NON INTERCEPTING BEAM-CURRENT AND POSITION MONITORS FOR THE AGOR BEAMLINES.

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Many experiments planned to use AGOR beams need a rather low beam current, around 10 nA. This means that non-intercepting probes must be rather sensitive to be of any use. To realise the required sensitivity synchronous detection techniques are used. For the inductive monitor the beam is chopped with 225 Hz synchronised with the 50 Hz mains. This beam induces a signal in a high-mu toroid tuned to 225 Hz and followed by synchronous detection. In this way a sensitivity of 100 pA is realised.

The capacitive probes detect the second harmonic of the cyclotron beam frequency. This signal is mixed with a phase modulated second harmonic of the cyclotron frequency. The modulation frequency is 400 Hz synchronised with the mains. In this way we can, at the moment, detect less than 1 mm displacement from a 1 nA beam. In this contribution the techniques used and the results will be discussed.

1. Types of non-intercepting probes.

In the AGOR beamlines there are three types of probes which do not intercept the beam: a residual-gas profile monitor, a capacitive centroid position monitor and an inductive beamcurrent monitor. In addition there are intercepting probes like a multiwire probe to get a beamprofile and beamstops to measure current.

In this contribution the capacitive probes and the inductive probes are described in section 2 and 3.

2. The capacitive probes.

The capacitive probes consists of two half cylinder shaped electrodes, 4 cm long, situated above and below or on the right and left side of the beam. The aperture is 70 mm. The voltage induced by the finestructure of the beam is amplified and sent to a signal processing unit.This is shown in more detail in figure 1. The cyclotron RF ranges from 20 to 60 MHz. The amplifiers just after the electrodes have a bandwidth of 500 MHz and a high impedance FET input stage. This means that the charge induced by the RF beam bunches is converted to voltage. The input capacitance of each half cylinder is about 12 pF.

In the signal processing unit the signals of both halves are substracted and added together by means of transformers and fed into a balanced-mixer. Up to this point the bandwidth is still 500 MHz. Additional circuitry to secure e.g 50 Ω impedance levels and to reduce crosstalk between the channels is not shown. In the balanced mixer the sigal is mixed with the second harmonic of the cyclotron frequency generated by a Phase-Locked Loop. Thus the second harmonic of the beam signal would produce a DC signal after the balanced mixer which is easily filtered out but difficult to amplify because of offset drift.

To overcome that problem the PLL-signal is phasemodulated over 180 degree with 400 Hz. This 400 Hz signal is in turn locked to the 50 Hz mains. As a result the output of the balanced-mixer is also a 400 Hz signal which is filtered out and amplified. It is then fed into a synchronous detector followed by an integrator with a bandwidth of 1 Hz.

In this way there are three noise barriers: the balanced mixer, the synchronous detector and the integrator, which reduces the overall bandwidth to 1 Hz.

For the moment we have benchtests available for this probe only. In the benchtest we use an off centered wire which can be rotated from +5 through 0 to -5 mm inside the probe. The signal on this wire is the second harmonic of the RF and the signal induced on the probe can be compared by calculation to the signal the real beam should induce. In this way we got figure 2 showing the signal for a +5 to -5 mm displacement at 30 MHz. The 80 dB point on the curve corresponds to .3 nA of beam. The same figure is valid up to 50 MHz. The detection limit is close to 90 dB or .1 nA.

In the beamline control computer an offset will be substracted from the difference signal and the result is divided by the sum signal to get an current independent centroid position signal.

