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Wake Field Study Using Two Spaced Bunches [1]

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Abstract

Wake field studies using calorimetric methods are reported. Measurements show interference between wake fields generated by two bunches. The described technique can be used to determine which elements introduce bunch coupling.

Introduction

Due to finite resistance and irregularities of beam pipe wall the bunch of charged particles traveling through a beam pipe leaves behind a wake field. The structure and characteristic time of this field depend on beam pipe material as well as pipe shape.

Consider several bunches circulating in a storage ring. If somewhere the wake field exists longer than period between bunches there will be bunch to bunch interaction which in turn may cause multibunch operation problems. If the wake field decays before the next bunch appearance, there will not be an interaction between bunches. So, the above shows the importance of having a practical method to determine the elements generating long lived wake fields.

This paper reports the experimental study of wake function performed at CESR in 1994. It was based on measurements of temperature variation

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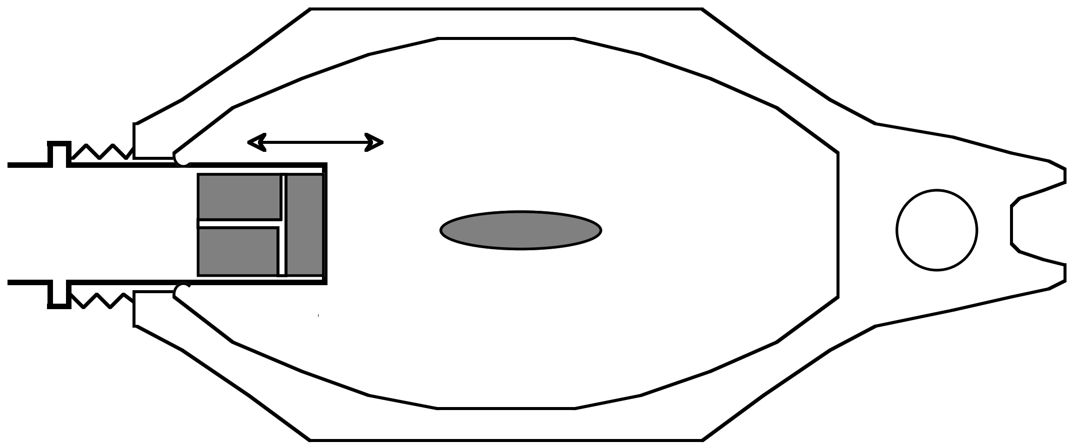


Figure 1: The H18E scraper and CESR's beam pipe cross section.

caused by wake field energy absorption. The first part describes the used method as well as the single bunch wake field study. The next section reports observation of the effect of interference of wake fields generated by two bunches.

Method and tools

There are several scrapers around CESR. One of them, H18E, located in west arc of ring was used in the reported experiments. It is shown at 1:1 scale in figure 1 together with the CESR beam pipe cross section. The scraper is a stainless steel tube of $0.75in$ diameter captured from one side. Inside there is a copper plug of 65 grams weight with air-cooling channels and a thermal sensor. The weight of scraper is mostly the mass of the plug. Airflow through plug provides cooling.

Generally there are two reasons for beam pipe heating by circulating beam. The first one is synchrotron radiation. In this case the temperature change is proportional to circulation current. The second reason is wake field. It causes quadratic dependence of temperature on beam current. The measurements of H18E scraper temperature versus beam current, shown on figure 2 indicate pure quadratic dependence. It means that the scraper heating is due to the wake field.

