Tune Measurement in the APS Rings*

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I. INTRODUCTION

The APS system will contain three rings. The first is a positron accumulator ring (PAR). Its function is to coalesce 24, 30-ns-long positron bunches into one 290-ps bunch. The second is the injector synchrotron (IS). It accelerates the 450-MeV positron bunches to 7 GeV for injection into the storage ring (SR). Five IS bunches are accumulated into one SR bucket to produce 17.5-nC, 60-ps bunches. Twenty buckets will be filled in the SR to give a current of 100 mA. Additional important tune measurement related parameters for the three rings are shown in Table 1.

Table 1. Various Tune Related Frequencies

	PAR	IS (7 GeV)	SR
R.F. (MHz)	9.7757	351.93	351.93
Revolution (kHz)	9775.7	814.3	271.5
Fractional Tune (kHz)			
x	1662	620	60
y	2121	652	81.5
z	19.0/60.2	21.2	1.96
Line Width (Hz)			
x	96	741	220
y	78	741	220
z	136	1481	440

II. SYSTEM DESCRIPTION

Betatron and synchrotron motion frequently occurs in circular machines, without any deliberate excitation. However, the amplitudes of this motion cannot be predicted. Therefore, it is desirable to have controlled ways to excite these modes.

Two types of devices will be used to excite the beam. One will be a magnetic kicker or bumper. All rings already have these devices planned for the horizontal direction for injecting and extracting beams. Some of these magnets will be used for exiting horizontal betatron motion. In the storage ring, a special kicker will be installed to produce up to 1 mm amplitude motion in the vertical direction.

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Two 8.4-in striplines (SL) (1/4 wavelength at 352 MHz) will be installed on all rings. One stripline in each ring will be used to drive all three tunes, and the other stripline will be used as a pickup. In the PAR and IS, the pickup stripline will be in a dispersive region. This will allow observation of both betatron and synchrotron motions. In the SR, the stripline will be in a nondispersive region because it is not practical to install it in a dispersive region. To do synchrotron tune measurements in the SR, one of the button BPMs located in a dispersive region will be used.

Figure 1 shows the drive circuit for the stripline. The biphase modulators will control the phase of the signal applied to the stripline. When all lines are in phase, the synchrotron tune can be excited. For x-betatron tune, the left pair of strips will be 180° out of phase with the right pair and for y-tune, the top and bottom pair will be out of phase. The amplifiers will be 500 mW for the PAR and 25 W for the IS and SR.

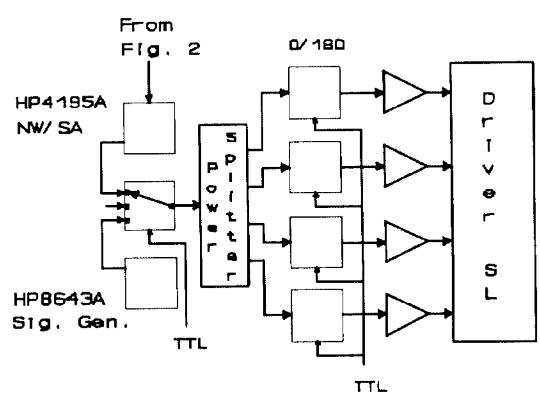

Figure 1. Stripline Driver Circuit

To minimize development effort, as much of the BPM system electronics as possible will be used in the tune measurement system [1]. The BPM electronics uses the AM/PM conversion technique. This system operates at 352 MHz. Thus, tune measurement components were also designed to operate at 352 MHz.

The two parts of the BPM system used here are the filter comparator (FC) and the monopulse receiver (MR). The FC inputs are the four beam pickup outputs. Hybrids are used to generate two signals proportional to the x and y beam displacement and the charge. A third signal is proportional to the total charge. These signals are passed through matched 352-MHz filters of 10 MHz width. The filters are nearly phase constant over about 20 MHz. The MR converts these signals to a position signal which is independent of charge and depends on position only. A stable position signal exists at the monopulse receiver output for about 100 ns.

If the beam is exactly in the center of the position pickup and the pickups are perfect, the filter comparator difference outputs would be zero. In the real system, one expects offsets. This can make synchrotron motion tune measurements difficult. Thus, for tune measurement, the BPM filter comparators will be modified with a 3-db voltage-controlled attenuator in each of the input signal lines. These will be adjusted to minimize the offsets such that the beam always appears to oscillate near the center of the pickup.