To lock the 400 Hz phase modulation to

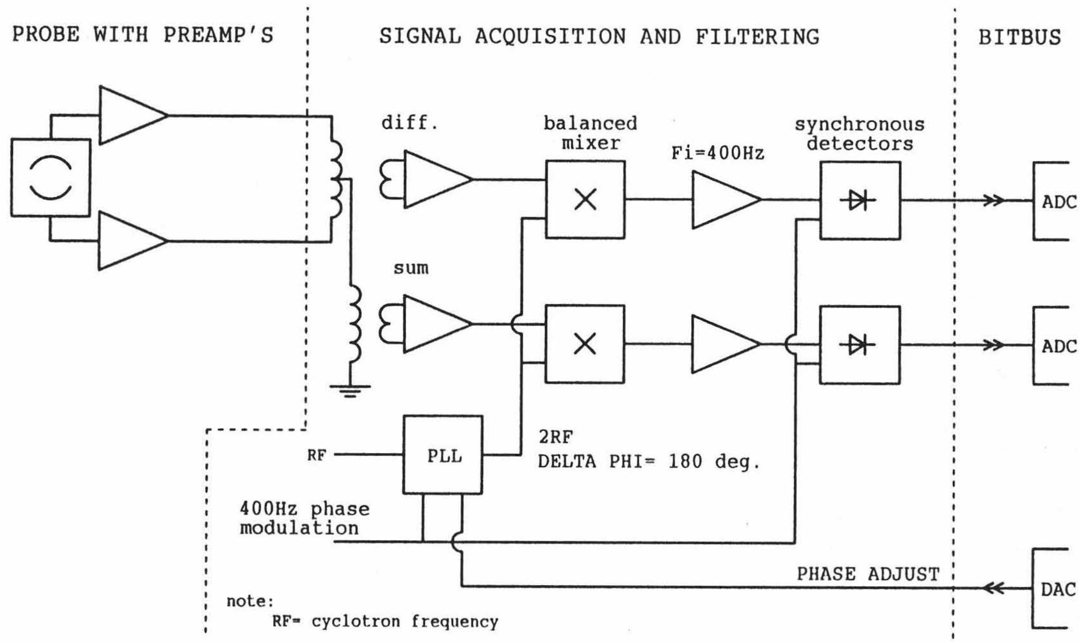

Figure 1. Blockschematic of the capacitive probe setup

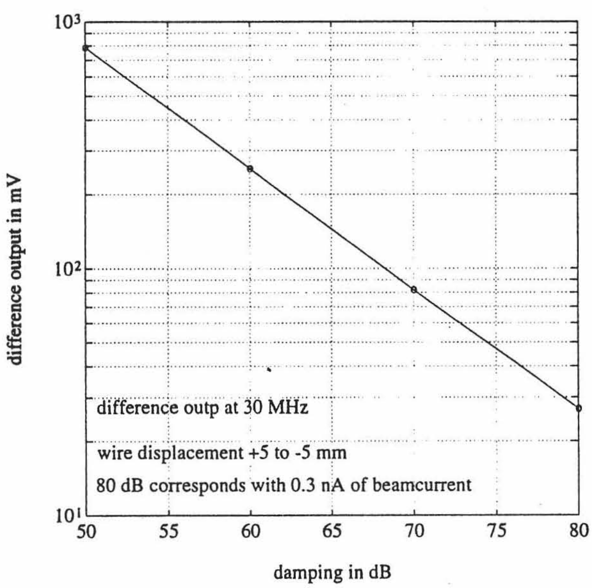

Figure 2. Output signal of the capacitive probe.

the mains has the advantage that mains interference will produce an offset which is likely to be constant once the whole setup, cyclotron-beamline-experiment, is tuned.

3. The inductive beam current monitor.

The inductive beam current monitor consists of a toroid wound on a high-mu core placed around the beamline. The core material is vitrovac 6025F from VAC. The beam acts as the primary winding. To get a signal out of the toroid which is proportional with the beam current the beam has to be modulated by a low enough frequency.

This is done with a beamchopper in the low energy injection line of AGOR. The setup is shown in figure 3. As a deflector one of the two 45 degree electrostatic deflectors will be used which bend the beam from the horizontal line into the vertical hole in the yoke. This deflector needs a maximum of + and - 6 kV for 45 degree bending power and is followed by a diaphragm.