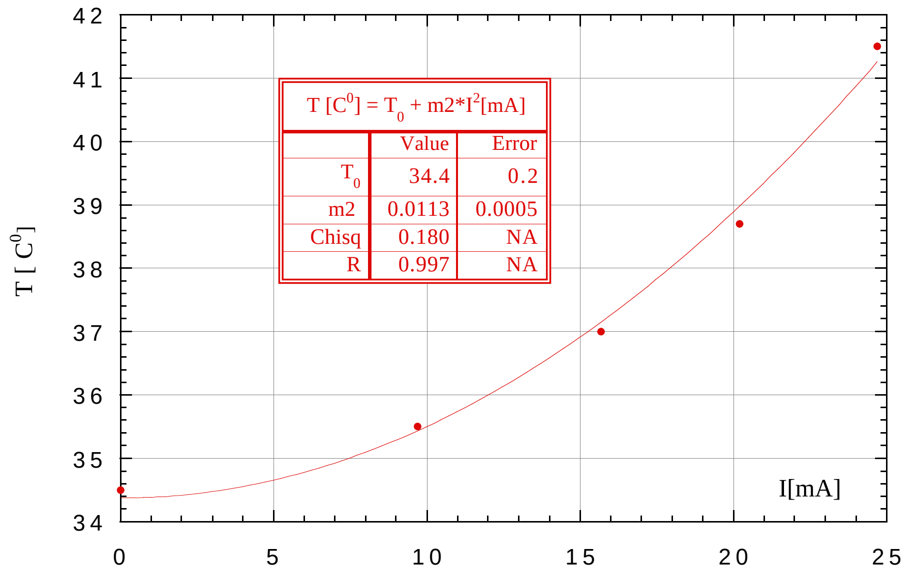


Figure 2: Dependence of scraper temperature on single bunch current.

The scraper temperature evaluation can be described by the following equation:

$$\frac{dT_s}{dt} = \frac{P_w}{mC} - \frac{(T_s - T_a)}{\tau_c} \tag{1}$$

Here T_s is scraper temperature, m and C are plug's mass and copper heat capacity, τ_c is cooling time and T_a is incoming air temperature, P_w is the wake field power absorbed by scraper. In the case of equilibrium, i.e. when $\frac{dT_s}{dt} = 0$, equation 1 can be rewrited as:

$$P_w = \frac{mC}{\tau_c}(T_s - Ta) \tag{2}$$

Figure 3 shows the process of scraper cooling after

circulating beam was tuned off. Using exponential fitting it was found that cooling time is about $68.3 \pm 0.3 sec$. All that give us :

$$P_w[W] = 0.38 \Delta T[C^0] \tag{3}$$

Where $\Delta T = T_s - T_a$.

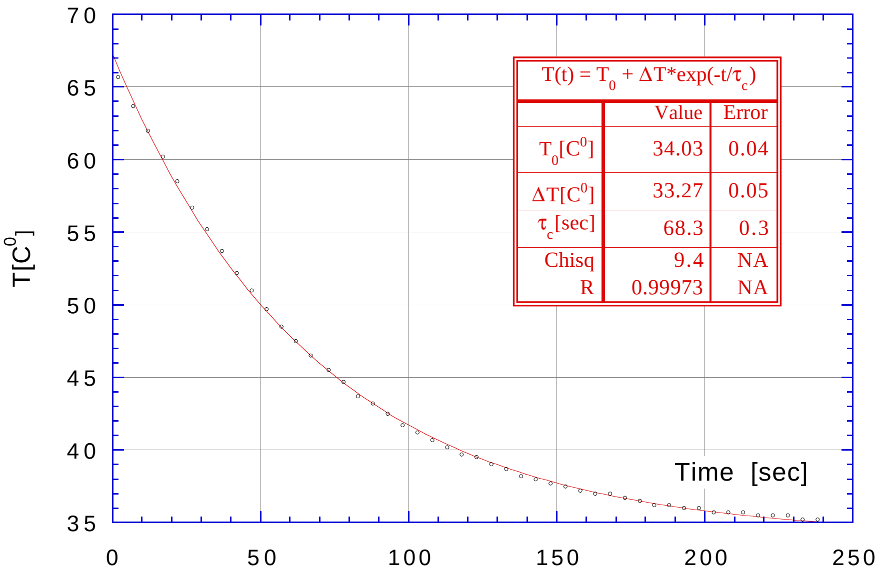


Figure 3: Scraper cooling after beam was turned off.

Wake field energy absorption has been measured versus scraper position as well as versus bunch length. These data are presented on figure 4 and 5. In both cases the scraper temperature was measured and then wake field power was calculated using equation 3. Figure 4 shows that the wake field increase very rapidly when scraper goes close to beam. Figure 5 indicates that shorter beam leaves behind more wake field energy than longer one.

