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PHASE-SPACE MONITOR SYSTEM

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Abstract Phase-space monitor system has been used these two years to observe the transverse bunch oscillations in the TRISTAN Main Ring on (x, $\beta x'$) and (y, $\beta y'$) vector displays. The system provides real-time visual phase-space informations in millimeter-unit, on which we can easily distinguish the types of bunch-oscillations. For example, when a coherent betatron oscillation is excited, it becomes a circle trajectory. On the other hand, when a synchrotron oscillation is excited, the bunch trajectory becomes a horizontal straight line on the (x, $\beta x'$) display due to the dispersion. A large amplitude oscillation excited by injection kicker shows a beautiful pattern like a "star", in which we can follow the history of the damping process using a digital storage-scope. The "star" clearly shows the amplitude dependence of betatron-tune shift due to the non-linear optics.

SYSTEM DESCRIPTION

Figure 1 shows the system diagram of the phase-space monitor system. The bunch signals are sensed by two pickup electrodes installed in the symmetry point in the arc-section, where each of two electron and two positron bunches alternatively arrives in equal time separation of 2.5 μsec. The spatial separation of two pickup electrodes is 14 m, whose betatron phase difference is 40 degree. The bunch signals, named A, B, C and D, are filtered by the low-pass filter (LPF), where the cut-off frequency is chosen to 15 MHz so as to make low technical expense in peak detector circuits and cut off the beeper signal of 27 MHz broadcasted in the laboratory.

The peak voltages of the filtered signals are stretched and held in the peak detectors. The position determination is performed by the analog divider rather than the gain feedback scheme,[1] since the bunch-to-bunch interval of 2.5 μsec is long enough to settle the analog divider output signal. Benefits of this scheme are

(1) Simple system: All bunch signals with different intensities are processed on a single circuit.

(2) Fast system rise-time: We can observe the bunch oscillations from its first revolution at the beam injection into the ring.

(3) Precise position normalization: All signals are normalized to 100 mV/mm.