In series with the high voltage a transformer produces a square voltage of ±500 V with a low frequency. When the chopper voltage is zero the beam is normally bent over 45 degree and injected into AGOR. The chopper voltage to switch the beam off is a bipolar square being at +500 V during 1.5 msec followed by -500 V during the next 1.5 msec. The rest of the period the voltage is zero during either 2.5 msec or 37.5 msec. The risetime of the square is 1 μsec. Thus, except for a short time of 1 μsec when the voltage switches from +500 to -500 V, the beam is off during 2.5 msec and the repetition frequency is either 200 or 25 Hz. This frequency is again locked to the 50 Hz mains.

In series with the transformer a very fast high voltage switch is present which can lower the voltage on the deflector by 20% in 100 nsec and then the beam is fully switched off. This switch will be used for other purposes and it gives the possibility to calibrate the current moni-

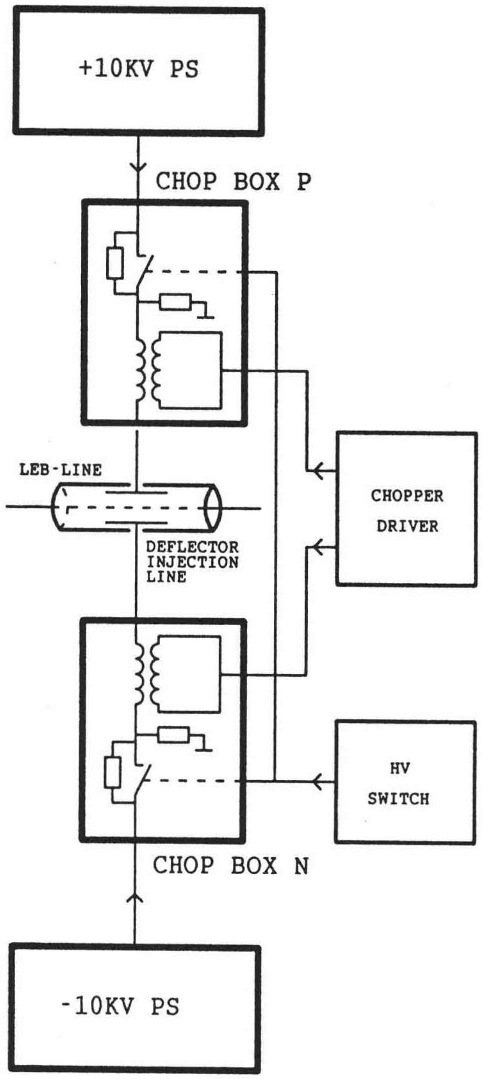

Figure 3. The beamchopper control.

tors without beam present.

In an early setup we got a signal from the toroid using the response to the fast rising or falling edge of the beam puls. The resonance frequency of the unloaded toroid is about 7 kHz and the Q-factor at this frequency about 6. Thus the response is damped out after 3 periods. This signal can be amplified and sampled by a sample-hold at its first maximum. This procedure has the advantage that it is independent of the repetition frequency but the disadvantage that it is rather noise sensitive and it needs a risetime of less than 2 μsec to become independent of the risetime. Still the sensitivity was, surprisingly, about 1 nA of beam current.

A higher sensitivity is realised when the toroid is tuned to 200 Hz. At this frequency the Q-factor is about 20 and the advantage is that one uses the full energy of the first harmonic instead of the high frequency part of the signal. Another advantage is that the rise- and fall-time of the beam pulse becomes less important. The signal from the tuned toroid is amplified and sent to a lock-in amplifier. With an integration time of one second or longer this gives a sensitivity and reproducibility better than 0.3 nA beamcurrent. This setup is shown in figure 4 and the output signal of the lock-in amplifier as function of beamcurrent at 50% dutycycle is shown in figure 5.