Figure 2 shows the pickup system for the PAR. This, combined with components of Fig. 1, constitutes the entire PAR tune measurement system. The IS system is the same, except that there will be two digital signal processors (DSPs) and the network analyzer (NWA) will be an HP8711A. The SR system will be the same as the PAR system except that the pickup device will be switchable between the stripline and a button.

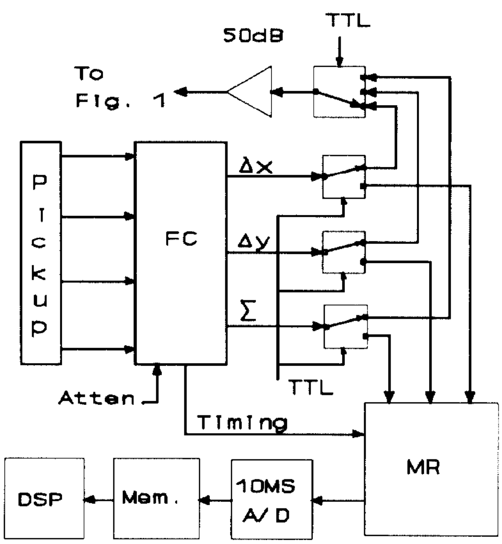

Figure 2. PAR Pickup System

III. OPERATION

Each tune measurement system will have several modes of operation. In one mode the spectrum analyzer will be used to look at bands inside the pass-band of the 352-MHz filters. The beam could be self-excited; it could be excited using the FM modulated signal-generator, or the magnetic pinger could be activated. The IS acceleration time is 250 ms, and magnet-related tune constants are about 25 ms. Thus, this mode is not available in the IS during acceleration because no spectrum analyzer seems to be able to capture spectra in 25 ms or so.

A second mode of operation uses the network analyzer. In the IS, the HP8711A NWA will be able to take spectra over a 100-kHz span in 20 ms. However, it takes over 60 ms to read this information out, so no real time measurements can be made. However, different 20-ms sections of the acceleration process can be observed during successive IS cycles. Thus, a tune history can be generated in a few seconds.

The last mode of operation is the time domain mode. In this, the position of a bunch is observed on every revolution and recorded in memory. After sufficient data is collected, a digital signal processor does a fast Fourier transform (FFT), finds peaks, and passes the results on to the control system. In the IS, two DSPs will be able to obtain all tune frequencies every 20 ms. The excitation methods will be the same as for the spectrum analyzer mode.

Table 1 can be used to predict what a network or spectrum analyzer will see. The filter comparator limits signals to about 40 MHz around 352 MHz. In the PAR, there will be five revolution frequency lines in this band. These will be suppressed as much as possible by the attenuations in the filter comparator. In the x-direction above and below these, there will be one or more synchrotron lines separated by 19 or 60.2 kHz. Whether it is 19 or 60.2 depends on whether the 12th harmonic bunching cavity in the PAR is off or on [2]. Above and below each revolution line there will be an x-betatron line 1.662 MHz away. In y motion there will be a line 2.121 MHz away. The synchrotron line widths will be 136 Hz and the betatron width will be 96 Hz in the PAR. The IS and SR will have similar spectra, except that the line densities will be higher.

The time domain measurement with FFT effectively down converts the spectra to base-band, without losing the advantageous signal-to-noise ratio of working at 352 MHz. Half the sampling rate is the highest frequency one will be able to observe. Since the sampling rate is equal to the revolution frequency, one will need to contend with only one betatron line for each of x and y, and only one synchrotron band. The frequency resolution will be determined by the observation time. Thus, a 10-ms observation time will yield 100 Hz resolution. This should be adequate for most measurements.

Table 2 shows expected difference output power, voltage, and displacement at the tune measurement pickup sensor for the stated input power at the driver stripline. It is assumed that the driving frequency is near 352 MHz and corresponds to the exact frequency of one of the fractional tune lines discussed above. The stated output power is that of the difference signal from a lossless filter comparator. The actual signal will be about 20 db less.

