TUNE SYSTEM APPLICATIONS AT THE APS *

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Abstract

The Advanced Photon Source (APS) storage ring is a third-generation X-ray synchrotron radiation user facility. The storage ring tune measurement system consists of signal pickup and beam excitation drive striplines, a network analyzer, and a vector spectrum analyzer. The system has been used for daily tune tracking, beta-function measurement, chromaticity measurement, lattice correction, magnet power supply stability analysis, machine coupling impedance, and observation of beam instabilities. Several software applications were developed to automate the instrument control and data collection processes. We present the current configuration of the tune measurement system, the software tools, and their application at the APS.

SYSTEM DESCRIPTION

The APS storage ring tune measurement system consists of signal pickup and beam excitation drive striplines, an HP4396 network analyzer, and an HP89441 vector spectrum analyzer. Figure 1 shows the block diagram of the system.

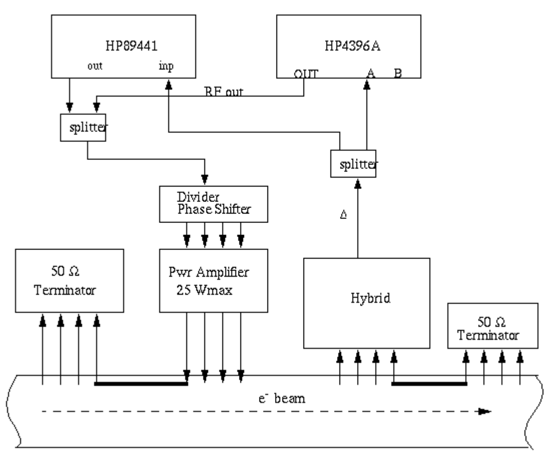

Figure 1: Block diagram of the tune system.

The input signal is connected to the difference signal of a pair of diagonal electrodes of the pickup striplines. The rf source from both the VSA and the NA are summed together to drive the excitation striplines. On/off is controlled remotely through the rf on/off command of each of the analyzers.

The HP89441 VSA is connected to the controls network via standard Ethernet connection. It has an X-window screen for a remote control panel, which can conveniently be called up from any workstation. TCP/IP commands are used for automatic data acquisition. The HP4396A network analyzer is interfaced to a VME-based IOC. MEDM screens and channel access commands are available for remote control and data acquisition.

STORAGE RING TUNE ARCHIVING

The HP4396 network analyzer is used mainly for routine tune measurement. A Tcl script was developed for this purpose. It is used for daily tune archiving during normal user beam operation and machine studies. Figure 2 shows a tune spectrum plot for the low-emittance lattice.

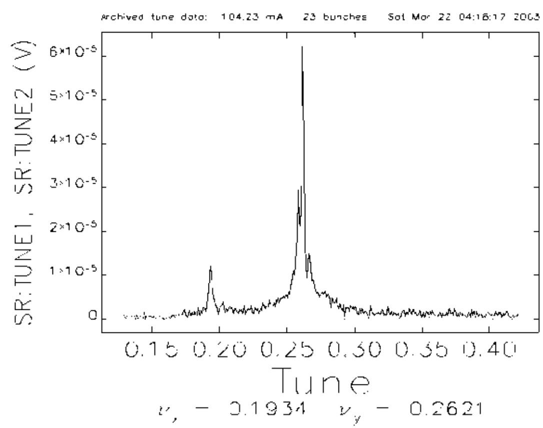

Figure 2: Tune plot of the low-emittance lattice.

The tool also allows one to review the storage ring tune history, which is useful for troubleshooting storage ring lattice problems.

The resolution of the tune readings is estimated to be 0.001.

BETA FUNCTION MEASUREMENT

The beta functions of a storage ring can be measured with different methods. The quadrupole magnets of the APS storage ring are all powered by individual power supplies. This is ideal for measurement of beta functions using the quadrupole field variation method.

The beta function measurement application (see Figure 3) graphically displays all the quadrupole magnets of the storage ring in a matrix. The user can select the quad locations where the beta functions are to be measured and the model machine lattice to use. The script automatically varies each quad and reads the tune spectrum from the VSA. After each measurement, the program adjusts the quad current to restore the tunes to the same value before the measurement. This prevents the lattice from walking away due to magnet hysteresis.

