

DIGITAL TUNE TRACKER FOR CESR*

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Abstract

Numerous storage ring diagnostic operations require synchronous excitation of beam motion. An example is the lattice phase measurement [1], which involves synchronous detection of the driven betatron motion. In the CESR storage ring, the transverse tunes continuously vary by several times their natural width. Hence, synchronous beam excitation is impossible without active feedback control. The digital tune tracker consists of a direct digital frequency synthesizer which drives the beam through a transverse kicker, and is phase locked to the detected betatron signal from a quad button position detector. This ensures synchronous excitation, and by setting the correct locking phase, the excitation can be tuned to peak resonance. The fully digital signal detection allows a single bunch amid a long train to be synchronously driven, which allows lattice diagnostics to be performed which include collective effects. The collective effects potentially of interest in CESR include wakefield couplings within the train, and plasma effects such as ion trapping and electron cloud trapping.

HARDWARE

No hardware was specifically constructed for this instrument. Existing CESR feedback units were adapted with minor modifications by reprogramming the large scale logic devices. The feedback unit operates at a clock frequency of 71.4 MHz, and this clock is used for beam sampling, filtering, and synthesis of the betatron drive signal. Since only a single bunch is to be used for phase locking, the instrument can be used with any bunch configuration.

Position and Phase Detection

The position signal is taken from a set of microstripline electrodes, which are separated into amplitude and displacement signals with a network of sum and difference combiners. The microstriplines were used instead of the standard CESR button detectors because the button detectors will not function over the full range of orbit displacements which occur in the pretzel configuration, which used for simultaneous e^+ and e^- storage.

The difference signal is digitized with a 10 bit ADC which is timed to peak signal amplitude, and the signal from the selected bunch is latched for one turn. The latched amplitude signal is digitally mixed at 71.4 MHz with two square wave representations of the betatron drive signal in quadrature phase. This produces a vector representation of

the phase difference between the synthesized betatron drive and the actual betatron motion of the beam. The betatron clock is represented as square waves to eliminate the need for real-time multiplication.

The demodulated position signals are filtered in a pair of single pole IIR (infinite impulse response) filters. Only one of the filtered signals is used to represent betatron phase error, and the other is only used to reconstruct signal amplitude.

Betatron Frequency Synthesis

The DDS (direct digital synthesizer) is straightforward, consisting of a phase register which is incremented by the frequency command at the 71.4 MHz clock rate, a sinusoidal lookup table implemented in a high speed cache RAM, and a 14 bit DAC. Adjustments of drive phase and amplitude are effected by changing the contents of the RAM, and the 14 bit output resolution gives sufficient dynamic range for all applications without the need for analog attenuation.

The betatron drive signal is coupled to the beam with the existing feedback kicker [2], which allows the isolated drive of a single bunch in the 14 ns spacing configuration. In closer bunch configurations, there is some crosstalk of the drive signal to bunches adjacent to the one selected for phase locking.

Loop Closure

The phase locked loop requires a proportional channel and an integrating channel. The proportional channel shifts the betatron frequency command by an amount proportional to phase error. This is necessary to maintain loop stability, and to give the loop sufficient agility to track the tune fluctuations of the storage ring in real time. The integrating channel increments the frequency command on every revolution by an amount proportional to phase error. This is necessary to bring the phase error to zero, and thus provide a stable phase reference for lattice measurements.

Phase Output

The DDS phase register value is latched once per accelerator revolution, and the phase is sent by a parallel digital link to the clock modulator for the CESR BPM (beam position monitor) system [3]. The BPM clock modulator imposes both the vertical and horizontal phase values from the two tune trackers on the BPM clock using a pulse width modulation system. The individual BPM modules then extract the phase values and use them to reconstruct the betatron drive signal, which is used to synchronously detect be-

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tatron phase at each BPM station. The synchronous phase measurement is used to determine the phase advance between BPM stations, and hence the phase function of the entire lattice.

SOFTWARE AND OPERATION

The operating configurations of the tune trackers, including center frequencies, gains, and filter settings, are saved and restored along with the storage ring configuration. This gives a high probability of successful phase lock without adjustment. The signal acquisition and locking functions can be operated through a GUI (graphic user interface), and the same functions can be executed automatically by other system processes using control system subroutines.

Signal Acquisition

The tune tracker can initially acquire a betatron signal by sweeping the drive frequency through a band, typically 20 kHz wide, and recording betatron amplitude and phase error relative to the DDS. A fit of center frequency, center phase, peak width, and peak amplitude is then automatically done to a Lorentzian resonance model. The results are shown in Fig. 1. The fit is done efficiently using Newton's method independently for each of the four parameters. As an example, consider fitting a parameterized amplitude function $f(\omega, \vec{c})$ to a set of amplitude data $a(\omega_i)$, where \vec{c} is the vector of fitting parameters. Defining a quadratic merit function for the fit:

$$S = \sum_i (f(\omega_i, \vec{c}) - a(\omega_i))^2$$

Observe that the derivatives of S with respect to the parameters only involve the partial derivatives of f , and so the gradient and the second derivatives of S can be directly computed from the data. Then Newton's method is applied by cycling through the parameters repeatedly until all components of the gradient are zero. This corresponds to a local minimum of the merit function S .

