BPM for Spectrometry Design Concept

We are going to outline here possible design solutions for the BPMs in the energy spectrometer. Those solutions that are shown to work, or must be feasible in the nearest future are marked as baseline ones. All others went into alternative subsections as they need additional R&D efforts.

BPM type

The resolution required for the spectrometer is at least 100 nm. The only BPM type proved to have a resolution better than 100 nm is a microwave cavity BPM [1]. The supression of the undesired symmetric cavity modes with coupling slots is also well established [2], [3]. This means a substantial improvement in the stability and the accuracy of the beam position measurement vs. a standard technique utilizing two feedthroughs per axis for coupling with a following 180^0 hybrid canceling out the monopole modes [4]. The recent progress in the waveform processing and analysis tools and cheap microwave electronic components available on the market also played a certain role in the choice of the technology in favor of microwave cavity BPMs.

BPM cavity shape

Baseline shape

Cylindrical pill-box (fig.1, left) is the most common cavity shape. It's easy to produce precisely in order to control the frequency (few μm accuracy can be achieved), which is important for a multibunch operation and also convenient if a single oscillator is used for downconversion in several BPM channels. A very high precision is already demonstrated with cylindrical cavity BPMs.

The only disadvantage of the cylindrical shape is the uncertain position of two orthogonal dipole mode polarizations excited in the cavity. This position depends

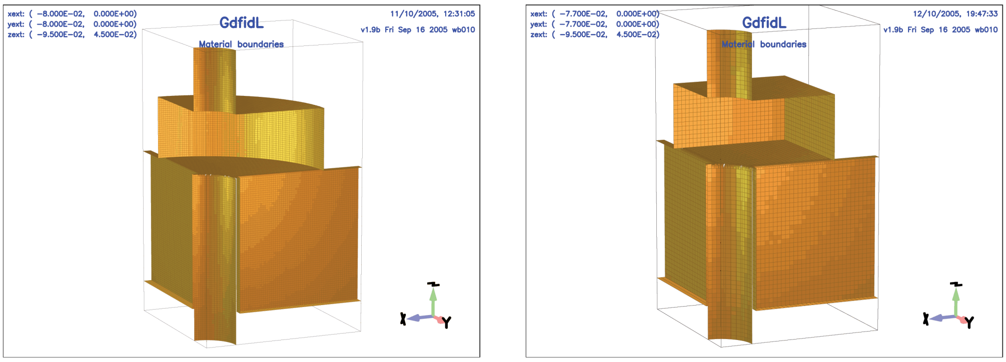

Figure 1: Baseline cylindrical (left) and alternative rectangular (right) shapes of the cavity BPM

on unpredictable small asymmetries in the cavity and also causes a small difference in the frequency between the polarizations. This difference does not disturb the operation of the BPM if it is much less than the decay rate of the dipole mode and the initial phase difference between the polarizations is negligible. The first requirement is satisfied in most cases while the measured data showes that the phase advance between the polarizations can be surprizingly large. Further investigations are needed for a complete understanding of that fact.

Alternative shape

Rectangular cavities (fig.1, right) were used to monitor the beam position in the SLAC beamline. The resolution was not very high, hundreds of μm, but it was not foreseen to be. But in fact, even the same cavities that have no built-in common mode suppression are expected to provide a 0.5 μm resolution with a modern signal processing electronics.

Rectangular cavities are produced by CNC machines and the mechanical accuracy is not as high as for the cylindrical ones (usually around 10 μm), so a post tuning can be desireable in this case, but the polarisations of the dipole mode are fixed to the geometrical axes of the cavity, which means their separation in the output and a less problematic waveform analysis.

Couplers

Either cylindrical or rectangular cavities will be preffered, combination of rectangular coupling slots and waveguides with a rectangular cross section is foreseen for the coupling. This way of coupling is demonstrated to have a very low coupling of the monopole modes and therefore important for the resolution, stability and accuracy of the system. Couplers for both transversal directions must be foreseen to exclude possible effects of the cavity rotation on the measurement.

Frequency and beam aperture

Baseline dipole mode frequency

A resolution of 20 nm was demonstrated with cavities tuned to 6426 MHz. These cavities have a beam aperture of 18 mm. To allow for some extra flexibility in the beam optics and to enhance the safety it was decided to increase the beam aperture up to 30 mm. An empiric rule (with a simple theory of field propagation into the beam pipe behind it) is that the cavity diameter has to be by a factor of 3 larger than the beam aperture. This means that cavity's diameter has to be at least 90 mm. This corresponds to a dipole mode frequency close to 4 GHz. This frequency can already be used, but a lower frequency is preferrable. A frequency of 2856 MHz is quite attractive because it's a very well explored frequency range and a lot of cheap ready to use microwave components are available for this frequency.

A lower frequency has some consequences on the system. The energy coupled into the dipole mode of the cavity becomes lower. This has to be compensated by a stronger coupling, but on the other side, a resolution of 100 nm is sufficient for a BPM in the spectrometer. Furthermore, there are several advantages of a lower frequency: lower losses in the microwave part of the system; wider linear range of the cavity due to a larger beam pipe; better phase stability; looser mechanical tolerances; lower sensitivity to the bunch length.

Alternative dipole mode frequency

The alternative is to keep the frequency and the beam pipe as in previous designs.

Coupling strength

Baseline coupling strength

It makes sense to keep the coupling factor of about 1 in order to provide enough cycles for the analysis. In that case for a multibunch operation the remaining signal (left in the cavity by previous bunches) must be substracted from the actual one. This operation has to be proved in the next experiments.

Alternative coupling strength

Another solution is to provide a strong coupling to reduce the decay time of the dipole mode so that the remaining signal is negligible when the next bunch arrives. In that case only DDC algorythm is likely to work, providing a good measurement of the resonant frequency is still possible. One of the possible solutions is an online measurement of the resonant frequency, for example with adjustable LOs. This would also help to keep the frequency of the downmixed signal the same. Otherwise the frequency of the digitized waveforms must be increased to help the analysis to work.

Signal processing electronics

Baseline electronics

One stage downconversion electronics (2 stages if needed), most likely an SSB mixer similar to the one proposed for the ATF2 BPMs. Downconversion to 10-30 MHz. Both DDC and fitting algorythm can be used in this case.

Alternative electronics

Preferably a 2 stage electronics converting the signals down to 2-5 MHz, or even DC (needs a beam off calibration and individual oscillators for each channel to set the frequency to the resonance). Needs a different analysis, like a simple amplitude measurement (although the DDC algorythm may still be able to handle it, this has to be checked).

Extremely alternative electronics

In case a stronger coupling will be needed in order to decrease the decay time for the multibunch operation or to increase the cavity output, a smaller time interval will be available for the analysis. But this interval should still contain a certain number of cycles enough for the analysis. This means that the frequency of the signal delivered by the electronics must be increased (to about 30-50 MHz). As a consequence, the sampling frequency must be increased as well.

Digitizers

Baseline digitizers

100-150 MSamples/s, at least 14 bit.

Alternative digitizers

Triggered sampling as in case of KEK system installed at ATF.

Extremely alternative digitizers

More than 200 Msamples/s, 14 bit

Reference cavity

One reference cavity is foreseen for each three position cavities to avoide changes of the phase due to the magnets. A good isolation between reference and position cavities has to be ensured by enough space between them. A symmetric coupling is proposed to reduce the field leakage into the beam pipe. In that case one channel can be used for the charge measurement and another one as a phase reference.

Bibliography

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