Quadrated Dielectric-Filled Cavity Resonator as Beam Position Monitor for a medical cyclotron facility at PSI

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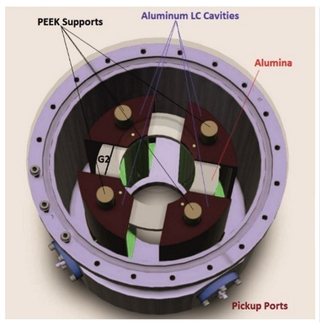
Dielectric-filled Cavity BPM, TM_{110}



- d - Beam pipe diameter
- d - Ceramic inner diameter
- d - LC cavity inner diameter
- D - LC cavity outer diameter
- C - ceramic outer diameter
- t - ceramic thickness
- P - PEEK height
- W - G. cylinder diameter
- E - Pickup height
- L - LC cavity height
- G1 - Gap 1
- G2 - Gap 2

Parameter	Value(mm)
d	90
D	180
C	146.8
t	10
W	240
E	30
P	30
L	180
G1	25
G2	40

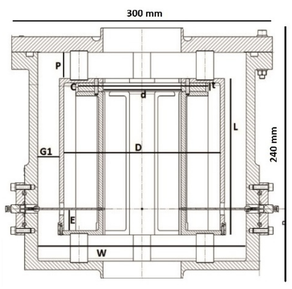


Fig. 1: Cavity BPM geometry. Marked are the important dimensions.

Dipole mode (TM_{110}) linearly proportional to beam position and zero for centered beam [1].

TM_{110} mode matched to 2nd harmonic of 72.85 MHz i.e. 145.7 MHz

Dielectric: Alumina (99.5%) Cavity: Aluminum

Mode contamination is used to determine the beam position sign

Reference cavity demand is nullified

Complex construction results in cavity asymmetries that affect sensitivity

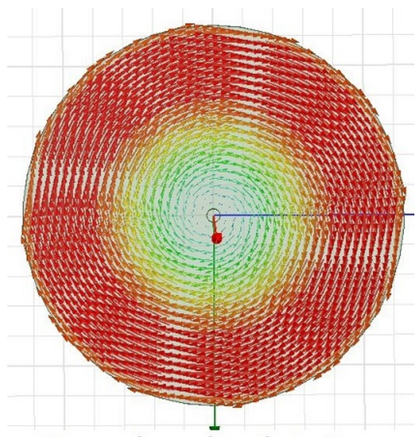


Fig. 2: Mode contamination is used to determine the sign of the beam position.

Beamline installation at PROSCAN, PSI

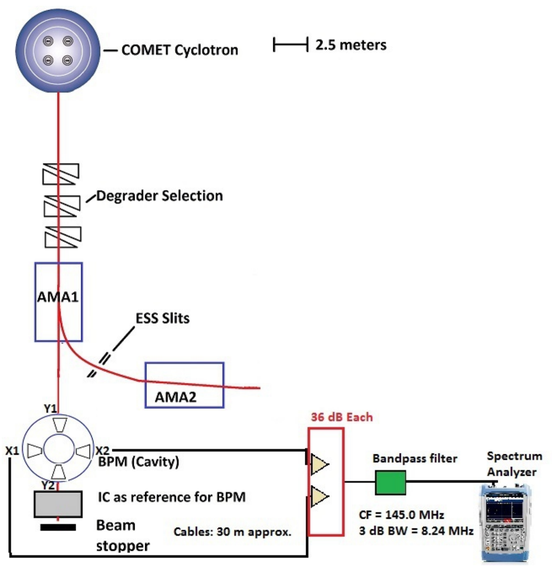


Fig. 3: BPM located at six meters from the degrader exit. 36 dB gain with a bandpass filter constitute the measurement chain.