Wake field study with two spaced bunches

Consider the case of two equal bunches passing a scraper. Let them be spaced by the distance d or by time $\delta t = d/c$, where c is speed of light. Assume that the wake field trapped by scraper has a dominate mode with frequency f_w. After the first bunch passed scraper the time dependence of dominated mode can be written as:

$$E(t) = E_0 \exp\left(-\frac{t}{\tau_d}\right) \cos 2\pi f_w t \tag{4}$$

Where τ_d is the decay time. The second bunch will generate the same

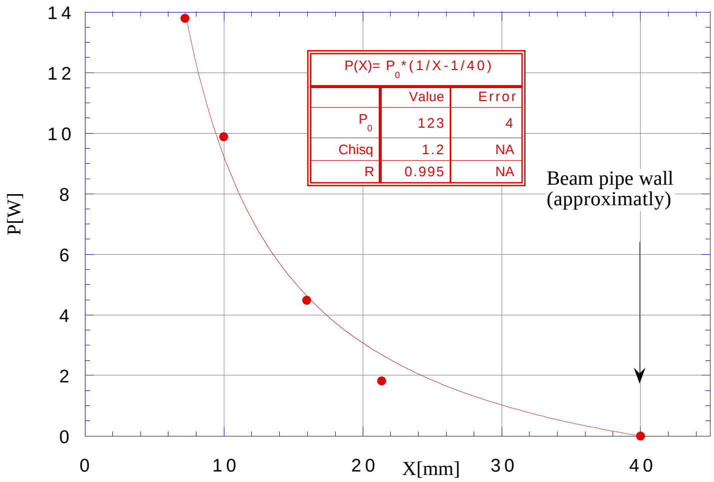


Figure 4: Wake field absorbed power versus distance between scraper and beam center. 90mA of total current in 7 equal bunches spaced by 366ns

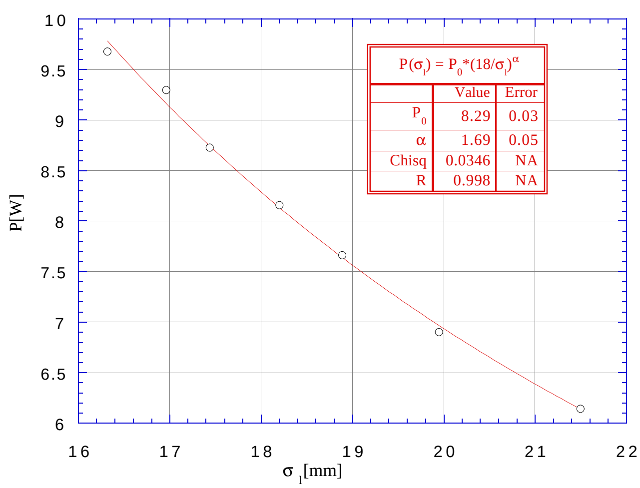


Figure 5: Wake field absorbed power versus bunch length. 85mA of total current, 7 equal bunches spaced by 366ns. Scraper position is 9.5mm from beam center.

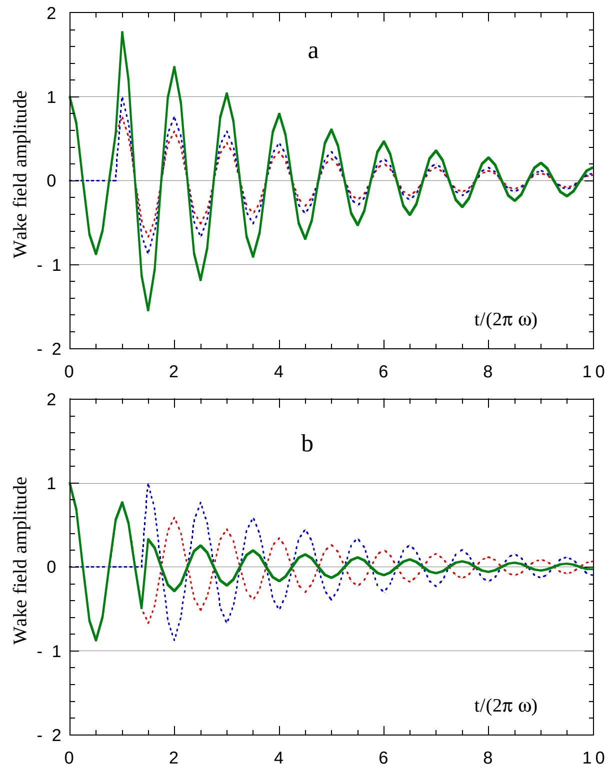


Figure 6: Resulting wake field after two bunches pass scraper. Dotted lines are single bunches wake fields. Solid line is resulting amplitude. Decay time is 4 cykles. a) one cykl of wake field oscillation delay between bunches, b) one and half cykl delay

wake field, but delayed by time δt. Figure 6 shows the resulting field after two bunches passing scraper. If δt is equal to integer number of dominated mode oscillations the resulting field is approximately two times bigger than it is for single bunch, see figure 6a. If the number of oscillations is equal to a integer and a half, the resulting field will be much smaller, figure 6b.

