FIRST MEASUREMENT OF THE PARASITIC MODE LOSS IN TRISTAN AR

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Summary

Three methods have been tried to measure the parasitic mode loss in TRISTAN AR. With an aid of the computer code BCI, a contribution to the parasitic mode loss from the bellows of the vacuum chamber is isolated. Using the obtained loss parameter , the longitudinal coupling impedance of the cavities and of the bellows are estimated separately, by the broad band impedance of a resonator model.

Introduction

Parasitic modes (higher order modes) generated by the interaction of a highly bunched beam with a number of cavities and vacuum chamber components are of a primary importance for the design and operation of large electron-positron storage rings. Their excitation leads to not only an significant energy loss for a short bunched beam in addition to a synchrotron radiation loss, but local overheating in chamber components and destructive instabilities of a beam. The parasitic mode loss can be computed for RF cavities and other resonator structures by using standard computer codes[1,2]. Experimentally it is possible to measure the parasitic loss for individual components in bench tests[3]. From these calculations and measurments, total parasitic loss for all ring components can be estimated. Direct measurements of total parasitic loss in the ring has been developed in SPEAR[4] and PETRA[5]. Their measurements provide useful data for the design of elecron storage rings.

In this work, we have done measurements of parasitic mode loss in TRISTAN AR by pursuing three measurement techniques. In the first method, the parasitic mode loss is obtained by measuring the net RF power input into the accelerating cavities; in the second and third, it is obtained from the measurement of shift in synchronous phase, but using different technique. From the data taken for wide-ranging values of bunch length, the longitudinal broad band impedance is derived and parasitic mode losses in RF cavities and vacuum chamber components are separately assessed.

Measurement techniques and data reduction

Measurements of the parasitic loss impedance have been done at several constant cavity voltage Vc , with increasing or decreasing the intensity of the single bunched beam . The energy of the beam has been 2.55 GeV throughout this experiment.

The techniques of the net RF power measurement (mehtod-I), and of the phase shift measurement between the RF-signal of the cavity and of the beam (method-II) are described in the Ref.-4 extensively. The basic equation of the beam loading is given as follow,

$$V_c\cos(\phi_s)=V_s + I*Z_{pm} \qquad (1),$$

where Vc, ϕs, Vs ,I and Zpm are peak cavity voltage, synchronous phase, synchrotron radiaton loss, and parasitic mode loss impedance, respectively. Figure-1 shows the experimental instrumentation of the method-II. The accuracy of this measurement is fairly good as shown in Fig.-2, typically the fluctuation of phase shift are around ±.3°.

In the method-I , it is rather simple, in principle, to extract the bunch length dependence of the loss impedance, once if we know the correlation between the bunch length and beam current at some constant Vc. There is however other difficulty for this method as discussed later. On the other hand, in the phase shift measurement the absolute phase is still unknown and the equation-(1) can't be applied directly to extract Zpm as a function of the current.

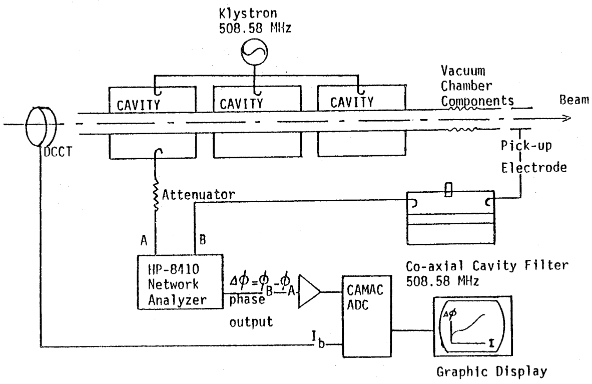

Fig.-1 Experimental Instrumentation of the method-II.

The strategy , we adopt in the method-II, are following. At the low current , the bunch length is almost constant for a given cavity voltage and this bunch length is consistent with the natural bunch length. This is confirmed by the bunch length measurement in AR[6] as shown in the Fig.-3. We expect also, at these small currents, Zpm is almost independent of the currrent, which will be reasonable if the shift in synchronous phase depends on the current linearly, as shown in the Fig.-2. Then, in our experiment, we can expect the validity of the following equation

$$Z_{pm}=-V_c*\sin(\phi_s)*(d\phi_s/dI) \qquad (2).$$

In this expression, $\sin(\phi_s)$ is still unknown. However ,if the cavity voltage is greater than 0.8 MV, we can set $\sin(\phi_s)=1$, with the risk of introducing the error of at most 2 %. Our data have been taken at the range of the Vc from 0.84 MV to 5.45 MV.

