Summary of the “High Intensity per Bunch” Working Group

Third Generation Light Sources are supposed to store high intensity beams not only in many tightly spaced bunches (multibunch operation), but also in few bunch or even single bunch modes of operation, required for example for time structure experiments. Single bunch instabilities, driven by short-range wake fields, however spoil the beam quality, both longitudinally and transversely. Straightforward ways of handling them, by pushing up the chromaticity ($x = DQ/(Dp/p)$) for example, enabled to raise the charge per bunch, but to the detriment of beam lifetime. In addition, since the impedance of the vacuum chamber deteriorates with the installation of new insertion devices, the current thresholds tend to slope down continuously.

The goal of this Working Group was then to review these limitations in the existing storage rings, where a large number of beam measurements have been performed to characterise them, and to discuss different strategies which are used against them. About 15 different laboratories reported on the present performance of storage rings, experiences gained in high charge per bunch, and on simulation results and theoretical studies. More than 25 presentations addressed the critical issues and stimulated the discussion. Four main topics came out:

- Observation and experimental data
- Impedance studies and tracking codes
- Theoretical investigations
- Cures and feedback

Many beam measurements, in both longitudinal and transverse planes, have been performed on different facilities. These measurements are needed to identify the mechanisms of the instability and can help in characterising the ring impedance, most often modelled by a broadband resonator.

In the longitudinal plane, they are based on standard bunch length and energy spread measurements. Large efforts have been made during the last decade to reduce the impedance budget (use of separate vacuum join and RF constacts in flanges, screening of vacuum ports, shielding of bellows, smoothing of tapers …) and the inductance has been significantly lowered ($Z/n << 1\ \Omega$). However, due to unavoidable resonances, which contribute to the resistive part of the broadband impedance, the onset of the microwave instability is relatively low and of the same order of magnitude in all machines, ranging from 2 mA to 7 mA. At the ESRF for example, the energy spread is doubled above threshold. The spectral flux of undulators, operating at high harmonic of the fundamental wavelength, can then be severely spoiled.

In the transverse plane, a model of the impedance can be inferred from the observation of the mode coupling at low chromaticity and head-tail mode detuning as a function of current. Tracking codes and solutions of Vlasov-Sacherer equation are both then able to reproduce the mode-merging mechanisms, in agreement with the measurements. Furthermore, the installation of new insertion devices results in continuous increase of the current-dependent tune shift. For example, a drop of the mode-merging threshold by a factor 2 was observed at ALS after the installation of 4 small gap insertions. ELETTRA now sees the threshold at around 40 mA, while it was above the maximum of 65 mA accumulated in the commissioning times. Incidentally, copper coating of any new small gap undulator is recommended so as not to make the resistive wall impedance worse.

The general trend consists in using higher and higher chromaticities to cope with this instability. For example, chromaticities as high as 4 and even 12.9 are required to reach 15 mA per bunch in Spring-8 and the ESRF, respectively. Although a large chromaticity eludes the mode merging by shifting the mode spectra, it is not a very "clean" remedy. The dynamic aperture is then reduced and the lifetime becomes much shorter. In addition, higher-order head-tail modes are successively excited, which are clearly detected by beam measurements. A theoretical study made at the ESRF indicates that there can be transitions from head-tail types to much faster blow ups shorter than a synchrotron period, which is supposed to occur at the ESRF.

Besides, transverse feedbacks of the m=0 dipole mode have been implemented in several rings and have shown their capacity for pushing away the mode-coupling threshold. Resistive feedback seems the most efficient techniques and enhancement factors of 2 and 5 have been obtained at ALS and the ESRF, respectively. A new and more ambitious feedback scheme has been proposed at the ESRF, which would be able to damp not only the dipole mode, but also higher order head-tail modes. Due to the very high frequencies involved, differential detection and kick of the head-tail motion is not an easy task and the technological realisation is thus a challenge. As for the development of the digital multibunch feedback, it would be worth joining efforts to develop such a promising tool.

Meanwhile, large efforts have been undertaken to estimate the impedance of all components. There are many electromagnetic (em) codes now available. Unfortunately most components are not axis-symmetric and 3-dimensional, and hence very time-consuming codes must be used. Some uncertainties remain, like the big and not understood difference between 2D and 3D results for tapered transitions or undulator sections. These questions are still open but should be rapidly solved. Lists of impedance budget exist for all machines. However, only the low frequency part, which can be easily estimated, is generally given. In addition to this inductive component, the high frequency part in longitudinal and transverse planes is essential for predicting the microwave or transverse mode-coupling instabilities. To know the impedance of the whole vacuum chamber over a large frequency spectrum is certainly a dream, but an estimation of the most critical components will definitely help in the design and selection of components.

The effect of very specific devices, like in-vacuum undulators, is anyway difficult to predict. Experiments with such existing devices are thus very desirable in the near future and will be of benefit to all facilities. Quantitative analysis of different measured instability effects, in terms of chamber materials (e.g. aluminium versus stainless steel), chamber shape and dimensions, or of other principal machine parameters (energy, circumference, etc.) would also be of interest to the whole community.

A better understanding of single bunch limitations is also essential for finding remedies. In addition to theoretical studies, for example on microwave instability or vertical fast blow-up, which were reported during the workshop, many laboratories have developed tracking codes. These simulations agree more or less with measurements on a particular machine. A crosscheck of all these codes would be beneficial for all and of course for future light sources. It was also pointed out that future tracking codes could make use of realistic wake potentials calculated by em codes, as already attempted at CERN.