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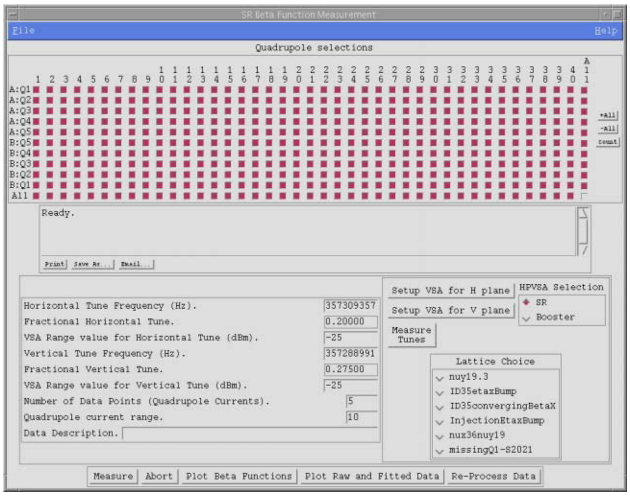

Figure 3: Front page of beta function measurement application.

Fitted results are displayed together with model calculated beta function curves. Figure 4 shows a plot of fitted beta functions.

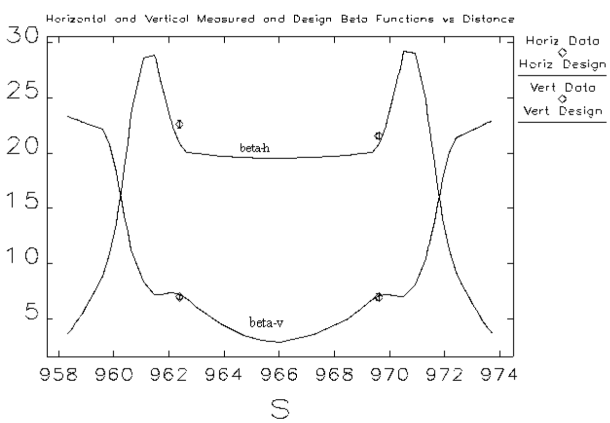

Figure 4: Plot of a fitted and design beta functions.

CHROMATICITY AND DISPERSION FUNCTION MEASUREMENTS

Chromaticity and dispersion function measurements are performed by varying the rf frequency and acquiring tune spectrum waveforms and beam position monitor readings. The chromaticity is calculated from the relationships $\Delta\nu/\nu = \xi\,\Delta p/p$ and $\Delta p/p = -\alpha^{-1}\Delta f/f$, where ν is the betatron tune, ξ is the chromaticity, p is the momentum, and α is the momentum compaction factor. The rf frequency f is typically varied over the range ±100 Hz, over which the tune shift is linear. An example chromaticity measurement is shown in Figure 5.

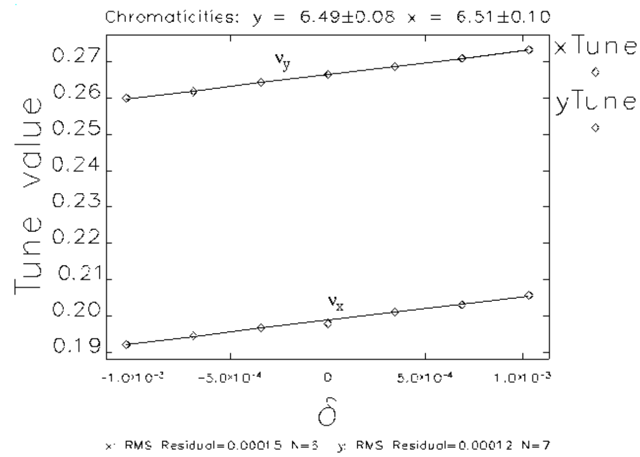

Figure 5: Chromaticity measurement results.

For the dispersion measurement, fitted results are displayed together with model calculated dispersion function curves. Figure 6 shows a plot of fitted dispersion functions.

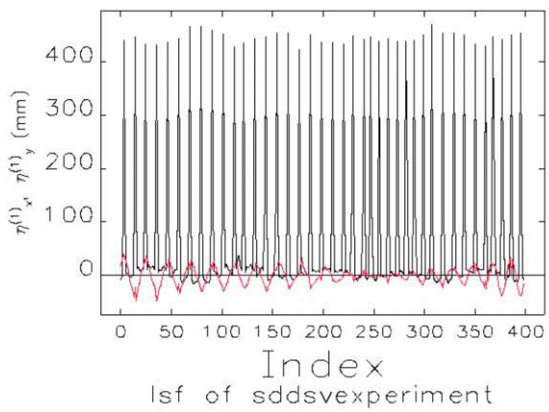

Figure 6: Dispersion measurement results.