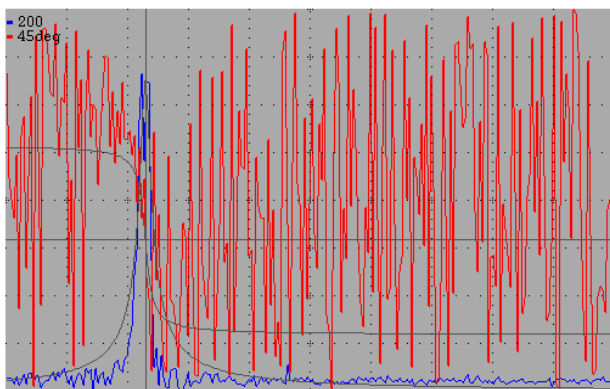


Figure 1: Frequency sweep over 10 kHz. Blue trace is amplitude and red trace is phase error, showing fit to Lorentzian resonance model

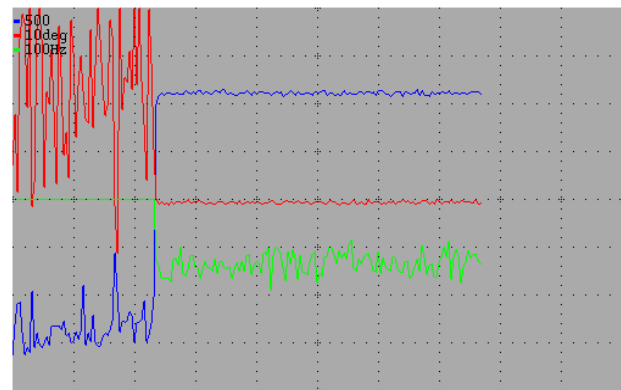


Figure 2: Time scroll, showing lock acquisition. Green trace is DDS frequency offset

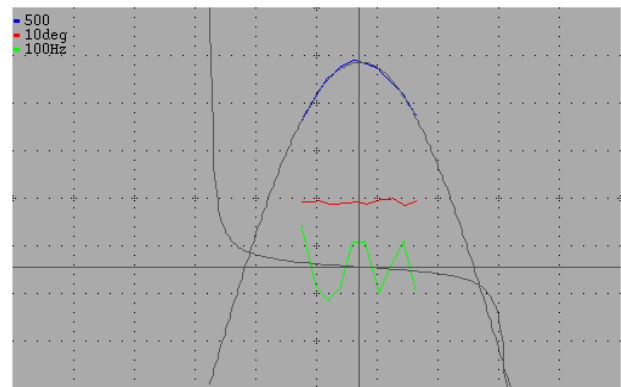


Figure 3: Drive phase sweep over 70°, showing fit to Lorentzian resonance model

Phase Adjustment

Only a rough fit is possible to the tune of an unlocked beam because of the tune noise of the storage ring, which is approximately several hundred Hz. Acquisition of phase lock is accompanied by a large increase in betatron amplitude. The transition to phase lock is shown in Fig. 2. Once phase lock is established, a fine fit to the resonance can be done by sweeping the betatron drive phase, and recording betatron amplitude and drive frequency. A fit of the same four parameters is automatically done to the Lorentzian model by the same method described above. This consists mainly of fitting the amplitude to a cosine function, and gives the closest possible approach to the resonance peak. The results of the centering sweep is shown in Fig. 3.

EXPERIMENTAL RESULTS

A train of 30 positron bunches with 14 ns spacing and an individual bunch current of 0.75 ma was stored, and the digital tune tracker was used in conjunction with the CESR BPM system to measure the lattice phase function for each bunch individually. The CESR transverse feedback was turned off for the one bunch being phase locked, but was fully active for all of the other bunches in the train. The

bunch 1 phase function was used as a reference, and the later bunch phase functions were represented as a difference from that of bunch 1.

An approximately uniformly distributed phase shift was observed which increased with bunch number to about 0.5 degree at bunch 12, corresponding to a tune shift of 500 Hz. The differential phase is shown in Fig. 4.