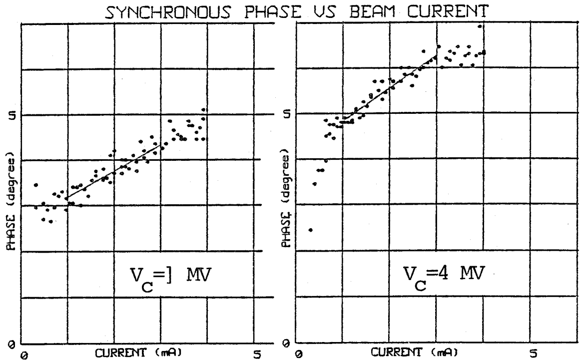

Fig.-2 Typical data of the method-II.

The limitations of obtaining Zpm by the method-I mainly come from the difficulty of the very precise power measurement. In the procedure to extract the Zpm, we must subtract the cavity stored power Pc from the power input into the cavity Po. The remaining beam loading power Pb=Po-Pc is very small compared to Po or Pc, when the beam current is low. In our experiment the practical lower limit is around 10 mA. At that low

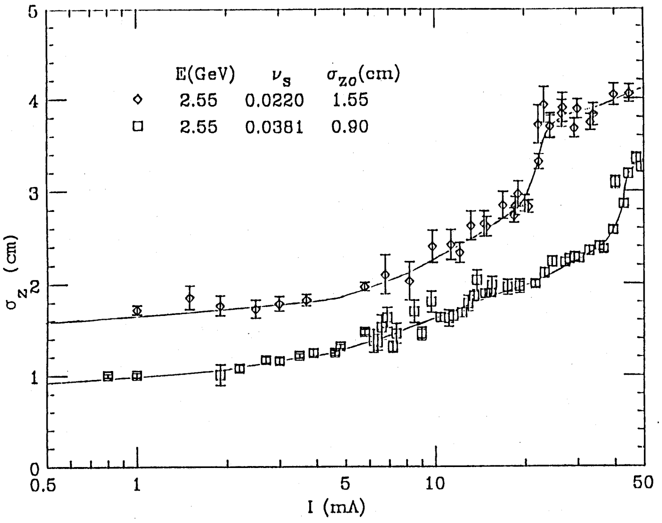

Fig. 3 Bunch length as a function of beam current

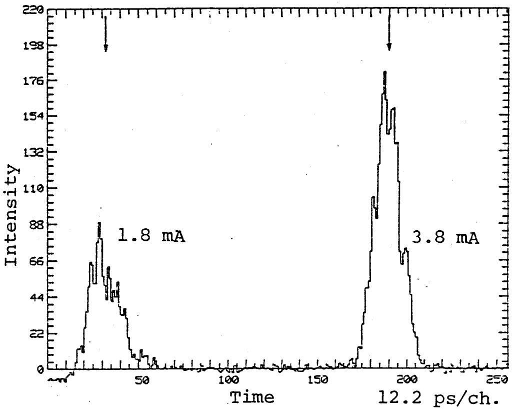

Fig. 4 Bunch shapes and positions taken with the streak camera at E = 2.55 GeV and υ_s= 0.017. The bunch length is 2.0 cm.

current, the resulting parasitic mode loss power Ppm may be a comparable level with the noise level. The data, shown in the Fig.-5, have been taken at Vc=1 MV, and in order to avoid a extra complexity, only one cavity (DAW-B type) has been used to accelerate the beam and the remaining two cavities have been completely detuned.

It is also possible to make a direct measurement[5] of the shift in synchronous phase by observing a bunch on time axis with a low current prebunch as a timing reference (method-III). The prebunch is injected into the preceding bucket ahead of the high current main bunch. In this method the current of prebunch must be small enough so that a wake field generated by the prebunch does not affect the main bunch. It is also assumed that the multi-turn effect of the main bunch can be neglected. The time difference between the prebunch and the main bunch is measured by observing the synchrotron light with the streak camera[7]. Two bunch shapes and their positions taken with the streak camera are shown in Fig. 4. A time shift of the center of main bunch is obtained from a deviation of the time difference between two bunches from a RF period with the measurement error of 3 ps. When the time shift is Δt at the average beam current I of the main bunch, the loss impedance is given by

$$Z_{pm} = -(2\pi\ \nu_s)^2 f_0 E\Delta t/\alpha I \qquad (3),$$

where ν_s is the synchrotron tune, f_0 is the revolution frequency 794.65 kHz and α is the momentum compaction 0.01252. The measurement shown in Fig. 4 was done for E=2.55 GeV, ν_s=0.017 and I= 3.8 mA. From Eq.-(3) the loss impedance is calculated; Zpm= 22.2 Mohms at the bunch length σ_z=2.0 cm. The error of this measurement is estimated to be about 7 %. In our measurement, sometimes the longitudinal oscillation occured on bunches so that we failed to make reproducible data.