One of the important functions of the SR system is that it should be able to provide continuous tune monitoring. It is essential that the tune measurement process should not disturb the photon beam experiments. This is accomplished by keeping transverse beam motion below a few microns. An HP4195A was evaluated for this purpose. To do this, a crystal filter with 8.83 MHz central frequency and bandwidth of 500 Hz was put between a down and up converter pair. An adjustable oscillator running at around 343 MHz drove one side of each mixer. This produces an effective 500-Hz-wide filter with a control frequency of 352 MHz. The 4195 was used in a network analyzer mode to look at the passband of this filter. The 4195 was set up for an IF bandwidth of 100 Hz and a span of 80 kHz. It took 8.62 seconds to make a sweep. The power through the passband was adjustable using attenuators. Signal (S) was about equal to noise (N) when this power was -115 dbm. When a 50 db amplifier was added, S = N occurred at the -135-dbm signal level.

Table 2. Typical stripline input and resulting output.
Pin = power input per strip on drive stripline unit; Pout, Vout = power and voltage after pickup output passes through filter comparator; X = maximum displacement amplitude of beam bunch at pickup sensor. The pickup sensor is a stripline everywhere, except for the longitudinal SR results.

		Transverse	Longitudinal
PAR	Pin (mW, dbm)	.1 (-10)	10 (10)
	Pout (mW, dbm)	.09 (-10.5)	.1 (-10)
	Vout (mV)		95100
	X (μm)	.97	1.02
IS	Pin (mW, dbm)	10 (10)	25,000 (44)
	Pout (mW, dbm)	$5x10^{-7}$ (-63)	$1.26x10^{-6}$ (-59)
	Vout (mV)		.22.55
	X (μm)	13	21
SR	Pin (mW, dbm)	10 (10)	25,000 (44)
	Pout (mW, dbm)	$7.14x10^{-4}$ (-31.5)	$2.5x10^{-7}$ (-66)
	Vout (mV)		8.455.0
	X (μm)	16.5	9.8

From Table 1, for the SR transverse motion, .1 mW of drive power will result in 1.7 μm beam motion and -52 dbm of signal power. Assuming 20-db loss through the filter comparator, and a 50-db gain before the 4195 input, an S/N of 63 db should be obtained. For longitudinal motion, 2.5 W of drive power will result in 3 μm beam motion in the dispersive region and an S/N of 39 db on the 4195. For commissioning, currents may be 1000 times lower, but beam motion can be larger. By using narrower IF bandwidths (10 Hz) and averaging, it should be possible to clearly see both betatron and synchrotron motion.

The time domain measurement system is expected to be particularly useful in the IS. To assure adequate beam motion, the FM-modulated signal generator will be used. It will typically be swept through 200 kHz every ms for betatron tune measurements. It is clear that the data of Table 2 is not directly applicable. To estimate how much power will be needed, it was assumed that the system can be represented as a driven oscillation with a resonant frequency equal to the fractional tune frequency. This shows that for a 200-kHz sweep around the resonant frequency, the average beam motion amplitude will be a factor of 50 less than what is shown in Table 2. To get 13 μm of motion, 2500 times more power will be needed (or 25 W). The single turn, noise-related rms error of the monopulse receiver system is 10 μm when the high signal levels from striplines are used. In a typical IS measurement, data will be collected for 10 ms, resulting in 8192 points and a frequency resolution of 100 Hz. Once the FFT is done, the fractional error at the fractional tune frequency will be $10/(13\sqrt{8192})$ = .0085. Thus, the tune signal will be clearly visible. The FFT and tune peak search will take about 10 ms. With two DSPs in the IS system, tune measurements will thus be made effectively in real time.

For synchrotron motion in the IS, similar results can be obtained but the swept frequency will need to be over a narrower range. In the PAR, the HP4195A network analyzer will be able to make 100 Hz resolution tune measurements in one to ten seconds. The time domain system will be able to collect 10^5 points in 10 ms, and the FFT will take about 300 ms. Thus, a tune measurement can be done in 310 ms. Increased beam motion and lower frequency resolution could be used to decrease measurement time by an order of magnitude.

In the SR, use of the time domain method will result in a tune measurement about every 15 ms. This method would ordinarily not be used during normal operation because the resulting beam motion would be excessive for the x-ray beam users.

IV. REFERENCES

[1] E. Kahana, "Design of Beam Position Monitor Electronics for the APS Diagnostics," *Proceedings of the Third Annual Workshop on Accelerator Instrumentation*, Newport News, VA, October 1991, pp. 235-240.

[2] M. Borland, "Update on the Argonne Positron Accumulator Ring," these proceedings.