Beginning with bunch 14, large localized phase signals began to appear, as shown in Fig. 5. These evidently do not represent actual lattice phase errors, because the spurious phase signals are localized to portions of the storage ring and do not contribute to the integrated phase of the lattice. Presumably, these spurious phase signals are due to the direct detection of synchronously excited electron clouds. These signals would be difficult to analyze quantitatively in this experiment because they appear as vector additions to the bunch betatron signals. Fig. 6 shows the extent of the electron cloud expanding later in the bunch train, and Fig. 7 shows an unexplained change in the distribution, where the electron cloud abates at the north straight section of CESR.

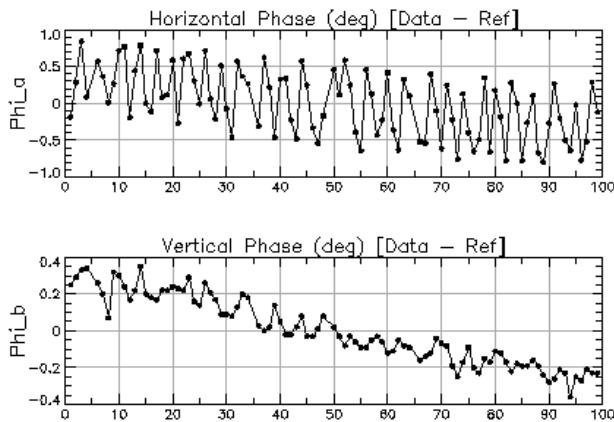


Figure 4: Bunch 12 phase

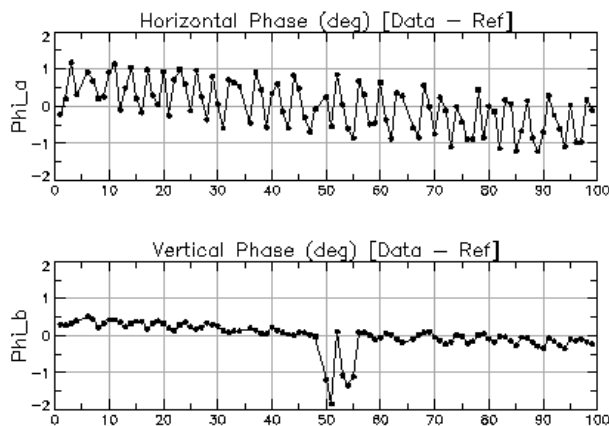


Figure 5: Bunch 15 phase

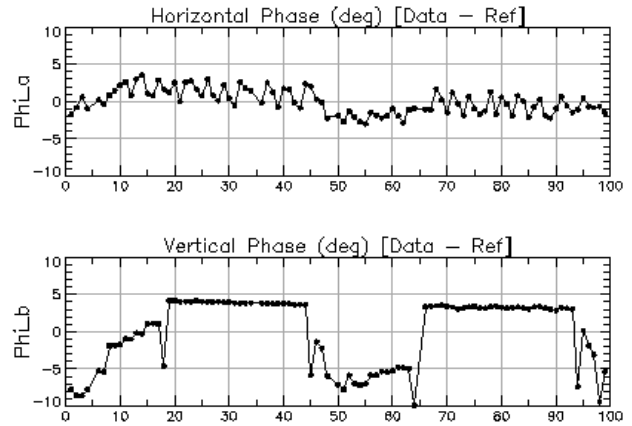


Figure 6: Bunch 25 phase

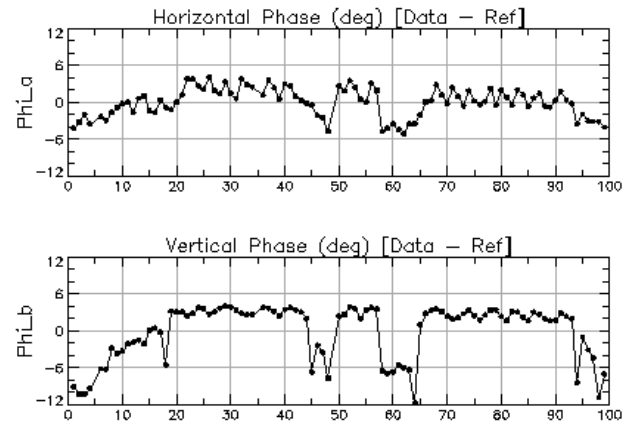


Figure 7: Bunch 29 phase

CONCLUSIONS

Digital tune trackers have been implemented in CESR using surplus hardware, and have supplanted the function of the existing analog tune trackers, with the additional convenience of digital configuration and single bunch analysis. Single bunch measurement of the lattice phase function in a long bunch train has shown systematic tune shifts of unknown origin, and has also shown direct evidence of electron clouds. It is not clear if the electron cloud signals can be quantitatively analyzed. This might be possible by timing the BPM modules to sample after the bunch passage, so that only the electron cloud signal is observed. The measurements done to date do show a full ring map of electron cloud activity at all BPM stations for each bunch location in the bunch train.

REFERENCES

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