The peak cavity voltage Vc has been caliblated for every change of the Vc, by measuring the synchrotron frequency at the low beam current. Synchrotron motion has been excited by modulating the amplitude of the RF signal in this frequency. The accuracy of this frequency measurement is less than 1 %, which suggests the accuracy of the Vc is determined by the sin(ϕ_s) and the machine parameters (α,E; momentum compaction factor and energy, resp.). As discussed before, sin(ϕ_s) is almost unity in our experimet.

In the next section , the obtained Zpm in the method-II are mainly used for analysis.

Parasitic mode loss

The measured and computed parasitic loss impedance Zpm are shown in Fig.-5 , as a function of the bunch length. The parasitic mode loss at the cavities and at the bellows of the vacuum chamber have been estimated by the computer code BCI[8]. The BCI code can only be applicable for a cylindrical symmetry structure, therefore, the computation has been done for some simplified structures. Especially, a circular cross section shape has been used for the bellows[9] instead of the actual elliptical shape. On the other hand, the simplificaton of the cavity structure is less significant, we expect that the computed Zpm of the cavities will not be far from the true value.

Among the three different measurements, the obtained Zpm from the method-III are rather inconsistent with the results of the other methods and with the computed Zpm. The difficulties of this method is already described in the previous section. The measured Zpm at relatively shorter bunch length which are obtained by the method-II, show a steep falling off as increasing bunch length, and around 1 cm bunch length, it changes to less steep slope. In the longer bunch length , the bunch length is greater than 1 cm , it seems that the Zpm almost come from the parasitic loss in the cavities only. The results of the method-I (net power measurement) also suport these behaviour in the longer bunch length.

The steep falling off of the Zpm at shorter bunch length , would be explained by a parasitic mode loss in the bellows in accordance with the parasitic loss in the cavities. The computed Zpm of the bellows and of the cavities reproduce this behavior fairly good, at least qualitatively. From these discussion, we adopt the excess part of the measured Zpm above the calculated Zpm of cavities, as a contribution from the parasitic mode loss at the bellows. Then Zpm^{tot} can be expressed as

$$Z_{pm}^{tot}(\text{measured})=Z_{pm}^{cav}(\text{computed})+Z_{pm}^{bell}$$

Using the loss impedance Zpm^{cav}(computed) and Zpm^{bell} (obtained), we could obtain the loss parameters k=Zpm/Tb as a function of the bunch length, for each component of the Zpm ,where Tb is revolution time. Each of loss parameters k^{cav} and k^{bell} is fitted separately with the following curves in the limitted region of the bunch length as described below

$$k^{cav}(V/pC)=11.8*\ \sigma_z^{-0.651} \quad \text{for } .5<\sigma_z<2 \text{ cm ,}$$

$$k^{bell}(V/pC)=162.9*\exp\{-(1.912*\sigma_z)^2\} \quad \text{for } .68<\sigma_z<1 \text{ cm.}$$

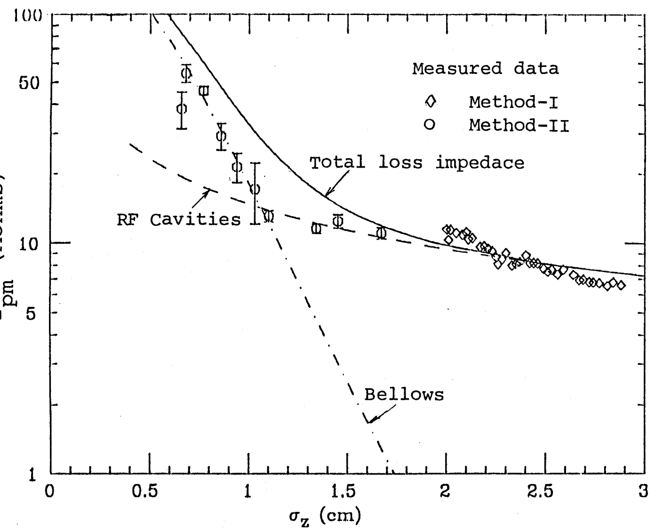

Fig. 5 Computed and measured parasitic mode loss impedances as a function of bunch length.

