[mm x mm]
length	2.41	0.667	2.06	[m]
turns	1	1	4	
max. current	2.0	2.1	5.0	[kA]
B=mo·N/I/g	0.1	0.151	0.970	[T]
B·l	0.20	0.10	2.00	[T-m]
Septum	(C-type)	0.76	15.9	[mm] (Cu)
Pulse mode	half sine 360 ns base	(DC)	(DC)	

Table A.2. NewFEB Beam Parameters

User	g-2	RHIC [P]	RHIC [HI]	
Particles	Protons	Protons	Heavy Ions	
Momentum [p]	22-29	28.0	28.0x(Z/A)	[GeV/c]
		28.73x(Z/A) for $_{197}Au^{77+}$		
SBEs/AGS Cycle	1,2,3,,(12)	3 [x19x2(2)] / [Filling for 2 rings]		
Ions/Bunch	< 4000	100	1-6	[10^9]
Emitt.[ε_h*(95%)]	< 50	< 20	< 10	[π μm-rad]
$(dp/p)_{full}$	<± 0.2	<± 0.06	<± 0.10	[%]
Bunch Area	1.0	< 0.3	< 0.3	[eV-s/N]
Bunch Length	< 40	< 17	< 17	[ns]
Operation Mode:	with SEB	filling two rings every 10 hours		

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