NON-INTERCEPTING BEAM DIAGNOSTICS:

INTRODUCTION:

Non-intercepting (NI) (or non-destructive) beam diagnostics are obviously important for efficient operation of accelerators. The simplest diagnostics can measure beam current, or beam position, or both. More advanced non-interceptive devices can measure beam spatial distribution (moments), emittance, or energy spread. The goal of the experiment is to calibrate 2 NI home-made devices in UMER (1 in LSE) against a calibrated commercial one. All three permit time-resolved measurements of beam current, but the home-made devices require additional study and processing. The two uncalibrated devices are a simple Rogowski coil and a beam position monitor (calibrated for position measurements, though). The commercial device is a fast Bergoz current transformer.

**Rogowski Coil (RC):** It consists of a simple coil wound around a break in the vacuum pipe of the accelerator beam line, or inside vacuum (as in UMER and LSE). The changing magnetic flux of the passing beam induces a voltage that is proportional to the time derivative of the beam current. For this reason, RC is a type of “B-dot” detector. The actual beam current waveform can be obtained with an external passive or active integrator circuit, or the built-in integration function in modern digital scopes. Available in both UMER and LSE.

**Beam Position Monitor (BPM):** Fast capacitive pickup consisting of four plates, two in the horizontal plane and two in the vertical. The BPM is an electrostatic detector because of the induced image charges and the fast response involved. In UMER, the BPMs are fitted with gain-1 amplifier circuits where the high input impedance effectively integrates the raw signals. The time response of the UMER BPM is of the order of 2 ns. There are no BPMs in LSE.

**Bergoz Transformer (BT):** Fast commercial device for current measurements. It includes passive components (proprietary design) to do the required integration. The time response of the BT in UMER and LSE is a few 100ps, more than adequate for our 30-100ns beam bunches.

Numerical Integration, offline or in the digital scope, of the raw signals from either the RC or the BPM, typically presents problems because of DC offsets that are almost always present. An example is shown in the plots below: the small positive offset of the raw RC signal leads to the tilted integrated curve (blue) in either numerical integration offline or in the scope (Fig. 1). One solution in the scope is to switch from the normally used 50 Ω input impedance (which typically handles DC coupling only) to 1 MΩ input impedance with AC coupling and a 50 Ω termination. One numerical fix is to shift the raw signal by some quantity like the mean value of the signal in the center part. In Fig.2 below, the raw signal was
shifted down by 0.42702 mV (the mean signal calculated between 20 and 100 ns). The integrated (and inverted) signal is a much better representation of the true current waveform (the type obtained with the BT). (The overshoot at the ends of the waveform is caused by mismatch in the electron gun pulser circuit). It is also possible to use an external circuit to either integrate the raw signals or to eliminate the DC offsets before integration.

Additional details about NI diagnostics can be found in the presentation by D. Sutter.

**Figure 1:** RC raw signal (with DC offset) and integral curve (blue).

**Figure 2:** RC shifted signal and integral (and inverted) curve (blue).

EQUIPMENT:

UMER or LSE electron guns, matching section (or just solenoids 1 and 2 in LSE) and built-in diagnostics (RC, BT, BPM), Agilent oscilloscope, Tektronix scope.

PROCEDURE:

This experiment can be conducted by changing the beam current in either of 2 ways: in Method 1 (stand alone), different apertures at the gun exit plane are used; in Method 2 (concurrent with the Child-Langmuir experiment), different energies are used (2 keV up to 10 keV in UMER, or 0.5 keV to 5 keV in LSE).

1. Record basic operating e-gun conditions (use “Basic Record” sheet).
2. Power only the matching section elements in UMER (or the 2 solenoids in LSE). Use default matching solution for 23 mA beam (UMER).
3. Power the BPMs (UMER only).
4. Method 1: For each of the 5 apertures (see relevant Technical note for aperture locations and sizes – do not include the 5-beamlet aperture) measure mid-pulse beam current at 10 keV with Bergoz transformer (BT). The multiplication factor of the BT is 1.25, i.e. an effective 0.8mA/mV; coupling to the scope should be 50 Ω. Before changing the aperture, record also the amplitude of the integrated signal from the RC. You can integrate the signal with the Math function of the Agilent scope (use the following settings: manual scale, 20-100 pVs, offset, -20 to -100 pVs), and/or save the digitized RC signal for integration off-line. If getting a clean signal with the lowest current beam is a problem (especially with the RC), skip it and move to the next aperture.
5. Method 2: see the guides to the Child-Langmuir experiment in UMER and LSE.
6. (UMER only) For each of the 5 apertures, observe the 4 signals from BPM “0” at chamber IC2. Use the Math function on the scope to add the four signals (Top, Bottom, Left, and Right). Record the amplitude of the sum signals.
ANALYSIS / QUESTIONS:

1. Tabulate your results and include measurement errors.
2. Use the Bergoz transformer (BT) beam current data to find the calibration for the Rogowski coil, i.e. its characteristic Volt per Amp.
3. Use the Bergoz coil beam current data to find the calibration for the BPM as current monitor (UMER only).
4. How linear are the RC and BPM relative to the BT? Comment.
5. (Method 1 only) If the full beam current is 100 mA, can you estimate from the known data for the aperture radii and the measured currents the radius of the full beam at the aperture plate? Assume that the beam has a uniform distribution.