Note that after both bunches passed scraper the energy of a trapped mode will be absorbed by scraper and by beam pipe around it. As beam pipe is made of aluminum and the scraper with high resistance stainless steel, most of energy should be absorbed by scraper.

Using expression 4 one can write a formula for wake field absorbed power of two equal bunches versus the space between them. It is:

$$P_w(\delta t) = 2P_0 \left(1 + \exp\left(-\frac{\delta t}{\tau_d}\right) \cos 2\pi f_w \delta t\right) \tag{5}$$

The distance between bunches in the storage ring can not be changed continuously. The minimum step is defined RF wave length, i.e. by the RF frequency f_{rf}. Due to that the *measured* dependence of power P_w on δt will be described by 5 with f_w replaced by $f_w - n * f_{rf}$ were n is integer part of $\frac{f_w}{f_{rf}}$:

$$P_{w,measured}(\delta t) = 2P_0 \left(1 + \exp\left(-\frac{\delta t}{\tau_d}\right) \cos 2\pi \left(f_w - n * f_{rf}\right) \delta t\right) \tag{6}$$

Figure 7 shows the result of the measurement of power absorption versus distance between two equal bunches. The point of zero distance means one bunch had two times higher current than for other points. CESR's RF frequency of 500 MHz determined a 2ns minimum step for variation of distance between bunches.

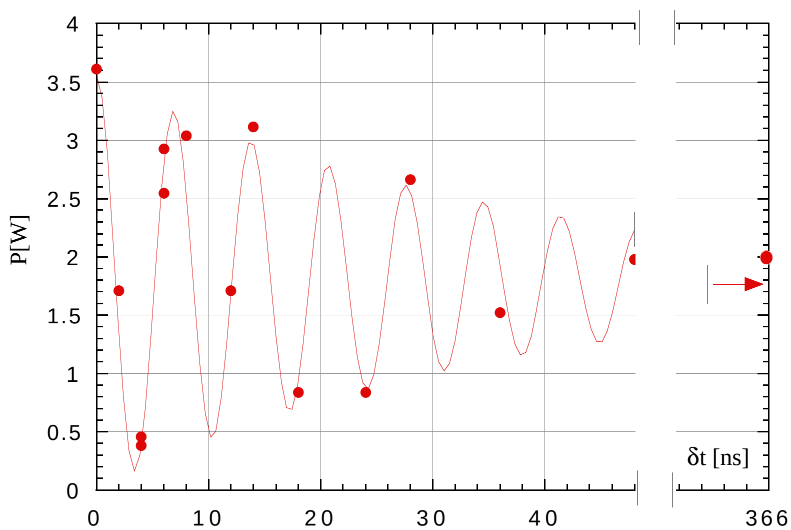
This data was fitted using expression 6 with P_0 calculated from previous experiments, see figure 2. Two parameters τ_d and $f^\star = f_w - n * f_{rf}$ were used as free ones. The fitting resulted in $f_w - n * f_{rf} = 0.145 \pm 0.001 GHz$ and the decay time of wake field $\tau_d = 36 \pm 7ns$.

Taking into account the geometry of the scraper and beam pipe one can suggest that n should be in range between 4 and 6. The more precise answer can be obtained with computer codes.

Now CESR is under operation with bunches separated by $28ns$ and there is plan to reduce this time to $14ns$. Comparing τ_d with these times, one can say that using of scraper may introduce the bunch coupling and cause mutibunch operation problems now and especially in future when the time between bunches will be significant shorter then wake field existing time.

Conclusion

It was found that the heating of one scraper is caused by wake fields. The scraper's temperature variation with the space between two equal bunches



$P[W] = 2.*0.89*(1+\exp(-\delta t/\tau_d)*\cos(2\pi f^{*}\delta t))$

	Value	Error
τ_d[ns]	36	7
f^{*}[GHz]	0.145	0.001
Chisq	0.72	NA
R	0.98	NA

Figure 7: Wake field absorbed power versus space between two bunches.

indicated the interference of two wake fields excited by bunches. The decay time the wake field was extracted from measured data.

On the base of these experiments one can make a general conclusion. Any temperature variations of storage ring elements with the variation of spacing between circulating bunches indicate interference between wake fields generated by the bunches. This interference in turn indicates bunch coupling. As a result, the effect of temperature variation with spacing between bunches may be used to determe elements which cause coupling between bunches.

Acknowledgments

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