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Summary of the Session on Other Effects*

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Summary of the Session on Other Effects

The theme of this workshop is to discuss the effects of foreign particles on the native beam in a storage ring. An ion in an electron storage ring, or a photo-electron in a positron storage ring, for example, would be a foreign particle. These foreign particles – which I shall call the "gaijin" (外国人) particles – can do damage to the stored native beam, especially when the beam consists of a long train of bunches as in a B-factory, or a 3-rd generation synchrotron light source.

Exactly what is meant by "other" effects is to be defined by the workshop participants. Presumably these are effects included in the theme of the workshop, but not covered in the other three sessions. Thus

$$\Big(\text{Other effects}\Big) = \Big(\text{Theme of Workshop}\Big) - \begin{cases} \text{Fast ion instability} \\ \text{Electron cloud instability} \\ \text{Cures} \end{cases} \tag{1}$$

There are perhaps four ingredients of the physics of gaijin particles:

1. The beam
2. The gaijin particle
3. How are the gaijin particles trapped?

4. How do gaijin particles and beam couple?

The beam

We may have $e^-, e^+, p, \bar{p}$, or heavy ion beams. We assume the beam is relativistic. The main parameters relevant here are the charge of the beam and the bunch structure (including gaps) of the beam train. Otherwise, there is not much to say about them.

The gaijin particle

(a) Ions mainly come from the residual gas. We typically have the atomic mass of $1 \leq A < 100$ (CO ions have $A = 28$). One should take note that residual gas can be greatly enhanced due to photo-desorption, and that this problem is not unique for $e^\pm$ storage rings (This consideration plays a role in the LHC design, for example).

(b) There are many sources for gaijin electrons:

photo–electrons due to direct synchrotron radiation

photo–electrons due to photons reflected off the wall

secondary electrons by other electrons hitting the wall

H^- stripping[1]

residual gas

multipactoring[1]

cosmic ray[2]

Among them, the most worrying candidate is the electrons due to multipactoring. They are most difficult to detect and to avoid.

(c) Another type of gaijin particles is the dust particles (positively charged). The equivalent atomic number would be $100 < A < 10^{6-8}$.

By combining a type of beam with a type of gaijin particle, one could explore various gaijin particle physics. It then seems that, based on Eq.(1), the "other" effects should include multipactoring electrons in a heavy ion beam, or a dust particle in an electron beam. In particular, the dust particles are real, and they do have the potential of harming the beam. On the other hand, neither effect was discussed in this workshop. We had our hands full with the fast ion and the photo-electron cloud effects.

Trapping

Gaijin particles can be trapped by electric or magnetic fields. Fields that can trap include

the beam field

bending magnetic field

quadrupole field

combined–function magnetic field[1]

static electric field from DIP leakage[3]

solenoid[4]

The beam field is probably the most effective trapping field. That is why photo-electrons are mostly expected only for a positron or a proton beam, while ions are only expected for an electron beam. A quadrupole, or a combined-function magnet has the potential to trap better than a dipole or a solenoid. Both dipole and solenoid fields can sometimes be useful to keep the gaijin particles away from the beam. (Solenoid field is a proposed cure in the KEKB to avoid photo-electron cloud instability [4]).

The degree of trapping can be very different in different cases. In the "conventional" ion trapping, the ions are trapped for a long time. In the fast ion instability (FII), ions disappear quickly after the passage of the bunch train, but they last during the passage, which may be 1000 bunch spacings. In a photo-electron instability (PEI), the photo-electrons typically last only for a few bunch spacings, and are hardly trapped at all. (This brings up the question whether there should be a small-but-nonnegligible photo-electron effect even for an electron storage ring.)

There is a word of caution here. It is conceivable that linear theories are too optimistic in predicting the clearing of the gaijin particles. For example, it was pointed out [5] that stable non-linear islands can trap ions even when the linear theory predicts ion motion is unstable. Another example is seen in the PSR [1] where one explanation of the observed instability is that the multipactoring electrons are trapped by the proton beam when the gap in the proton beam is not completely clean (the "beam in the gap" problem). These examples almost testify that it is difficult to clear the gaijin particles completely, because they seem to always find sneaky ways to stay in the vacuum chamber when we are not looking.

Beam dynamics

Various beam dynamics effects are predicted:

two–beam instability

nonlinear effects and saturation

betatron tune shifts across the bunch train

feedback damping and noise

Landau damping

heat load

One critical issue pointed out by [6] and [7] is the heat load due to the photo-electrons in the LHC. The estimated cryogenic heat load is somewhere around 5-10 W/m. This is to be compared with the design load of 0.2 W/m for the synchrotron radiation heating. First of all, there are many photo-electrons, which are accelerated due to the beam potential and become moderately energetic. Then these electrons hit the vacuum chamber wall and generate a large number (multiplication factor about 50) of secondary emission electrons, which are then again accelerated by the beam potential. As a result, the photo-electron heating is large. This is potentially a very serious issue and is under study at the LHC.

The PEI calculation is more subtle than the photo-electron heating calculation. While theories differ by a factor of 2-3 in the heating calculation, their predictions of PEI growth rate differ significantly. Ref.[6] predicts a growth rate of 25 ms – a serious issue at 7 TeV if one wants to feedback damp it. However, Ref.[7] predicts no instability because the "effective wake" is shorter than the bunch spacing. Furthermore, there seems to be a discrepancy between the PEI calculation in Ref.[8] for the KEK Photon Factory as compared with calculation in Ref.[7] for the same machine. These discrepancies will need to be resolved.

The status of simulations of the PEI is poor at this stage. The reason is that this effect is subtle and the simulations contain assumptions. A small change of some details can significantly affect the final answer. Details of the photon spectrum, the photo-emission efficiency, and the secondary emission efficiency, all play critical roles. Furthermore, photo-electrons are generated far from the beam, and their effect on the beam can not be dealt with using a linearized theory because there is no small perturbations to linearize against. This is in contrast to the FII because the FII problem can be linearized. For this reason, the theoretical predictions for the FII tend to be more dependable than those for the PEI.

Experiments on FII have been somewhat successful. In particular, one can switch on and off the residual gas pressure and observe the beam response. In comparison, the photo-electrons cannot be switched on and off, thus weakening the claim of their experimental verifications until a more direct evidence is detected. On the other hand, the mystery of the Cornell instability is now explained.[3]

It should be mentioned that there are "gaijin-like" instability effects, for example, observed in the KEK Booster. [9] Exploration of these effects are also under way.

The physics of gaijin particles is rich and complex. Recent interest has been triggered by the high-performance factories. But bits and pieces of this physics has existed in older accelerators. One should perhaps re-visit the old log books, as there might yet be hidden treasures.

It should also be pointed out that the conventional multi-bunch instabilities triggered by the vacuum chamber wall impedances (instead of the gaijin particles) remain one critical area for the factories and must not be forgotten. A few such studies [10], [11], and [12] were presented in this other-effects session.

References

[1] R. Macek, presentation, this workshop.

[2] O. Bruning, presentation, this workshop.

[3] J. Rogers, presentation, this workshop.

[4] S. Hiramatsu, presentation, this workshop.

[5] S. Heifets, presentation, this workshop.

[6] F. Zimmermann, presentation, this workshop.

[7] M. Furman, presentation, this workshop.

[8] K. Ohmi, presentation, this workshop.

[9] Y. Irie, presentation, this workshop.

[10] K. Harkey, presentation, this workshop.

[11] M. Hara, presentation, this workshop.

[12] D. Einfeld, presentation, this workshop.