OPERATION OF THE DOUBLE RF SYSTEM FOR LANDAU DAMPING IN TERAS

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Abstract

A double RF system with a 2nd-harmonic RF cavity is installed in order to obtain high quality electron beam for free electron laser experiment in the ETL storage ring TERAS. The coupled bunch longitudinal instability is effectively reduced by tuning the operation point of the system in the 3-bunch mode with stored current below about 30 mA.

Introduction

The experimental results of the dependence of the bunch length on beam current has been described I^X with x around 1/3 or 1/5.[1] According to a theory, the power 1/5 can be explained by the model of coupled-bunch beam instability.[2] The results of the measurements show the existence of the coupled-bunch beam instability in TERAS. The equilibrium quality of electron beam is determined by a balance of the growth rate of the instability and the dumping process due to a synchrotron frequency spread. Therefore it has been tried to reduce the instability by introducing a large frequency spread with a higher harmonic RF cavity (a Landau cavity) added to a main accelerating cavity.[3] The two cavity system efficiently works to obtain the high quality electron beam for lasing in visible of a storage ring free electron laser at ETL.[4]

Description of the double RF system

Fig. 1 shows the block diagram of the double Rf system for the Landau damping in the TERAS. In the main Rf system the Rf frequency of 171.62 Mhz is generated by a 10 kW transmitter and fed to the main cavity through a circulator. In the Landau cavity system the RF signal is multiplied to the second harmonic and fed through a 2 kW transmitter. The resonant frequency of the main cavity can be kept constant by using the feedback loop with a vector voltmeter. In the present stage , the phase feedback is not used in the Landau cavity system. Therefore its phase with respect to the one of the main cavity
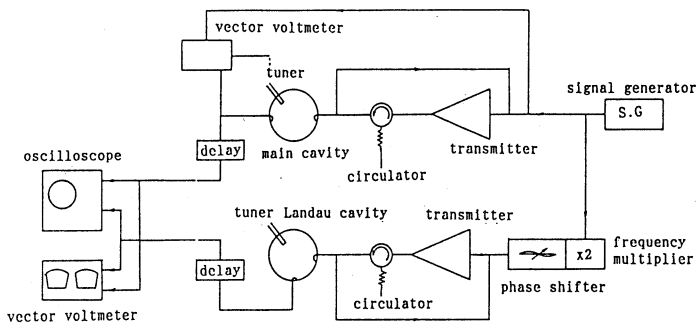
is adjusted manually by a plunger and a phase shifter.The output powers of both transmitters are kept constant at any tuning the cavities by using the circulators. Accelerating voltages, which are vector sums of the voltages generated by the transmitters and the one induced by beam current, can not be kept constant, since the voltage feedback loops are not provided. The main cavity is operated by adjusting the resonant frequency to Rf frequency. Both the cavity voltages are monitored and the relative phase of these signals are indicated on the an oscilloscope.   The parameters of the double RF system are summarized in table 1.

Fig. 2 shows the structure of the Landau cavity. The cavity body and side flanges are mostly made of oxygen-free copper-clad stainless steel plates. Accelerating electrodes and a tuning plunger are made of oxygen free copper. The acceleration gap between

Table 1
Parameters of the double rf system

		Main cavity	Landau cavity
Unloaded Q	Q_0	7500	12000
Shunt impedance	R_s(kΩ)	725	1900
Coupling constant	β	2.3	2.1
Generated power	P_k(kW)	10	2
Rf frequency	f_{rf}(MHz)	171.62	343.24
Harmonic number	h	18	36

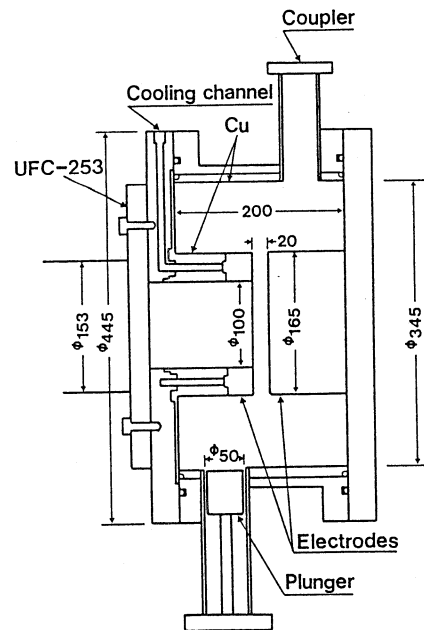Fig. 2. Structure of the Landau cavity

Fig. 1. Block diagram of the double rf system for the Landau damping

electrodes of 165 mm and 100mm in the outer and inner diameters is approximately 20 mm. The resonance frequency and tuning angle can be changed by moving the plunger with 50 mm Φ. Double Helico-Flex O-rings between the body and flanges keeps both vacuum tightness and electrical contact. The cooling water into the cavity controls temperature within 0.1 ℃ around 16 ℃. The resonance frequency curves of the cavity are observed by using a tracking generator and a spectrum analyzer. Resonance frequency tuning was accomplished by changing the acceleration gap with several machinery cuts. The nonloaded Q-value was measured to be 12,000 by reducing the coupling coefficients sufficiently. The shunt impedance was measured using a perturbation technique. The value was 1.9 M Ω.