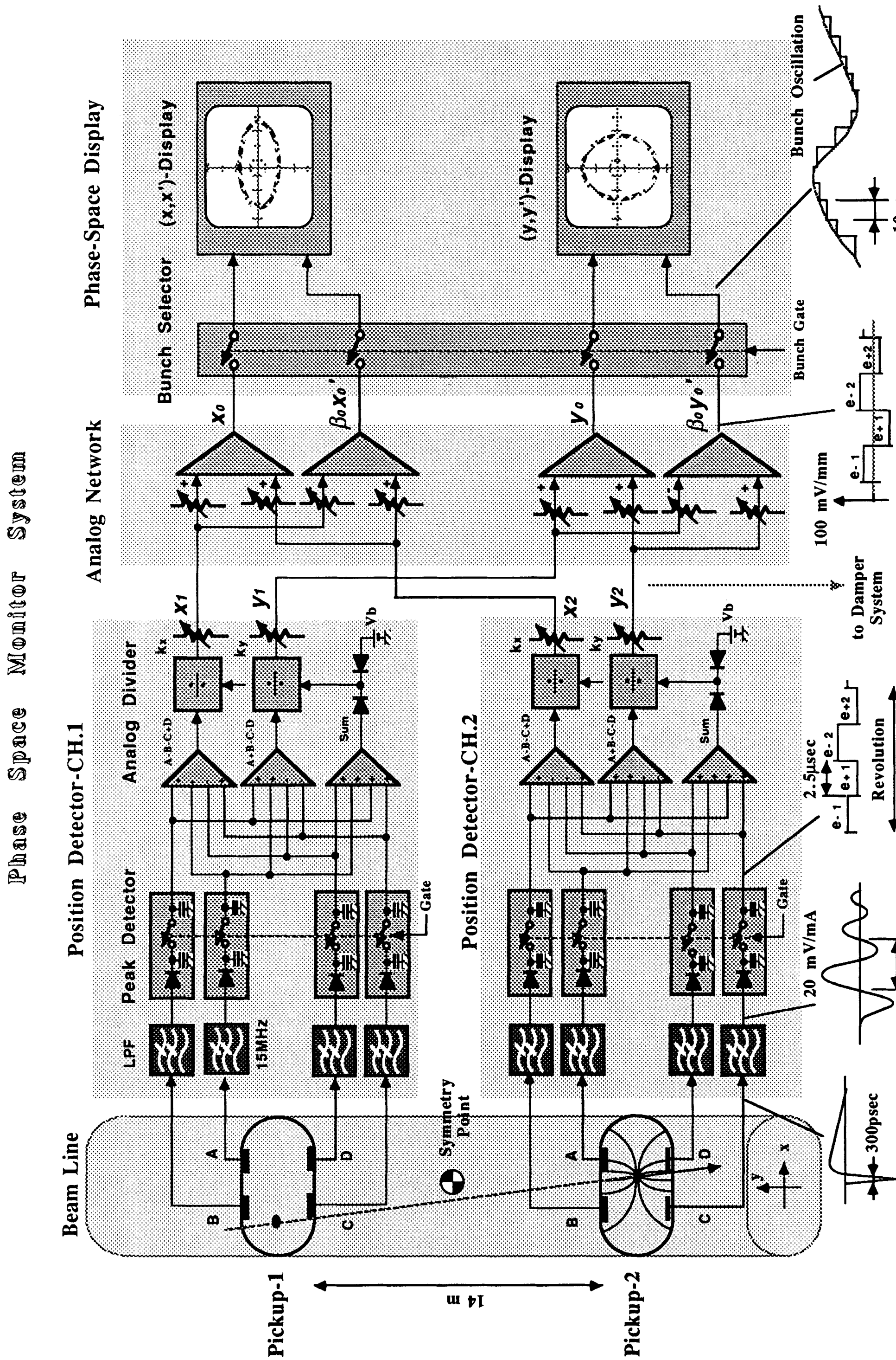


FIGURE 1 Phase-space Monitor System

The analog dividers convert the bunch signals into the position signals according to following relations.

$$x = k_x \cdot \frac{A + D - B - C}{A + B + C + D} \tag{1}$$

$$y = k_y \cdot \frac{A + B - C - D}{A + B + C + D} \tag{2}$$

k_x, k_y are the position sensitivities, which have been measured on a test-bench[2] as $k_x =$ 22.2 mm, $k_y = 26.5$ mm, in horizontal and vertical directions, respectively. The position output signals are normalized to 100 mV/mm. The bias voltage V_b clamps the lower-limit of denominator input to finite value in order to avoid large error generation for low level or zero denominator input.

The position signals provided by the two position detectors are then converted to the phase-space variables at the symmetry point by taking average and difference in the analog network. The gains in analog network are adjusted to satisfy the following relations.

$$x_0 = \sqrt{\frac{\beta_0}{\beta_1}} \frac{x_1 + x_2}{2\cos\phi_1} \tag{3}$$

$$\beta_0 x_0' = \sqrt{\frac{\beta_0}{\beta_1}} \frac{x_2 - x_1}{2\sin\phi_1} \tag{4}$$

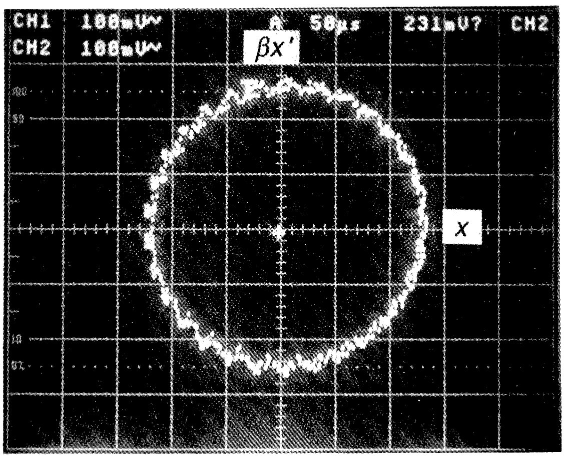
where β_0, β_1 are the betatron amplitude-functions at the symmetry point and at the pickup electrodes. ϕ_1 is the betatron phase difference between the symmetry point and the pickup electrodes. The normalization of the phase-space variables are made in the form of $(x, \beta x')$, not in $(x/\sqrt{\beta}, x'/\sqrt{\gamma})$, because in the practical machine operation the oscillation amplitudes are usually measured in the real scale of millimeter unit. The phase-space variables in the vertical direction $(y, \beta y')$ are also given in same way.

The beam optics has a dispersion η of ≈ 1 m, so that the horizontal axis on $(x, \beta x')$ display becomes an energy analyzer of 0.1%ΔE/mm. The dispersion takes same values at both of two pickup electrodes, so that the synchrotron (energy) oscillation comes out only in x motion. Hence the bunch trajectory becomes a horizontal straight line.

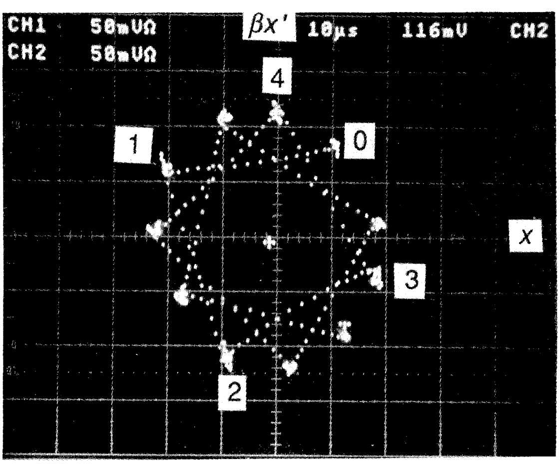
Finally, the phase-space signal of individual bunch is selected by the bunch selector, and send to $(x, \beta x')$ and $(y, \beta y')$ vector displays. The position signals are also send to the Transverse Magnetic Damper System and utilized to damp the transverse bunch oscillations.[3]

