RE-EXAMINATION OF BEAM INSTABILITY DUE TO BEAM LOADING

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In the synchrotron, a charged particle is guaranteed to stay in a ring by restriction force, which is produced by radio frequency (RF) electric field for the longitudinal motion. However, in a high intensity synchrotron, the beam image current flows into the RF cavity, in which the acceleration electric field is produced. Since the frequency of the image current oscillates following the longitudinal beam motion, the amplitude and frequency of the RF voltage is modulated. Then, the synchrotron oscillation known as longitudinal beam motion will be perturbed under such RF voltage. So these modulation and perturbation will be necessary to deal with self-consistent manner. Consequently, depending on the conditions of RF system, the instability occurs. Contribution of such a beam is called as the beam loading and Robinson [1] originally evaluated the instability.

According to the conventional study [2], it is suggested that the instability is dependent on the resonant frequency of RF system (ω_r), the revolution frequency of a beam (ω), the beam intensity (I_{bs}), and the impedance of RF system expressed as a L C R resonator. The stability diagram is shown in Fig. 1 (left). Then, if the beam intensity becomes higher than a threshold value with in $\omega_r > \omega$, the instability occurs. And in the case of in $\omega_r < \omega$, the instability occurs independent of the beam intensity. Since the instability occurs in the latter case even if intensity is low, the method for controlling the phase and amplitude of RF voltage has been prepared, and complicated operation has been performed in order to avoid such instability.

However, even if there is such no preparation, it has been known that a beam is accelerated appropriately in the region of $\omega_r < \omega$. So, suspecting that the conventional study is doubtful, we started the study to examine the instability. At first, we pay attention to the two points in advancing this study. That is, although the instability is dealt with as the relative motion to a reference particle, we notice that 1) it is necessary to choose the equilibrium particle under modulated RF voltage. On the other hand, the nominal equilibrium particle is chosen for the reference in conventional study. Furthermore, since the frequency of image current is oscillated with motion of a beam, 2) it was necessary to deal with the amplitude of image current as an oscillated term. In this way, even if the RF voltage is modulated, we suggest that the closed orbit for the reference particle could exist.

As a result of the examination for the instability, the stability diagram shown in Fig. 1

(right) is obtained. Comparing with the conventional diagram, the stable region appears in the both sides of ω_r. This stable region is extensible by optimizing the impedance of the RF system expressed by the $L\ C\ R$ parallel resonant circuit. Then, in order to avoid beam instability, it is suggested that the resistance (R), which consists of the loss in the RF cavity and the output-impedance of RF power supply, and the capacitance of the acceleration gap (C) should be small value.

From this result, we conclude that the control system considered to be required for stability is unnecessary any longer, and what is necessary is just to optimize the impedance of RF system intently.

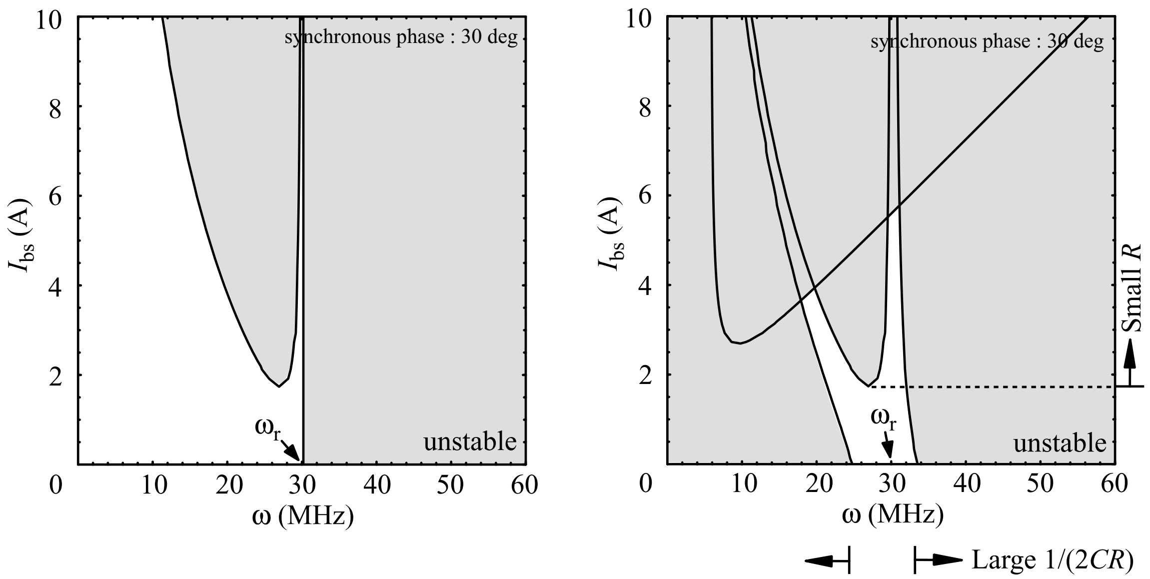

Figure 1: Typical stability diagram. In the left diagram for conventional study, when the beam revolution frequency (ω) is higher than the resonant frequency of RF system (ω_r), the instability occurs independent of the beam intensity. On the other hand, in a new diagram (right), the stable region appears in the both sides of ω_r.

Reference

[1] K. W. Robinson, CEAL-1010, (1964)

[2] F. Pedersen, IEEE Trans. Nucl. Sci. NS22, p. 1906, (1975)