Experiments and discussions

The experiments to suppress the coupled bunch longitudinal instability is mainly carried out in the 3-bunch operation mode of the storage ring. In the free electron laser experiment at TERAS, a 3 bunch operation is necessary, since the optical cavity length demands only 3-bunchs. The 3-bunch beam current is obtained by the RF-KO method feeding a frequency-divided ring rf signal mixed with the betatron frequency to an excitation electrode. The RF-KO method developed at TERAS consists of two stages of RF-KO procedure. The rf signal with 1/6 of accelerating frequency is at first used as modulated signal with the betatron frequency. In this case, six bunches are left at the zero-cross point of the modulation rf signal. And then the rf signal with 1/12 of acceleration frequency is used as a modulating signal to kill three bunches adjacent to the survivor. The actual frequency of modulated signal has to be different from betatron tune by 0.5 to compensate the shift of resonance line. These procedure are necessary because of short interval of electron bunches. In practice, the RF-KO signal is applied the the electrode in the filling time of the storage ring to obtain high stored current. So far, the beam current of 7.8 mA per bunch is obtained in the 3-bunch mode at 230 MeV.

The main cavity is powered with 3.8 kW and adjusted its resonant frequency to the frequency of rf power. In general the resonant frequency in a single rf system should be detuned to avoid the dynamic Robinson instability. Such operation point of the main cavity is chosen to keep the stability of the main cavity for the sudden change of the coupling of two cavity system caused by some effects.

The two-cavity system is quite sensitive to stored current. The Landau cavity strongly affects the 230-MeV electron beam with current higher than 30 mA. In the 3-bunch mode, the bunch length has been found to be shorter than the full-bunch operation. However the bunch shape continuously changes and the blow-up of beam profile is observed in a TV monitor. The RF power of several hundred watts is supplied to the Landau cavity and the phase of generated voltage is adjusted by changing the plunger position and the phase shifter. The beam instability is dumped by tuning the resonance frequency of the Landau cavity a little above the exciting RF frequency and by advancing the tuning angle of the cavity by π/2 to the main cavity. The dumping of the beam instability is obtained at a beam current lower than about 5.5 mA per bunch. When the Landau cavity crosses the resonance point toward the low frequency region by moving the plunger, electron beam is lost in almost all cases. Typical improvement of the beam stability is shown in Fig. 3. The figure indicates the improvement in the modulation of spontaneous emission spectrum due to the operation of the Landau cavity. Figure 4
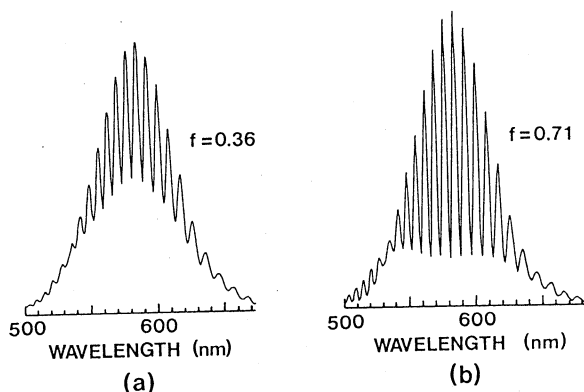

Fig. 3. Spontaneous emission spectra
(a) full bunch operation
(b) 3 bunch operation and Landau cavity on

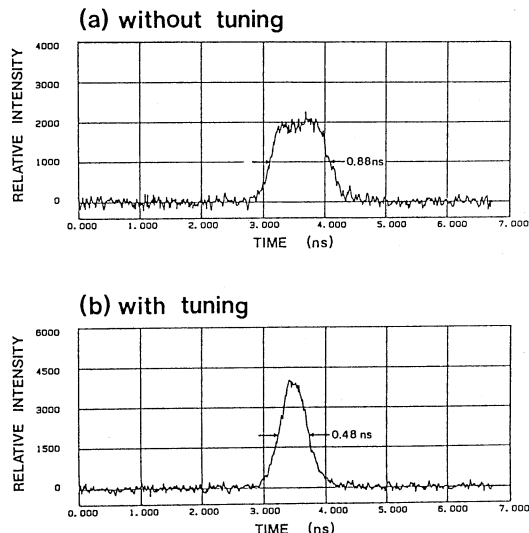## INFLUENCE OF LANDAU-CAVITY TUNING ON BUNCH LENGTH

Fig. 4. Bunch shapes of electron beam in the 3-bunch mode when the beam is (a) not stabilized and (b) stabilized.

shows the bunch shape of the electron beam in 3-bunch mode when the instability of beam current is (a) is not dumped and (b) dumped. It can been seen that the bunch length shortens when Landau cavity is worked, which is compared with the beam profile without damping. Experimental results prove that the energy spread of electron beam is improved as the longitudinal instability is suppressed. It is also found that the bunch shortening is correspond to the energy spread and the phase adjustment of the Landau cavity voltage with respect to the main cavity.