Beam current range (0.1-10) nA and position resolution demand 0.5 mm

Influence of energy spread from degrader on bunch length is minimal due to short distance of the BPM from the degrader exit [2]

X-plane cavities are used for measurement and Y-plane cavities terminated with 50 Ω

Beam current sweep, Beam energy dependency and Beam position sweep

Beam current response

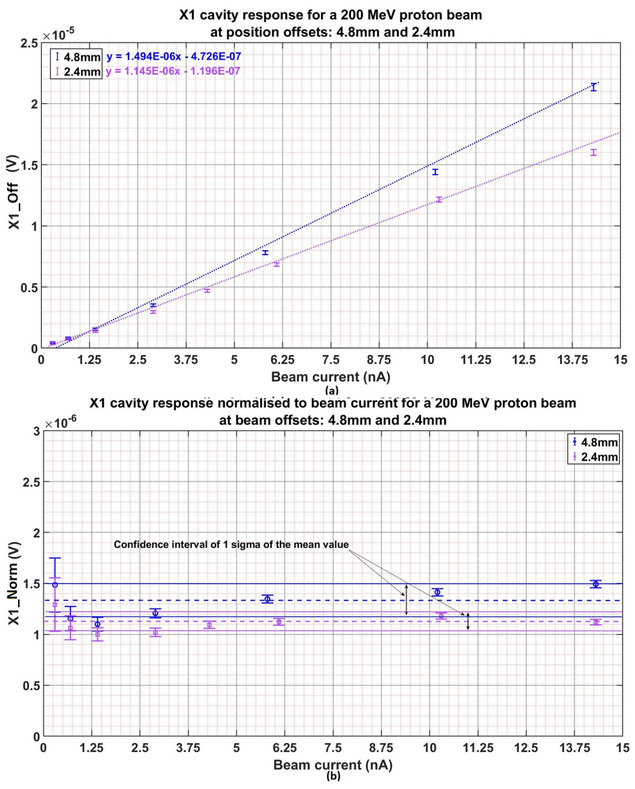


Fig. 4: X1 cavity response at two different position offsets as a function of beam current for a proton beam energy of 200 MeV. Error bars constitute two sigma standard deviation.

In Fig 3 (a), the cavity response represented in after subtraction of measurement-offset

RF interference from HAM communications and cyclotron (measurement-offset)

The BPM has a linear relationship with beam current as expected

The cavity response normalised to beam current increases with increasing beam position offsets

Beam current resolution of 100 pA

Beam energy response

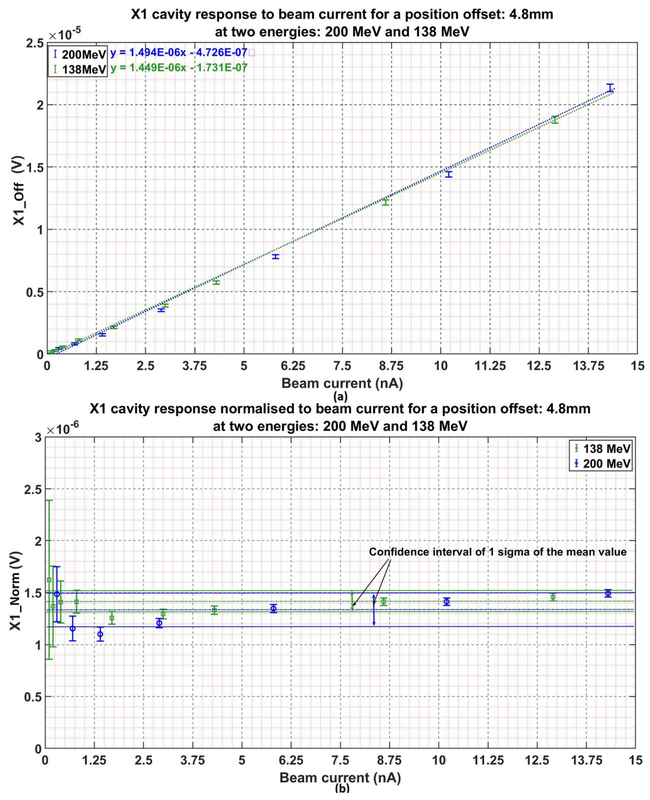


Fig. 5: X1 cavity response for two different beam energies as a function of beam current. Error bars constitute two sigma standard deviation.