TUNE SHIFT MEASUREMENT

In the APS storage ring there are many small-gap insertion device chambers. The contribution to the vertical impedance can be quantified by measuring the tune shift with beam current (tune slope) with the VSA [2]. The measured tune waveforms clearly show the mode merging between the tune and the lower synchrotron sidebands [3]. The transverse mode-coupling instability is avoided with a high positive chromaticity. The total effective impedance computed from the tune slope compares well with that computed from the impedance model [4].

SYNCHROTRON TUNE SPECTRUM

Amplitude modulation of the rf source at the harmonics of the line voltage results in rf noise sufficient to drive the synchrotron frequency, which can be measured using the signal striplines. These data can be archived and are used typically in two ways. First, the intercavity rf phase is adjusted to maximize the synchrotron frequency. Second, the data can be compared with the archive to diagnose increased rf noise coming from the low-level rf system. Figure 7 shows an example when the rf noise level was elevated. The first indication of problems was an increase in the horizontal beam motion by a factor of two. The noise source was traced to the main frequency synthesizer, which produced 120-Hz amplitude modulation when the AC line voltage was low [5]. The data were acquired at the seventh harmonic of the fundamental rf frequency.

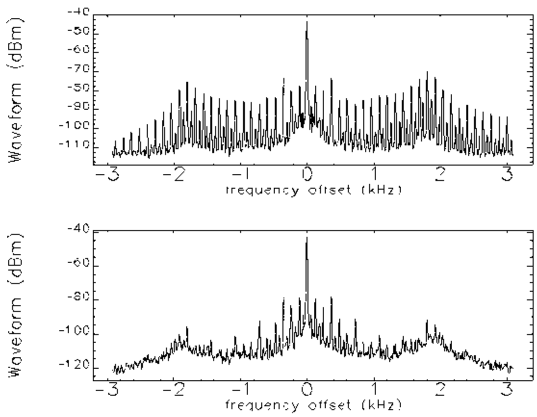

Figure 7: Synchrotron tune spectra, showing elevated (top) and normal (bottom) noise signatures. The synchrotron frequency is 1.8 kHz.

INSTABILITY OBSERVATION

Occasionally, while exploring new operating modes, an intensity-dependent beam instability is observed that is driven by the longitudinal or transverse impedance. Typically, the first observation of unstable beam motion is an apparent emittance blow-up observed on the bending magnet synchrotron radiation photon diagnostics. To identify collective motion, the VSA is used in a passive mode to acquire beam spectra and identify self-driven tune signals. We were able to identify a longitudinal coupled-bunch instability and its driving source to be a TM rf cavity HOM in one of the 16 rf cavities. In Figure 8 the upper trace is the longitudinal spectrum from a stable beam and the lower trace is from an unstable beam. The numbers of the lower trace indicate the phase shift between bunches in unit of $2\pi/3$. Clearly there is a strong mode $2\pi/3$ oscillation on top of the regular mode 0 bunch spectrum. Note the mode 0 spectral harmonics are reduced by f/54 due to the bunch fill pattern.

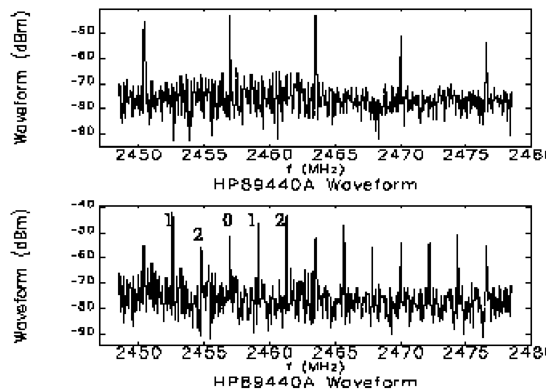

Figure 8: Stable (upper) and unstable (lower) spectra showing longitudinal coupled-bunch instability.

CONCLUSION

The tune measurement system at the APS has played an important role in accelerator operations, lattice measurement, and instability analysis.

ACKNOWLEDGEMENTS

The Beam Diagnostics Group designed and developed the original tune measurement. Michael Borland wrote the dispersion/chromaticity measurement application, and Nick Sereno developed the early version of beta function measurement application. The authors would like to thank Chuck Gold, Jim Stevens, and the operations crews for their support.

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