The experiments for the dumping was also carried out in the full bunch operation of the storage ring. Electron energy was 307 MeV, and stored current about 71 mA. The experiment was started with beam current of around 130mA, however, it is very difficult to stabilize the beam fluctua-

tion. The sudden beam loss happens in feeding rf power to the Landau cavity, although the rf phase of the cavity is carefully adjusted. Typical experiment results for dumping in this case are shown in the Fig. 5. Fig. 5 exhibits the frequency spectra of the signal from a button monitor and the phase relation of rf voltages between the main cavity and the Landau cavity. The sidebands of the coherent oscillation of the instability were reduced gradually by approaching the Landau cavity voltage to the optimum phase as shown. The sidebands in the figure indicate a dipole mode and higher mode of instability at a beam current of about 70 mA. The last picture, Fig. 5 (d), which was taken when the instability was most effectively dumped, indicates the fluctuation of the rf voltage of the Landau cavity. It was difficult to keep such beam condition long time manually. THe damping of the coupled bunch instability is obtained at a beam current lower than 70 mA. Above this current the two cavity system is however not kept at the optimum phase, but the power reflection of the Landau cavity becomes large. It is impossible to stabilize the Landau cavity from this condition without turn off.

Conclusions

The longitudinal couple bunch instability in TERAS was suppressed by the Landau damping in a double rf system composed of a second harmonic rf cavity at beam current 30 mA in 3-bunch mode and 70 mA in full bunch mode. The dumping becomes in effective, however, at beam current higher than these currents.
It is difficult to keep the optimum phase of the rf voltage of the Landau cavity for the damping. This phenomenon is accompanied with the deformation of the rf voltage. The defect of the system will be suppressed by introducing phase feedback loops and rf voltage feedback loops in both rf cavities.

References
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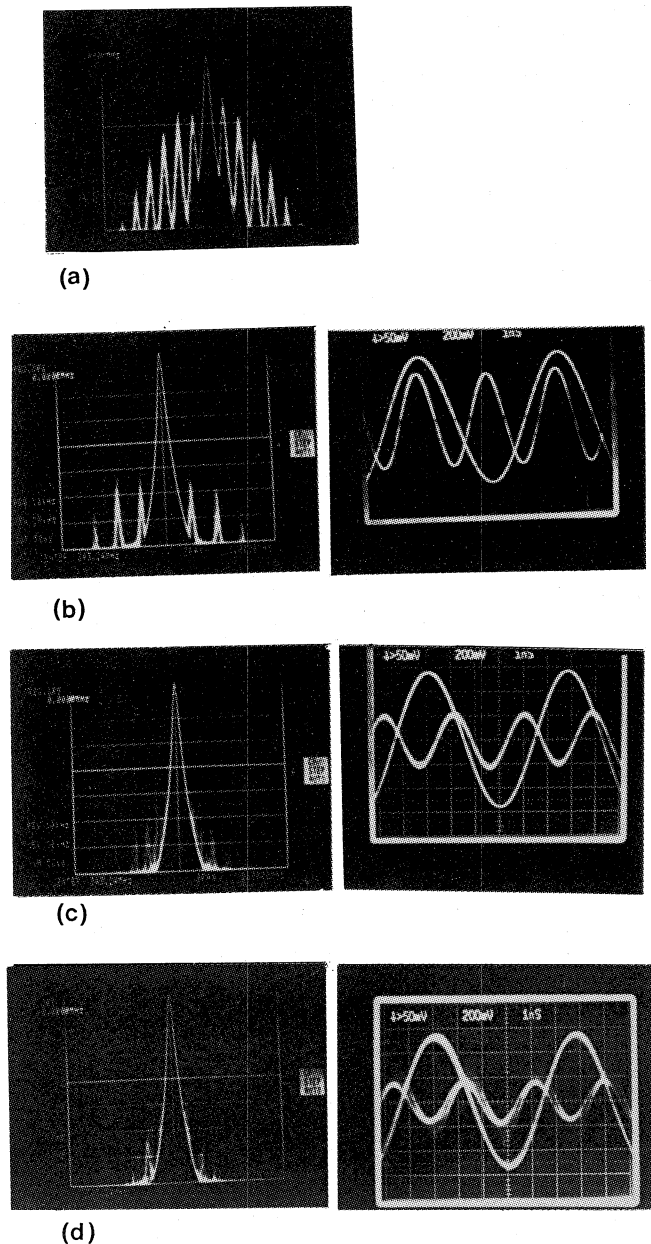

(a)

(b)

(c)

(d)

Fig. 5. Frequency spectra of signal from a button monitor in the full bunch mode when the Landau cavity(a) is not powered, (b), (c) and (d) are powered and conditions adjusted (b) and (c) also show monitored rf voltages of the main and Landau cavities.