Contribution to 2nd CARE-N3-HHH-EBI meeting in Lyon, December 2004, from Pete Cameron (BNL) and Julien Bergoz (Berrgoz Instrumentation).

DIFFERENTIAL CURRENT MEASUREMENT

Julien Bergoz reported the current status of discussions and plans regarding differential measurement of two RF beams. The cases considered are those of three new projects of Energy Recovery Linacs, where the current recovery objective is 99.9995%, leading to 1 ppm resolution requirement on the current measurement. Even though these new projects are electrons accelerators, the parameters considered are fully relevant for protons accelerators, which explain why the subject was included in this 2nd CARE-N3-HHH-ABI meeting.

**Parameters of the beam to be measured**

<table>
<thead>
<tr>
<th>Structure</th>
<th>CW</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td>703.75 MHz</td>
</tr>
<tr>
<td>Circulating current</td>
<td>150, 450 and 500mA resp.</td>
</tr>
</tbody>
</table>

*Two DC current Monitors in a differential arrangement*

Some solutions were considered earlier and eliminated:

* wideband AC transformers were eliminated because their beam spectrum dependance exceed 1% (!).

* circulating the two beams through the same instrument in opposite directions was considered too difficult

The solution considered here consists of two DC monitors, one on each beam.

If the differential resolution must be in the ppm order, five significant limitations to this solution are identified:

* 1 Hz to 10 kHz magnetic cores noise
* Temperature dependence

* Magnetic field dependance

* Gain and gain linearity errors

* Beam frequency spectrum dependance


1 Hz to 10 kHz magnetic cores noise

Currently, best DC transformers have a noise density ca. 100nA/sqrt(Hz). This is based on measurements made on 30-40 pairing measurements of 20 individual cores.

It is conceivable magnetic cores noise could be reduced below 1 ppm by processing: integration, filters...

Temperature dependence

Typical temperature dependance is 5µA/K

Must be reduced to < 1ppm full scale, i.e. 0.5µA for 500mA beam current

Therefore two solutions can be retained, or a combination of the two:

* temperature stabilisation < 0.1 K

* temperature and hysteresis correction

Magnetic field dependance

Typical magnetic field dependance is 1 mA/mT, must be reduced to 0.5µA (for 500mA beam)

This poses two problems:

* a time-variable field e.g. 1mTrms must be reduced to 0.5µTrms, requiring a 2000 shielding factor

* it may be very difficult to reduce the residual field to such low value, as the magnetic permeability gets lower when the field gets lower.
Gain & gain linearity errors

Depend on the current to be measured

Can be high: \( \% 1 \text{ppm/mA}, \) i.e. 500 ppm over 500 mA beam current range!

These errors are mainly caused by burden resistors, but not only: Other components contribute to these errors too. The gain & gain linearity errors can be near-eliminated by nulling the current flowing in the monitors. Proposed solution is a compensating current loop passing thru both monitors, to maintain the sum current seen by the monitors close to zero.

Beam spectrum dependance

The two beams have different bunch lengths. Their frequency spectra are different, and will cause different eddy current loss in their respective monitors.

Beam frequency spectrum dependance remains to be analysed.

Conclusions

Measuring 1 ppm difference current between two stable beams seems possible with state-of-the-art DC current monitors. But many questions must still be resolved:

* Magnetic cores noise processing
* Magnetic shielding
* Temperature stabilisation or correction
* Frequency spectrum dependance