THE TUNE METER SYSTEMS AT THE AGS COMPLEX*

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Abstract

A measurement system of the betatron tune is operational at the AGS and one for the AGS Booster is under development. Both systems use ferrite kicker magnets to excite coherent betatron oscillations. Difference signals are sampled at the revolution frequency and the tune is extracted from a Fast Fourier Transform. Details of the hardware of both systems will be described, as well as all the features of the application program through which the operator interacts with the hardware.

Introduction

To obtain the betatron tune, one generally kicks the beam in one of the transverse planes and analyzes the resulting coherent motion in that plane. The difference signal at a fixed position will contain all frequency components $(m-Q)f_0$, with Q the betatron tune, f_0 the revolution frequency and m the mode number. The modes which are closest to the tune have the strongest response [2]. All methods assume that the integer part of the tune is known and focus on determining the fractional part q. One way to extract q is to filter the position signal around one of the betatron sidebands and measure the frequency of the resulting signal with a fast electronic counter [1]. Fourier analysis is another way to obtain the fractional part of the tune. By sampling the position signal turn by turn, the Nyquist frequency of an FFT spectrum will equal $f_0/2$ and all the betatron sidebands will be folded back to the same frequency qf_0 or $(1-q)f_0$ for tunes below or above the half integer, respectively [3,4]. Both methods have been tested at the AGS. The second method has proven to be more robust and even provides tune values when the coherent signal lasts only for a very short time [5]. Also, more information is available in the frequency spectra than in an average frequency measurement; for example, when there is coupling between the horizontal and vertical plane. Therefore, this method has been selected for the tune meter systems at the AGS.

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The AGS System

The kicker magnets used in the AGS are 90 cm long, full aperture window frame kickers made of stacked ferrite bricks with a single turn conductor. To prevent beam induced heating of the ferrite, shorted coils are mounted around the yoke in the longitudinal direction [6]. The power supplies are LC pulse-forming networks which are charged by 20 kV dc power supplies. These networks are located in the injection equipment building and connected to the magnets with 200 feet of coaxial cable. Thyratrons are used as switches for the discharge of the pulse forming networks. The current pulses have rise and fall times of roughly 0.5 μs, and a width which can be set to 2 or 4 μs. The maximum amplitudes of the current pulse is 1000 A for the horizontal and 2000 A for the vertical pulser. The charging time for the maximum pulse height is about 300 ms and therefore limits the kick repetition rate to effectively once per AGS cycle.

For each transverse plane, a position signal is fed into an eight-bit transient recorder. The revolution frequency is divided down from the rf frequency and is used as a clock for the transient recorders. For each transverse plane there is a master trigger, derived from either a real time clock or from the Gauss clock, which feeds variable delays to trigger the pulse forming networks to discharge and to stop the transient recorders.

All the different parameters can be controlled from an application program. The menu allows the operator to set the triggers and the kick amplitude, and to select the kick plane. Menu options include selection of multiple measurements, averaging of the spectra, and provisions to study coupling. When one or more measurements are done, the triggers are turned on and the transient recorders will generate an interrupt upon which a 1024 point data record for the horizontal and/or vertical plane will be transferred into the application program. The FFT is calculated and the digitized data and the frequency spectra are displayed.

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Figure 1 shows an example of a measurement. The top trace shows the position signal in the vertical plane. The beam is kicked at roughly turn number 350. The maximum amplitude of the betatron oscillation is calculated to be 2 mm for this case. The fast beating of the signal is a result of undersampling of the position signal. The coherence is seen to decay in a few hundred turns due to the non-zero chromaticity. The lower trace shows the Fourier Transform. Figure 2 shows another example illustrating the sensitivity of the method. The kick amplitude for this case was reduced to 10% of the value in Figure 1. It is seen that, although the signal-to-noise ratio has become worse, the tune can still be obtained with the same precision. That the peak has the same height is because the program uses autoscaling routines when displaying frequency plots with linear vertical scales.

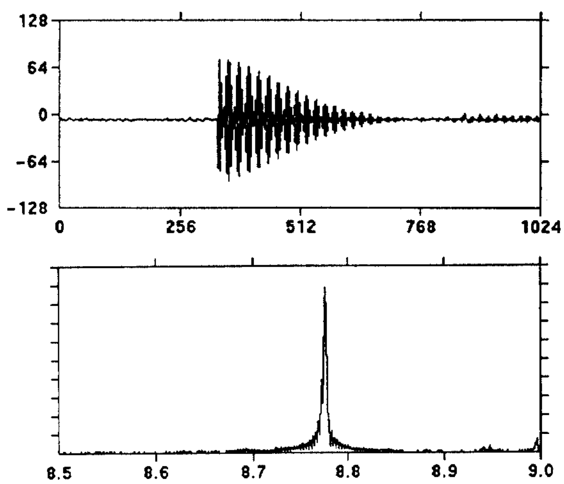

Fig. 1. Result of a tune measurement. At the top, the position signal is displayed versus the turn number. Bottom trace is the FFT spectrum assuming the tune is between 8.5 and 9.