The loss parameter can be related[3] to the longitudinal coupling impedance $Z(\omega)$ with assuming a Gaussian bunch shape ,as given by

$$k(\sigma_t)=\frac{1}{\pi}\int_0^\infty Z_R(\omega)\exp(-\omega^2\sigma_t^2)\,d\omega \qquad (4),$$

where σ_t and Z_R are bunch length expressed in time and real part of the longtudinal coupling impedance,respectively. Here, we also adopt the single broad band resonator model[10] for a longitudinal impedance, defined as below

$$Z(\omega)=R_s/(1+jQ(\omega/\omega_r-\omega_r/\omega)) \qquad (5),$$

where Rs, Q and $\omega_r/2\pi$ are shunt impedance, Q-value and resonant frequency of this resonator, respectively.

Using the loss parameter of the cavity k^{cav}, the resonator parameters , Rs, Q and ω_r are obtained by fitting to the Eq.-(4) in the relatively wide range in the bunch length. While the obtained loss parameter of the bellows are given for small range of the bunch length, therefore, only the Rs and ω_r are obtained from the fitting of the k^{bell} to the equation-(4). In this fitting, Q is assumed to be the expected value 3.60 as discussed below. The best fit gives the following values for each component.

CAVITY:DAW-A: R_s= 2.01 kΩ, f_r= 0.74 GHz,Q=0.31,

:DAW-B: R_s= 0.65 kΩ, f_r= 1.05 GHz,Q=0.38,

BELLOW: : R_s=41.60 kΩ, f_r=10.8 GHz,Q=3.6 (input).

The expected broad band impedance of the bellows are also estimated with the technique of the Fourier transform of the wake field computed at the bellows. The resulting spectrum are fitted to two broad band resonators, these are

(1st): R_s=26.46 kΩ, f_r= 7.76 GHz,Q= 3.60,

(2nd): R_s=13.99 kΩ, f_r=25.05 GHz,Q=11.84.

Figure-6 shows the summary of the broad band impedance. The parasitic mode loss impedance Zpm are re-calculated with using these obtained broad band impedance in accordance with the Eq.-(4) and -(5). The re-calculated Zpm, solid curve in the Fig.-5, show fairly well behaviour.

Conclusion

The parasitic mode loss have been measured in TRISTAN AR with three different methods. The method-II, measurements of the shift in synchronous phase at low current with constant peak cavity voltage, has given us rather reliable data for a relatively short bunch length region. Combining with other data, measured in the method-I, and with the assistance of the comupted results ,we could estimate the contribution from the bellows to the parasitic mode loss, as well as the effect from the cavities. More efforts are required to refine the data which have been taken in the method-III.

The longitudinal coupling impedance of the bellows and of the cavities are obtained in the form of the single resonator model, separately. The obtained resonant frequency of the bellows is around 10 GHz, which qualitatively agree with the computed resonant frequency of the simplified circular cross section bellows.

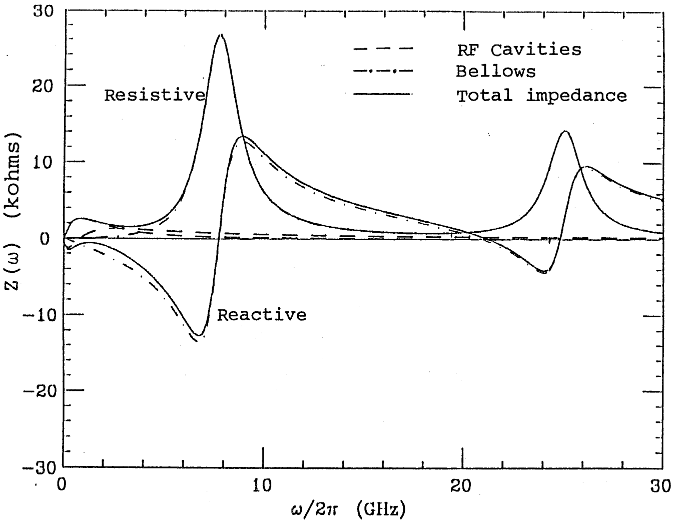

Fig. 6 A sketch of the longitudinal coupling impedance in TRISTAN-AR.

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