OBSERVATIONS

Figure 2(a) shows an example of transverse instability occurred in horizontal direction due to the transverse mode in RF-cavity, where a stable circle trajectory is displayed. Figure 2(b) shows a time-extended view on a digital storage scope, where the bunch positions of ten revolutions are displayed. We can follow the sequential bunch positions denotes by the number 0, 1, 2, 3,... The bunch rotates 360 degree on the phase-space within the periods of ≈ 3.7 revolutions. The bunch rotates counter-clockwise, which means that the tune number is above the half-integer. Hence the betatron tune becomes 1 - 1/3.7 = 0.73, which well agrees with the operation point of $\nu_x = 36.73$.



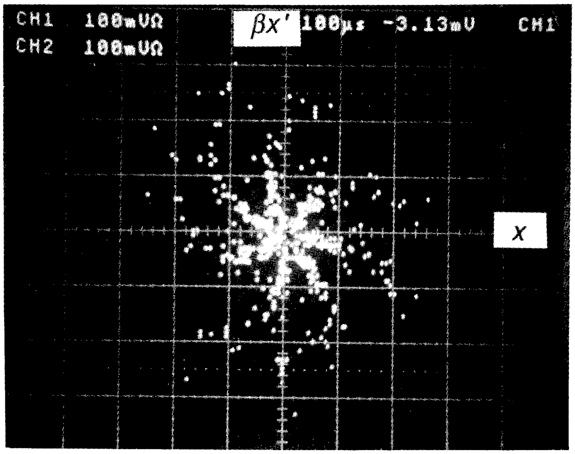
(a) The betatron oscillation becomes a circle trajectory.
Horizontal: x (1 mm/div)
Vertical: $\beta_0 x'$ (1 mm/div)



(b) Time-extended view on a digital storage scope (Textronix-2450). Bunch positions of ten revolutions are displayed. The bunch rotates following the sequential number of 0, 1, 2,.3.

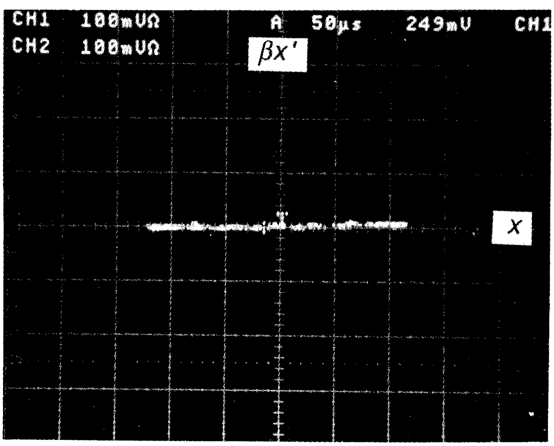
Figure 2. Phase-space display of a transverse instability.

Figure 3 shows a large amplitude oscillation excited by the injection kicker magnets. The bunch initially rotates on the outer circle and its radius becomes gradually smaller according to the damping. Since the tune number is near to 1 - 2/7, the trajectory shows a "star"-like pattern with seven arms. The curvature of the arm varies with its amplitude damping due to the amplitude dependence of the tune-shift. S. Kamada et. al.[4] analyzed this non-linear tune-shift, by sampling the damping oscillations and detecting its betatron phase variations on this system.



Horizontal : x (1 mm/div)
Vertical : $\beta_0 x'$ (1 mm/div)

FIGURE 3 "Star", a large amplitude damping oscillation excited by the kicker magnets.



Horizontal : x (1 mm/div)
= (0.1%ΔE/div)
Vertical : $\beta_0 x'$ (1 mm/div)

FIGURE 4. Synchrotron oscillation.

Figure 4 shows the synchrotron oscillation. The energy oscillation becomes a straight horizontal line. Hence, one can easily distinguish the types of oscillation, i.e., whether the oscillation is a betatron oscillation or a synchrotron oscillation.

CONCLUSIONS

Phase-space monitor system has been currently used to observe the transverse bunch oscillations on (x, $\beta x'$) and (y, $\beta y'$) vector displays. The system features and possibilities are

(1) The system allows rapid visual evaluations of the instability. One can easily distinguish the transverse bunch oscillations from the longitudinal energy oscillations, according to their trajectory patterns on the phase-space displays.

(2) One can directly observe the non-linear effects, such as non-linear tune-shift in the phase-space monitor system.

(3) The system provides the phase-space informations of four individual bunches at the same time. The system will be applied to measurements of the coupled bunch instability, and the coherent beam-beam effects.

(4) In future linear collider, such phase-space monitor system will be very useful to monitor the bunch-to-bunch position fluctuations in the linac, especially the beam extraction jitter from the damping ring.

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