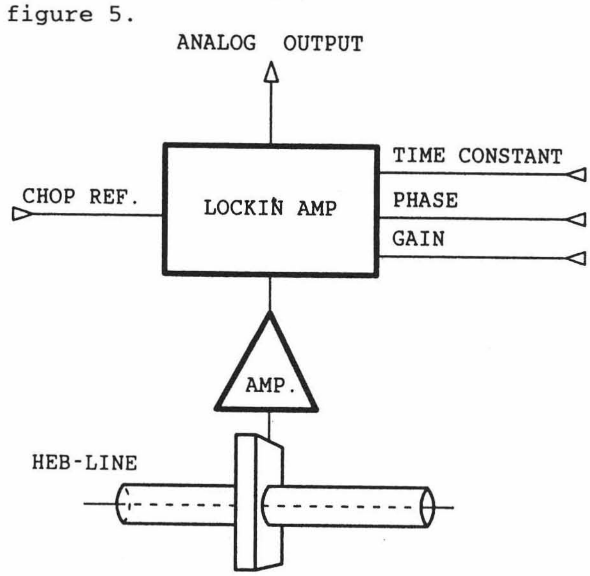

Figure 4. The current transformer.

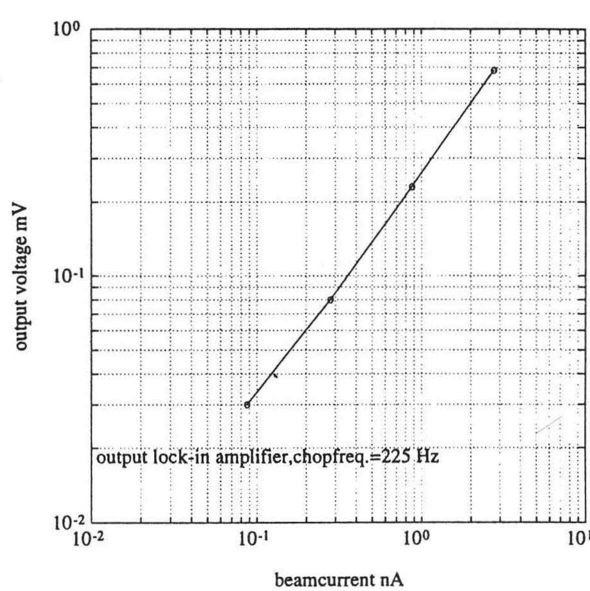

Figure 5. Output of the lock-in amplifier

It turned out that the 200 Hz repetition frequency was not quite optimal. Depending on the location where the toroid was and despite of the iron shielding a fourth harmonic of the mains still interfers with the signal. The quoted sensitivity in fig. 5 is realised with 225 Hz and again locked to the mains. This mode can be added to the system.

4. Remarks

4.1 The capacitive probes

The capacitive probes are followed immediately by amplifiers before both signals are substracted. This is of course not the best way to get longterm stability. It would be better to substract and add the signals first and amplify both results. In that case only the calibration will change over time but not the offset.

One is then forced to accept a low imput impedance because of the required bandwidth so that one measures current instead of voltage. It turns out that, with a good probe and inputstage design, the sensitivity can be the same.

In our case we were forced to choose the present solution because of the way the beamlines are designed.

4.2 The inductive beamcurrent monitors.

To realize the highest sensitivity with the beam current monitors they should be shielded with mu-metal. Even then the so called Barkhausen noise and the lowest level for magnetic excitation determines the sensitivity. To optimise both properties of the core material is unfortunately not possible because the same physical properties have to be changed in opposite directions. [1]

It is possible to overcome this limitation with a small AC bias of, in our case, 10 kHz and about 10 nA. This increases the sensitivity with a factor of about 2.

Figure 5 is based on bench tests too but in an earlier stage we had the possibility to compare these values with the signal produced by a real beam in our low energy beamlines. In this test the edge detection technique was still used.

In the present setup, using the lock-in amplifier, the low switch frequency, which is in addition locked to the mains, will be certainly helpfull to reduce the influence of beam noise.

In addition the time constant of the lock-in amplifier can be changed by remote control.

Acknowledgments

Many apprentices worked on this project whom we have to thank for their work. In return this type of projects give them a good chance to learn about electronics, RF techniques and signal acquisition.

This work was performed as part of the research program of the "Stichting FOM" with finantiel support of NWO.

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