The bunch length at the location of BPM for 138 MeV is 3% longer compared to 200 MeV

The beam current sensitivity is 4% lower for 138 MeV compared to 200 MeV

The measurement-offset is the dominant in the measured signal when the beam current is in the range given by 0.5nA ≤ Beam current ≤ 2.5nA

Beam position response

Position sensitivity of X2 cavity is 30% higher than X1 cavity, due to cavity asymmetries as seen in [3]

Both cavities have different position saturation range due to the position sensitivity difference

Linear range of X1 cavity is -10.0 mm to +10.0 mm and of the X2 cavity is -10.0 mm to +3.0 mm

Position sensitivity improves with increasing beam current

I/Q demodulation of the signal with respect to cyclotron RF recommended

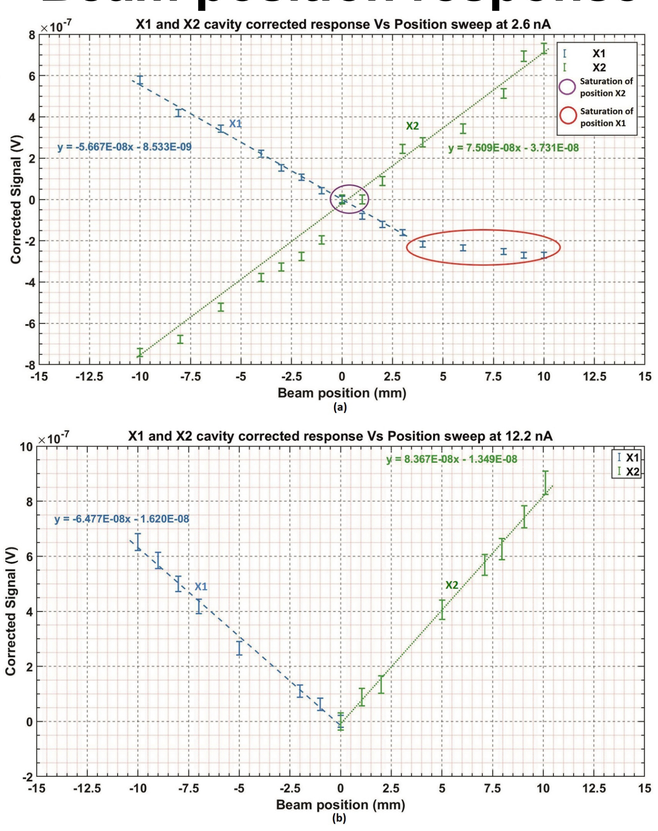


Fig. 6: X1 and X2 cavity response as a function of beam position for two different beam currents.Error bars constitute two sigma standard deviation.

Summary

Table 1: Measurement summary of X1 and X2 cavity

Position	2.6 nA		12.2 nA	
	X1	X2	X1	X2
Sensitivity, nV/mm	56.7	75.1	64.8	83.7
Error, mm	0.21	0.54	0.27	0.18
Resolution, mm	0.17	0.26	0.18	0.14

To our knowledge, this is the first non-interceptive device for beam position measurements at a proton therapy facility.

A dedicated measurement chain will have I/Q de-modulation of the BPM signal with respect to the cyclotron RF.

References

1. Ronald Lorenz, Cavity Beam Position Monitors, doi:10.1063/1.57039

2. Rizzoglio et al., Evolution of a beam dynamics model for the tranport line in a proton therapy facility, doi: 10.1103/PhysRevAccelBeams.20.124702

3. S.Srinivasan, P.A. Duperrex, J. M. Schippers, Quadrated Dielectric-filled Reentrant Cavity Resonator as a BPM, doi: 10.18429/JACoW-IPAC2019-WEPGW083

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