A less ideal case, in which operator interaction is required to obtain a value for the tune, is shown in Figure 3. The beam has been kicked in the horizontal plane during an interval in the acceleration cycle of constant magnetic field, a large negative horizontal chromaticity, and small vertical chromaticity. The coherence in the horizontal plane is decays very rapidly, while some energy is coupled in the vertical plane. This motion is picked up and since it lats a very long time, it translates to the very well defined peak at 8.76 in the frequency display, as compared to the very broad peak around 8.68 for the horizontal tune. The very fast decay in the horizontal coherence

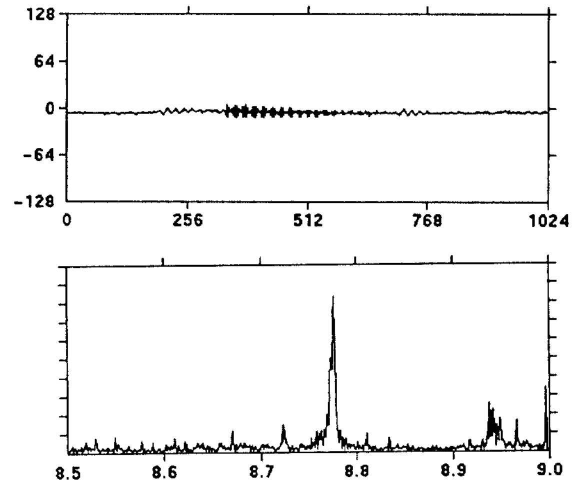

Fig. 2. Illustration of the sensitivity of the measurement. The kick amplitude has been reduced to 10% of the value of the kick used in Figure 1.

effectively acts as a window for the Fourier Transform and causes the fast beating in the horizontal peak. Identification of the tunes in these situations is facilitated by switching planes because when kicking in the vertical plane, the horizontal signal will be negligible compared to the strong vertical response.

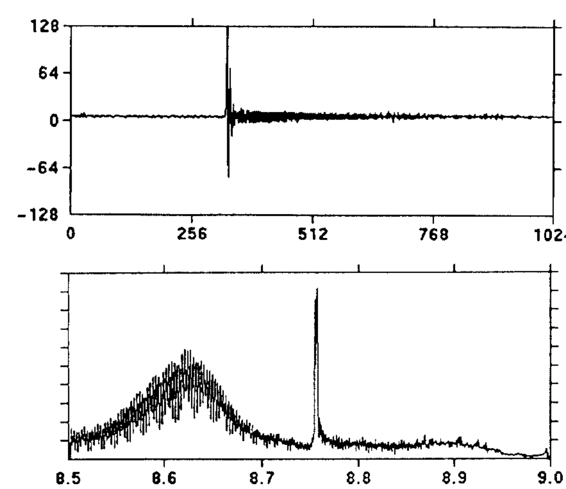

Fig. 3. Influence of betatron coupling and chromaticity on the frequency display.

The Booster System

The kicker magnets are full aperture window-frame ferrite magnets. Figure 4 shows a cross section of one for the horizontal plane. Copper sheets are inserted into the yoke to reduce coupling of the beam to the ferrite [7] and to maintain the magnetic properties of the ferrite [6]. These sheets are grounded to the vacuum chamber to provide a path for the image current. CMD 5005 ferrite was selected for its high rf permeability, low outgassing and high resistivity. Because the magnets have to operate in an ultra-high vacuum environment, all parts have been vacuum fired at 950° C except the ferrite, where the temperature was limited to 400° C to maintain its electrical characteristics [8,9].

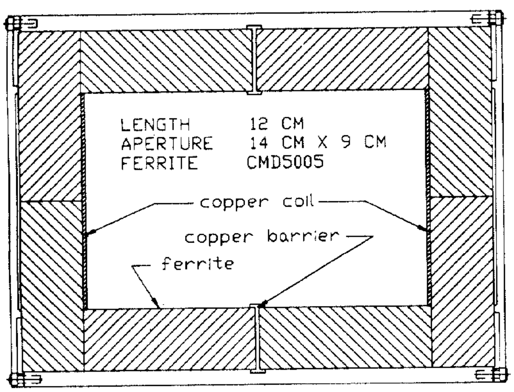

Fig. 4. Cross section of the horizontal kicker magnet.

The modulators for both the horizontal and vertical kicker are line-type pulsers with a maximum current of 1500 A at 20 kV. The pulse length can be selected to 1 μs or 3 μs. The principal difference from the AGS pulsers described above is the much faster charging time: 5 ms at 20 kV and a 1 μs pulse length. Details on the design and performance of the pulsers are described in a separate paper [10].

Position information is obtained from the Booster BPM system and transferred on an optical link to processing equipment, which is much more elaborate than that of the AGS system, because of the much larger range of revolution frequencies in the Booster. The revolution time in the Booster varies from roughly 0.7 to 15 μs and since a 1 μs or 3 μs pulse is available, it can happen that only a fraction of a turn will be kicked. The signals will be fed into high speed integrators. Baseline restoration circuitry will take care of the ac nature of the input signals. The revolution frequency will be used also as a clock for the transient recorders and with a small delay as reset for the fast integrators. All other timing signals for triggering the pulsers and to trigger the transient recorders are obtained from the central Booster timing system.

Another difference with the AGS system is the much higher repetition rate of the Booster (7 Hz). Four Booster pulses at this frequency will be needed to fill the AGS and comparative measurements in each of these cycles are highly desirable. The transient recorders are Camac modules which are connected to the station where the application code resides through a GPIB bus. The protocol for reading the transient recorders has been optimized such that data transfer from both planes is completed well within the time between interrupts. The selection of a particular cycle is therefore done in the application code and not at the system hardware level.

The application program will be very similar to the one for the AGS. The triggers which control the modulators and transient recorders will be derived from one single entry. The amplitude of the kick is the only other parameter, which has to be adjusted. Menu options will include selection of the result of a measurement in one or more cycles within a Booster group, averaging of spectra within a Booster group, and averaging cycles from consecutive Booster groups. Provisions will be made to acquire multiple measurements and transfer results to other application codes, for instance to the code which controls the tune correction power supplies.

All the system components are presently available and installation is in progress. First system tests are expected by the middle of May, 1991.

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